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Document EFFECTS OF FIBERGLASS INSULATION DEBRIS ON PILGRIM ECCS PUMP PERFORMANCE

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EFFECTS OF FIBERGLASS INSULATION DEBRIS ON PILGRIM ECCS PUMP PERFORMANCE

PREPARED FOR THE

BOSTON EDISON COMPANY

BY THE
GENERAL ELECTRIC COMPANY

JANUARY 1996

Prepared By

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DISCLAIMER OF RESPONSIBILITY

ABSTRACT

An evaluation has been performed to determine the impact, relative to draft Regulatory Guide 1.82, of using fiberglass insulation (Owens-Corning NUKON) on the drywell piping of Pilgrim Nuclear Power Station. The specific concern is the potential for degradation of ECCS pump performance resulting from the clogging of pump intake strainers with insulation debris following a postulated Loss of Coolant Accident (LOCA). The analysis was done in accordance with the procedures outlined in draft Regulatory Guide 1.82, rev. 1 and draft NUREG 0897, rev. 1. Conservative calculations were made of the volume of debris generated, the short term and long term transport of debris to the suppression pool, the head loss through a layer of debris on the intake screens and the "clean screen" NPSH margin of the Pilgrim ECCS pumps. It is concluded that NUKON fiberglass insulation debris generated in a postulated large LOCA will not impair the long term cooling performance of the ECCS.

CONTENTS

1.0 Introduction

1.1 Purpose

This analysis has been performed to determine the impact, relative to draft Reg. Guide 1.82, of using "soft" (Fiberglas) insulation on the drywell piping in the Pilgrim Nuclear Power Station.

1.2 Background

As part of the recirculation system piping replacement project for Pilgrim Station, the drywell piping insulation is being replaced with Owens-Corning NUKON insulation. This material is a low density fiberglass wool with a cover of woven fiberglass made up into convenient size blankets for ease of handling. A postulated concern with fiberglass insulation is that fibrous debris formed during a Loss Of Coolant Accident (LOCA) may possibly migrate to the intakes of the ECCS pumps where it could build up on the suction screens and reduce available NPSH to the point of impairing the cooling ability of these systems.

The NRC has done a substantial amount of work (References 1 through 4) to resolve this issue, particularly for PWR's. Regulatory Guide 1.82 (Reference 1), currently in draft form, is a key document in the NRC's resolution of this issue and is discussed in more detail below. This document is expected to be issued in final form sometime in 1984 and will require an evaluation of all drywell insulation to determine whether or not there is a potential problem with ECCS screen blockage.

1.3 Requirements of Regulatory Guide 1.82

The April 1984 revision of Regulatory Guide 1.82 was used for this evaluation. This document lists twelve criteria which are applicable to the suppression pool and vent system. Most of these are design criteria relative to the design of screens and trash racks and ECCS pump intakes. The item of concern with regard to insulation is criterion 7 which states that,

"Evaluations of (1) sump hydraulic performance (e.g., swirl and air ingestion), (2) LOCA-generated debris effects (e.g. debris generation, transport, screen blockage and head loss, and particulates clogging of pump seals), and (3) the combined impact on pump NPSH margin should be performed to ensure that long-term recirculation cooling can be accomplished."

Appendix A of RG 1.82 provides some specific guidelines for the review of ECCS sumps. Additional guidance is provided in Reference 3. The assessment of LOCA induced debris effects is dependent on the types and quantities of insulation employed, the location of these materials within the containment and with respect to the ECCS pump intakes, the estimated quantities of debris generated by a pipe break and the migration of debris to the intakes. The estimate of ECCS intake screen blockage effects therefore requires an evaluation which is specific to the plant and the insulation materials used.

1.4 Pilgrim Containment and ECCS

Pilgrim Station has a Mark I containment and the ECCS systems take their suction from the torus (i.e. the suppression pool). There are 4 RHR intakes, 2 core spray intakes and 1 HPCI intake and 1 RCIC intake located nominally 30-degrees from the bottom of the torus at various azimuth locations. Each intake is covered by a cylindrical screen constructed of perforated stainless steel plate. The location of the intakes in the torus is shown in Figure 1 and the geometry of the inlet pipe and strainer is sketched in Figure 2. Information describing the design and operation of the Pilgrim containment and ECCS was obtained from References 5 through 14.

1.5 NUKON Insulation

Since specific insulation properties must be known to do the evaluation, the properties of Owens-Corning NUKON were used. This insulation is a low density fiberglass in the form of blankets, and the characteristics of interest for this evaluation are documented in References 15, 16 and 17. NUKON blankets are wrapped around the pipe and held in place with stainless steel Velcro strips along the longitudinal seam. The thickness of the NUKON insulation on the major piping in the Pilgrim drywell is 3 inches except on certain horizontal sections of the steam and recirculation piping where it is 4 inches.

2.0 Summary of Evaluation

The general method of assessment as described in the April 1984 version of Regulatory Guide 1.82 is:

1. Calculate the maximum amount of insulation debris which may be generated by a LOCA jet.

2. Calculate the amount of debris which may be transported to the suppression pool and the ECCS pump intake strainers.

3. Calculate the head loss through the insulation fibers deposited on the strainers and determine the effect on the available NPSH for the ECCS pumps.

For Pilgrim, the maximum volume of shredded fiberglass debris was conservatively estimated to be 23 cubic feet from a guillotine break at either of the main steamline elbow welds identified as SLB-3 or SLC-3 in Figure 3. Ten percent of the shredded debris was assumed to stay in the drywell and 21 cubic feet was assumed to be blown into the torus and uniformly distributed throughout the suppression pool.

The shreds are assumed to remain suspended in the pool and transported circumferentially when the RHR system is placed in the pool cooling mode. All of the shreds except those which are below the torus ring girder in bays without ECCS intakes, are assumed to eventually migrate to the intake screens. With this transport model, 16.2 cubic feet of debris is assumed to be distributed over four RHR and two Core Spray intake screens in proportion to the flow rates. The volume on each strainer was calculated to be 2.9 cubic feet for RHR and 2.2 cubic feet for Core Spray.

The mathematical model for the distribution of the insulation debris within the torus is inherently symmetrical in order to maintain a reasonably simple and deterministic character for the calculation. The assumption that all RHR and Core Spray pumps are operating is consistent with this model and is judged to be the bounding case for debris

accumulation on the individual strainers. With all pumps operating, the pool velocity is maximized and uniform throughout the torus circumference thereby keeping the insulation shreds suspended and circulating with the lowest time and distance to travel before deposition onto a strainer.

The worst "clean screen" NPSH margins (the difference between available and required NPSH) were determined to be 15 feet for the RHR pumps and 12 feet for the Core Spray pumps. NPSH margin is based on calculations that include the effect from the increase in wetwell vapor pressure and gas pressure in equilibrium with increasing suppression pool temperature.

Test data for NUKON from Reference 17 was used to estimate the head loss through a shredded debris layer from the above transport model. The calculated head losses were 14 feet for RHR and 6 feet for Core Spray.

Since these conservatively calculated head losses are smaller than the respective NPSH margins it is concluded that the fiberglass insulation debris generated in a postulated large LOCA would not impair the long term cooling performance of the ECCS.

3.0 Analysis of the Debris Hazard

3.1 Overview of the Analysis

The objective of this analysis is to assure that the use of soft insulation in the Pilgrim drywell will not in any way degrade the ability of the ECCS systems to provide adequate long-term cooling following a postulated LOCA. Considerable guidance for this analysis is provided in Regulatory Guide 1.82, revision 1 (Reference 1) and NUREG 0897, revision 1 (Reference 3). The following general steps are applicable:

1. Identify potential break locations.
2. Assess possible break/target combinations.
3. Conservatively estimate level of damage and volume of LOCA-generated debris.
4. Consider both the short-term and long-term transport of insulation debris to the pump intake screens.
5. Estimate the head loss resulting from screen blockage by insulation debris and the resulting reduction in the available NPSH for the pumps.

3.2 Identification of Potential Break Locations

Jet impingement forces during a LOCA are the dominant source of debris generation. Other contributors such as pipe whip and impact have been studied and shown to be of secondary importance (Reference 3), i.e. on the order of less than 10 percent of the total volume.

For Pilgrim, postulated breaks in the feedwater, steamlines and recirculation system piping represent potential LOCAs that may require long term cooling. These are also the largest pipes in the drywell and are therefore those likely to cause the most destruction of insulation in case of a break. The pipe sizes are:

Recirculation - 28,22,and 12-inch

Steamline- 20-inch

Feedwater- 12-inch

Since the feedwater line is substantially smaller than both the main steam and the recirculation system piping and is not in close proximity to the recirculation piping, break locations in the feedwater line are not of concern here.

Postulated break locations in the recirculation system piping were determined consistent with the Standard Review Plan (SRP) 3.6.2 (Reference 18). These locations are at the terminal ends of the pipe and at certain highly stressed welds in-between. For the replacement recirculation system piping, these locations are at the 28-inch and 12-inch vessel nozzles, the RHR return connection and the welds attaching the 12-inch risers to the 22-inch header (Reference 19 and Figure 4).

SRP 3.6.2 was similarly used to determine steamline break locations as described in Reference 20. The postulated locations are shown in Figure 5.

3.3 Assess Possible Break/Target Combinations

The break/target combinations of interest are those in either the main steam line or the recirculation piping which can destroy the largest amount of insulation. Potentially, these are any of the break locations identified in Figures 4 or 5.

3.4 Estimate Level of Damage and Volume of Debris

Damage to fiberglass insulation by a high pressure jet from a broken pipe has been experimentally demonstrated in the Heissdampfreaktor (HDR) facility and some of the results are described in Reference 3. Although these tests were conducted at conditions more representative of a PWR, (i.e. higher temperature and pressure than a BWR) the evaluation model developed in Reference 3 will be conservative if used for Pilgrim.

Two-dimensional pressure distributions for a LOCA jet expansion region have been calculated and the results compared to the HDR test data. This work has led to the development of a three-region jet-debris-generation model for estimating the volume of debris generated by a LOCA. The model, described in Reference 3, is a 90-degree jet expansion cone as shown in Figure 5. Region I, less than 3 pipe diameters (3D), is a zone of total destruction, where the conservative assumption is made that all fiberglass insulation is completely shredded. Since the volume of this cone increases as the cube of the pipe diameter, breaks in the largest pipes are the most significant. In region II (3 to 7 pipe diameters), high levels of damage to the insulation could result, depending on the type of insulation used and method(s) of attachment. For NUKON or other fiberglass blanket insulation types, it is expected that the degree of damage will decrease in this region from total destruction (100 percent shredded) at 3D to minor damage (blankets dislodged & torn but little or no shreds) at 7D.

Region III (more than 7 pipe diameters) is a zone where some insulation could be expected to be dislodged or partially destroyed but not shredded as a result of the continued pressure loads. Dislodging in region III also depends on the specific material and its attachment.

The debris of most concern with respect to the clogging of intake screens is the insulation which is completely shredded. Insulation in any larger mass would tend to remain in the drywell or sink to the bottom of the torus and would not contribute to clogging of the ECCS intake screens. Completely shredded debris would primarily be generated in region I and to a lesser extent, region II of the jet cone model. To be

conservative, it is necessary to determine which of the possible break locations identified in Paragraph 3.2 would produce the largest volume of shredded debris. To do this, the insulation destroyed by the jet cone described above can be calculated for each break location.

For region I, according to the assumptions imposed by Reference 1, all of the insulation in the region is shredded, therefore it is only necessary to determine. the total volume of insulation on the piping within the 3-diameter jet cone.

For region II, as suggested in Reference 3, the fraction of insulation which becomes shredded debris is a function of the distance of the insulation from the break. This fraction can be expected to decrease from 100 percent at 3 diameters to near zero percent at 7 diameters. For Owens-Corning NUKON, this concept is supported by the liquid jet impingement tests reported in Reference 16. The pressure for BWR break conditions at 7 diameters shown in Reference 3 is less than the 25 to 65 psi jet stagnation pressure required to cause NUKON pillow damage. The expected type of damage considerations for fibrous types of insulation are illustrated in Figure 3.26(a) of Reference 3 and Figure 6. These figures roughly show how the generation of debris might be distributed in the jet cone (i.e. the fraction of insulation shredded as a function of the distance from the break).

To calculate the volume of shredded insulation in region II, it is necessary to have numerical values for the curve displayed in Figure 6. An overly conservative choice would be to assume the fraction of shreds to be 1.0 (i.e. 100 percent) between 3D and 7D. Based on nominal BWR pressure/temperature and the demonstrated sturdy construction of the NUKON insulation, a reasonable set of values for insulation shredded as a function of distance from the break is given below. These values are also plotted in Figure 6.

Distance from Break in Region II	Percent of Insulation Shredded
3D - 4D	100
4D - 4.5D	90
4.5D - 6D	60
6D - 7D	25

These values effectively divide region II in four sub-regions. The volume of insulation subjected to the jet cone in each of these sub-regions was calculated and multiplied by the appropriate value from the table to calculate the volume of shredded debris.

The volume of shredded debris generated in region III, i.e. more than 7 diameters from the break, is realistically anticipated to be zero.

The resulting volumes of debris for some of the most significant break locations of Figures 3 and 4 are shown in Table 1.

The break location resulting in the largest volume of debris is the weld identified as either SLB-3 or SLC-3 on Figure 5. These locations are on the inboard main steamlines and are close enough to include substantial portions of recirculation suction line and the opposite inboard main steamline in the jet cone. This break region is illustrated in more detail in Figure 7. The volume of shredded debris calculated for this break location is 21 cubic feet. It is assumed that pipe whip and small bore piping may contribute another 10 percent, thus the volume used in the evaluation is 23 cubic feet.

3.5 Short Term and Long Term Transport

The movement of insulation debris toward the ECCS pump intakes, following a LOCA, depends on the transport characteristics of the insulation debris and the flow field in the containment. The short-term flow field is primarily dependent on the containment response to the LOCA. Longer term flow patterns are established by the return of

cooling water from the reactor vessel to the various ECCS intakes. For the postulated large recirculation line break in Pilgrim, the reactor vessel depressurization transient is completed in about 5 - 10 minutes. The ECCS pumps begin pumping water to the reactor vessel before depressurization is complete and may continue for days or weeks.

The response of the Mark I containment, such as Pilgrim, to a large recirculation line break is characterized by rapid pressurization of the drywell from 0 to about 35 psig in less than 5 seconds. This pressure is quickly relieved by the flow of steam and air through the vent system to the suppression pool in the torus. This flow produces high velocities of steam, water and air in the vicinity of the break and in the vent piping to the torus. The rapid discharge of air into the pool produces a violent motion of the pool, i.e. "pool-swell", which thoroughly churns it and generates local velocity fields which may take several minutes to subside. The actual pool swell event is over within 10 seconds of the break time and high velocities in the drywell and vent system are substantially reduced within 30 seconds following the break. Steam may continue to flow through the vent system for many hours but the velocities are too low to be a factor in transporting debris to the torus.

The movement of the debris to the screens can be divided into two time periods which can be characterized as "short term" and "long term". Short term transport is the movement which is primarily produced by the velocity and flow field generated during the initial flow of steam, air and water to the torus. Long term transport is the movement produced by the flow of ECCS cooling water from the reactor vessel and RHR return lines to the ECCS pump intakes in the torus.

The buoyancy and transport characteristics of fibrous insulation debris were investigated in some tests conducted under NRC sponsorship and reported in Reference 2. Similar tests, specifically for NUKON, were performed for Owens-Corning and are described in Reference 17. In these tests, the mode of transport studied was the movement of insulation on floor by a stream of water. Some of the observations for NUKON were:

1. The water velocity required to initiate motion of shreds of NUKON debris is on the order of 0.2 to 0.3 ft/sec.

2. The velocities needed to initiate the motion of the insulation samples were rather independent of the sample size although a trend toward higher velocities for larger sample sizes can be detected.

These characteristics are useful primarily in the consideration of long term transport. No information was found describing the transport characteristics of fiberglass insulation debris in high velocity steam or air. It is assumed that because of the low density of NUKON, the air and steam velocities present in the drywell and vent system during pool swell are high enough to easily carry shreds along in the flow stream.

Based on this information, the following scenario describes the expected short term transport of fiberglass insulation debris subsequent to a large break in the recirculation system or main steam piping:

1. Most of the insulation shreds generated by impingement of the two-phase jet will become entrained in the high velocity steam and air flow field in the drywell and will be carried along through the vent system to the torus. Since the steam and air flow are nearly evenly distributed to the 8 vents, it is expected that the debris will also be nearly evenly distributed. The insulation will be blown out of the vents and into the pool along with the air and because of the motion of the pool during pool swell, can be expected to be well distributed in the water.

2. Some insulation shreds will be blown out of the flow stream and will land on pumps, valves, piping, floor grating and other equipment in the drywell. These pieces will not be carried to the torus during the reactor blowdown transient.

3. Larger pieces of insulation debris, i.e. whole or partial NUKON blankets will be scattered around the containment in the vicinity of the break. Most larger

insulation pieces will not be moved very far because of interference with the two floors of grating or other equipment in the vicinity of the break. Since large pieces also require higher velocities to transport them, they are less likely to be carried as far as the main vents. If they do get to the main vents, the largest pieces will probably be blocked by the jet deflector or its supports.

The long term transport scenario may be described as follows:

1. Some of the shredded debris which was not carried to the torus with the steam and air, may be moved by water flowing out of the pressure vessel at the break. If this debris happens to be in the flow path of this water, some of the shreds may be carried to the floor of the drywell. The entrance to the main vents is slightly elevated above the drywell floor and will allow a shallow pool to form in the drywell. The insulation debris which may reach the floor as a result of the cooling water flow will certainly be wet and thus most of it can be expected to sink to the drywell floor and thus migrate no further. Some small fraction of it may be washed into the suppression pool.

2. Shredded debris carried to the pool by steam and air flow during pool swell will continue to be more or less suspended in the water, but will begin to settle to the bottom of the torus as pool motion decreases. The RHR (LPCI mode) and core spray flow will return to the torus through the drywell vent and downcomer system in a relatively uniformly distributed manner.

   At some time after the postulated LOCA, it is expected that one or both of the RHR systems will be switched to the containment pool cooling mode. In this mode the RHR flow is discharged into the torus through a return pipe which is oriented tangential to the torus centerline so as to produce a bulk circumferential pool velocity which may be large enough to aid in the transport of debris to the ECCS pump intakes.

   The response of the Pilgrim suppression pool temperature to various plant transients involving SRV discharge was calculated and the results are

reported in Reference 10. The computer program used for these calculations, TPOOL, also calculates the bulk pool velocity which results from SRV discharge and RHR return flow. The calculated pool velocities were not reported in Reference 10, but selected output of the TPOOL cases is available in Reference 21. The maximum bulk pool velocity calculated for one RHR system in the containment cooling mode was about 0.23 feet per second and for two RHR systems was about 0.29 feet per second. These values are at the low end of the NUKON transport velocity range reported in Reference 17.

Since the pool cooling mode of RHR operation may not be turned on for some minutes or perhaps hours following a LOCA, it is likely that much of the insulation debris in the torus will begin to sink to the bottom. For any debris which does sink, it will be difficult for a low velocity, such as produced by the RHR return, to cause any resuspension of the fibers in the water. The transfer of sunken debris from one bay to the next will also be inhibited by the ring girder at the ends of each bay of the torus. It is concluded that the amount of debris which may be transported to the strainers by the bulk circumferential pool velocity should be quite small.

3. Whole blankets of insulation and large pieces will probably not be moved very far. Any pieces that get as far as the vent system will probably get stuck at a bend or on the lip where the downcomers attach to the vent header. If any large pieces are able to migrate as far as the torus they are expected to sink rapidly (Reference 15) to the bottom since the low velocities in the pool will not be sufficient to transport large pieces.

4. To determine the transport to the intake screens, the condition of the various ECCS pumps must be reviewed. The four systems which have intakes in the torus are RCIC, HPCI, core spray and RHR. The RCIC and HPCI pumps are driven by steam turbines which use steam from the reactor pressure vessel. Since the depressurization is complete within a few minutes

of the postulated large break, these two systems are not of concern for long term cooling. In Figure 1, it is seen that all six RHR and core spray intakes are in two bays, (i.e. two RHR and one core spray in each of two bays) located 180-degrees apart on the major circumference of the torus. It is possible that both core spray pumps and all four RHR pumps could run simultaneously for hours or days following the blowdown.

To calculate the volume of insulation which may migrate to the intake screens a conservative model has been postulated based on the above scenarios. The transport model assumptions are:

1. It is assumed that 10 percent of the shredded insulation debris is held up in the drywell and is not transported to the torus.

2. The other 90 percent of the debris is blown into the torus during pool swell by the air and steam velocities in the drywell and vent system.

3. The shredded debris is assumed to be uniformly distributed throughout the suppression pool.

4. Intact and damaged insulation blankets are not transported to the torus.

5. All of the shredded debris in the torus bay containing the ECCS intakes migrates to the intakes in that bay in proportion to the pump flow rates.

6. All of the shredded debris in the seven torus bays adjacent to

and upstream (relative to bulk torus pool velocity) from the bay containing the ECCS intakes, except the debris which is behind the ring girders, is transported to the intake strainers in proportion to the pump flow rates.

Numerically, the largest volume of generated debris calculated by the procedure described in Paragraph 3.4 (Reference 22) was 23 cubic feet. The 90 percent assumed to be transported to the torus is 21 cubic feet. It was found that the ring girder "blocks" 26 percent of pool area (Reference 14) and thus the total volume of debris transported to the 3 ECCS intakes is:

$$(21/16) + 7x(1.00 - 0.26)x(21/16) = 8.1 \text{ cubic feet}$$

The flow rates are (References 6 and 7):

RHR 5000 gpm

Core Spray- 3750 gpm

The volume of debris transported to the strainers is:

RHR- 8.1x(5000/(5000+5000+3750)) = 2.9 cu ft/screen

Core Spray- 8.1x(3750/(5000+5000+3750)) = 2.2 cu ft/screen

3.6 Head Loss and NPSH Reduction

With no insulation debris on the ECCS pump intake screens, the margin in the Net Positive Suction Head (NPSHM) of the pumps is defined as the available NPSH (NPSHA) minus the required NPSH (NPSHR). NPSHR was determined from the pump manufacturers performance curves, References 23 and 24. The NPSHA is dependent on the pump flow rate, the elevation of the torus water level above the pump inlet, the temperature of the water in the torus, the air pressure in the torus and the hydraulic losses in the pump suction piping. The process diagrams for the RHR and core spray systems (References 6 and 7) provide the conditions for several design operating modes of these systems. The NPSHA for each set of conditions on the process diagram which

might occur in a long term cooling situation, was calculated. All necessary information was available on the Process Diagram except for the RHR and Core Spray pump suction piping hydraulic losses.

The head loss for the RHR and Core Spray pump suction piping was calculated using the piping isometric drawings, References 25 and 26. At pump rated flow rate, the calculated head losses were 3.5 and 2.1 feet of water for the RHR and Core Spray Piping respectively. For the purposes of this evaluation of the available NPSH, the losses for both systems were conservatively taken to be 4 feet.

The lowest margins calculated, i.e. the worst "clean screen" conditions for the NPSHM were 15 feet for the RHR pumps and 12 feet for the Core Spray pumps, at 130 degrees F pool temperature. NPSH margin is based on calculations that include the effect from the increase in wetwell vapor pressure and gas pressure in equilibrium with increasing suppression pool temperature.

If insulation debris accumulates on the screen in a somewhat uniform coating, then the flow through the insulation will produce a pressure drop or head loss which will be a direct reduction of the NPSHM. If the insulation head loss is greater than the NPSHM, then it can be expected that the pump will cavitate. Under cavitation conditions, the flow rate of ECCS cooling water may be reduced and the effectiveness of the system impaired.

The head loss through a layer of shredded NUKON insulation debris can be estimated using the Alden Laboratory test data contained in Reference 17. The test was performed for beds of simulated debris, uniformly spread on a wire mesh screen with a relatively small area. The direction of flow was normal to the screen. The thickness of the bed of insulation ranged from 0.125 inches to 10 inches and the flow velocity was varied from 0.1 to 0.5 feet per second. The report includes an equation which correlates the head loss as a function of debris thickness and fluid velocity.

This data has a number of shortcomings with respect to the calculation of the head loss through insulation debris on the Pilgrim ECCS strainers following a LOCA. Among them are the unknown size distribution of the actual debris shreds, the distribution of debris on the strainer, the different geometry and material of the actual strainer and the velocity field in the vicinity of the strainer. However, most of the differences between the test and conditions which might occur in Pilgrim are anticipated to be minor or at least conservative. For example, the head loss in the Alden Laboratory test did not vary much with shred size hence the size distribution of actual debris is probably not significant. Another example is that a uniform distribution of debris on the strainer is likely to be conservative since any areas of reduced thickness would sharply reduce the resistance to flow.

One of the laboratory test variables which differs from the expected in-plant conditions is the mean fluid velocity normal to the layer of debris. The test velocity was in the range from 0.1 to 0.5 feet per second. For the Pilgrim RHR and Core Spray strainers, the calculated average velocity based on the gross area of the perforated plate material (13 sq ft) and the pump flow rate was 0.86 ft/sec and 0.64 ft/sec respectively. These are both outside the range of the velocity for the NUKON test data and therefore the data must be extrapolated to estimate the head loss values for debris on the Pilgrim strainers.

One extrapolation method is to use the Alden Laboratory correlation, but since no really satisfactory theory has yet been developed for the head loss, there is no physical basis for correlating the data or extrapolating it outside of the measured velocity range. To see if using the actual data for thicknesses near those expected would lead to an extrapolation giving a higher head loss than the correlation equation, the data for 1.0 and 5.0 inch layers was examined more closely as follows:

1. Calculate the expected debris thickness based on 2.9 cubic feet of debris for the RHR strainers and 2.2 cubic feet of debris for the Core Spray strainers, rated pump flow rates and strainer areas of 13.0 sq feet.

2. Interpolate the tabulated data points (Reference 17) for both shreds and 1 X 1 X 1/8 pieces at each test velocity to get a head loss value for the calculated thickness.

3. Plot the interpolated head loss values as a function of the velocity and extrapolate a "best" fit curve out to the calculated velocity for the Pilgrim strainers (Figures 8 and 9).

4. Compare the extrapolated head loss values from Figures 8 and 9 with head loss values calculated with the correlation equation for the same velocity and thickness. Also compare the extrapolated head loss with the NPSH margin to see if cavitation is indicated.

The data base used to develop the head loss equation in Reference 17 did not include any data for debris containing pieces of the outer fiberglass cloth or the fiberglass scrim used in the NUKON blankets. These materials represent only a small percentage of the total volume of the fabricated insulation, and probably an even smaller percentage of the debris which reaches the ECCS strainers. The woven cloth is much stronger than the fiberglass wool and is not likely to be shredded to small pieces as a result of jet forces in the vicinity of a pipe break (Reference 16). Large pieces of the cloth are less likely to be carried to the torus by the blowdown steam/water/air flow and more likely to be caught by floor gratings or equipment in the drywell.

Since debris of fiberglass cloth on the strainers would be expected to produce a greater head loss than shredded fiberglass wool debris, a conservative calculation was done to account for the cloth covering in the evaluation. For NUKON blankets manufactured from two layers of 2-inch thick wool, four layers of scrim and two layers of cloth cover, the volume of the cover and the scrim was estimated to be about 5 percent of the total volume of the insulation. If we assume that all of the cloth and the wool become shredded debris and are transported as a homogeneous mixture to the RHR strainer, then about 5 percent of the debris on the strainer will be from the outer cover and the scrim. If we assume that the pieces of the cloth will completely block the flow then

effectively the screen area will be reduced by 5 percent. The flow velocity used to determine the head loss has been based on 95 percent of the screen area, i.e. 0.95x13.0 = 12.4 sq ft.

The results are shown below:

system	thickness (inches)	velocity, (ft/sec)	head loss, ft (extrapolated)	head loss, ft (correlation)
RHR	2.63	0.90	13.8	11.2
C.S.	2.03	0.68	5.5	5.1

The head loss extrapolated by the method described above is higher than calculated from the correlation equation in Reference 17 and therefore the extrapolated values were used for conservatism.

4.0 CONCLUSIONS

The calculations are summarized in Table 2. Since the head loss through a conservatively estimated volume of debris on the Pilgrim ECCS intake screens is less than the margin in the ECCS pump NPSH, it is concluded that the fiberglass insulation debris which would be generated in a postulated large LOCA would not impair the performance of the system for long term cooling.

Table 1

Estimated Volume of fiberglass Debris Generated by Postulated LOCAs

Break Location	Volume of Debris, cuft
20-inch steamline at SLB-3 or SLC-3	21
20-inch steamline at SLB-2 or SLC-2	21
20-inch steamline at SLA-3 or SLD-3	20
20-inch steamline at SLA-2 or SLD-2	19
28-inch recirc elbow at RLA-1 or RLB-1	19

Table 2

<u>Head Loss Calculation for NUKON Debris on Core Spray and RHR Strainers</u>

System	RHR	Core Spray
Rated Flow, gpm	5000	3750
Strainer Area, sqft	13.0	13.0
Debris Volume, cuft	2.9	2.2
Strainer Velocity, v, ft/sec	0.90	0.68
Debris Thickness, e, inches	2.63	2.03
Head Loss, H, ft of water	14	6
NPSH Margin (clean screen), ft of water	15	12

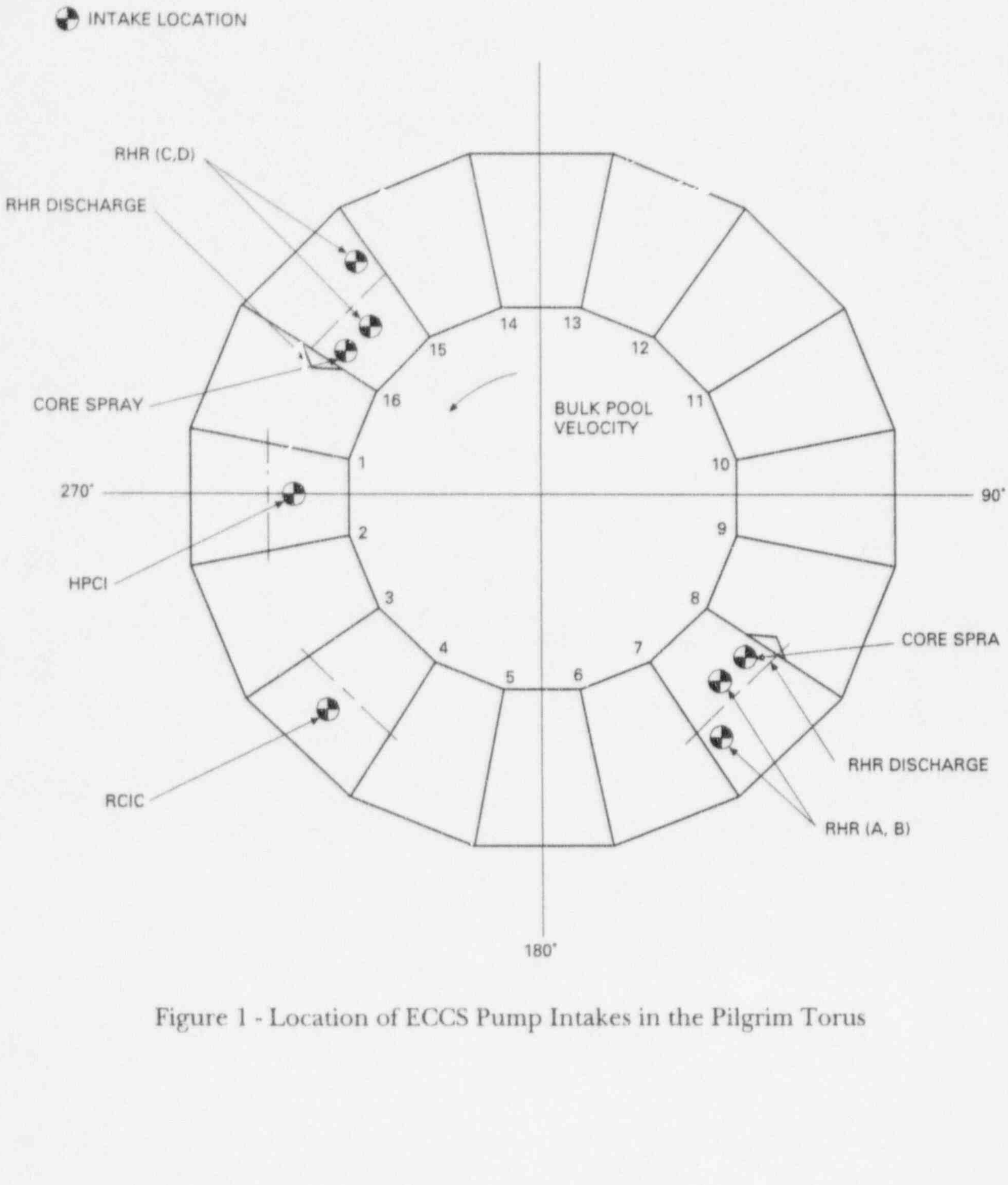


Figure 1 - Location of ECCS Pump Intakes in the Pilgrim Torus

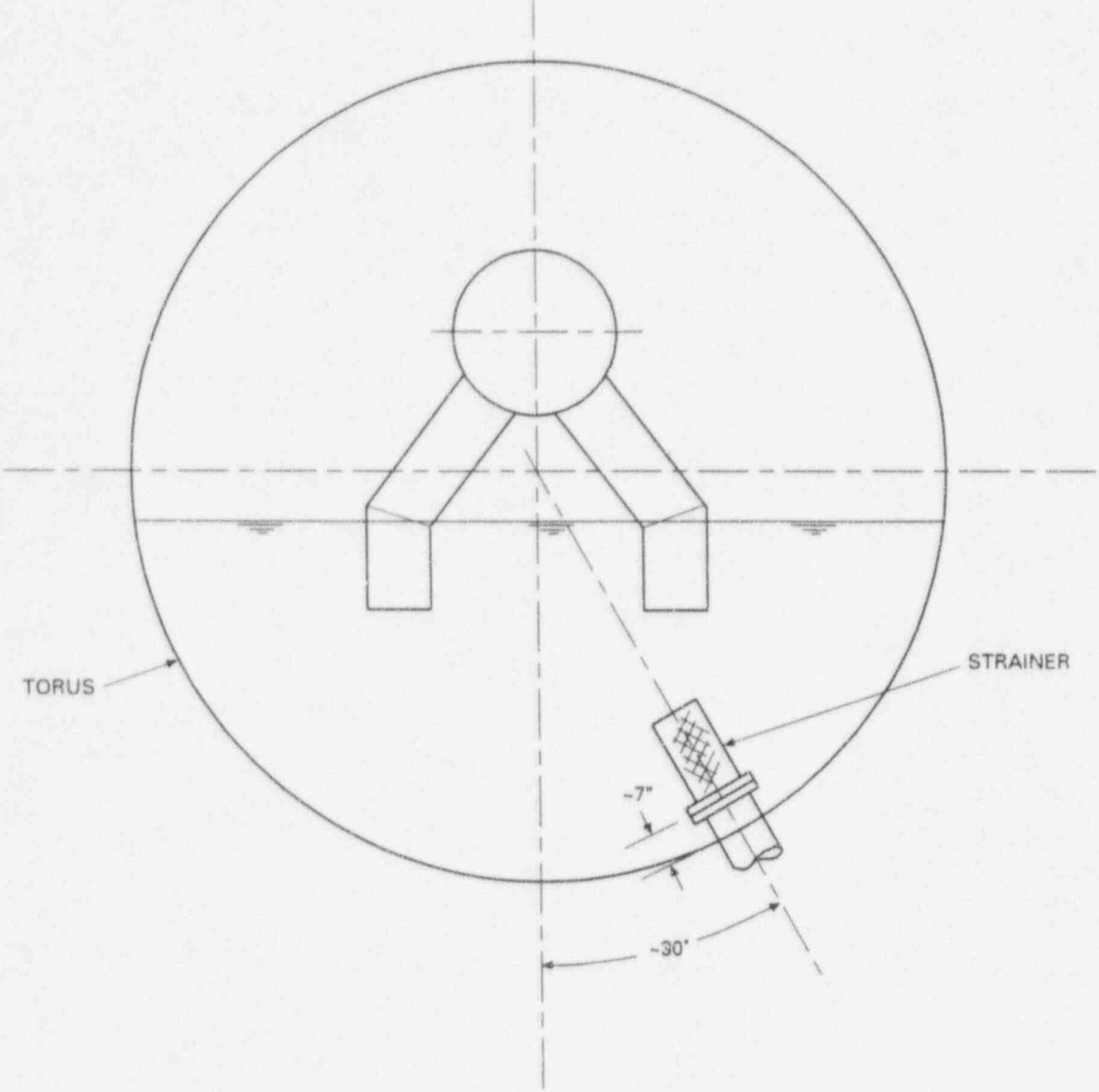


Figure 2 - Pilgrim ECCS Intake and Strainer Geometry

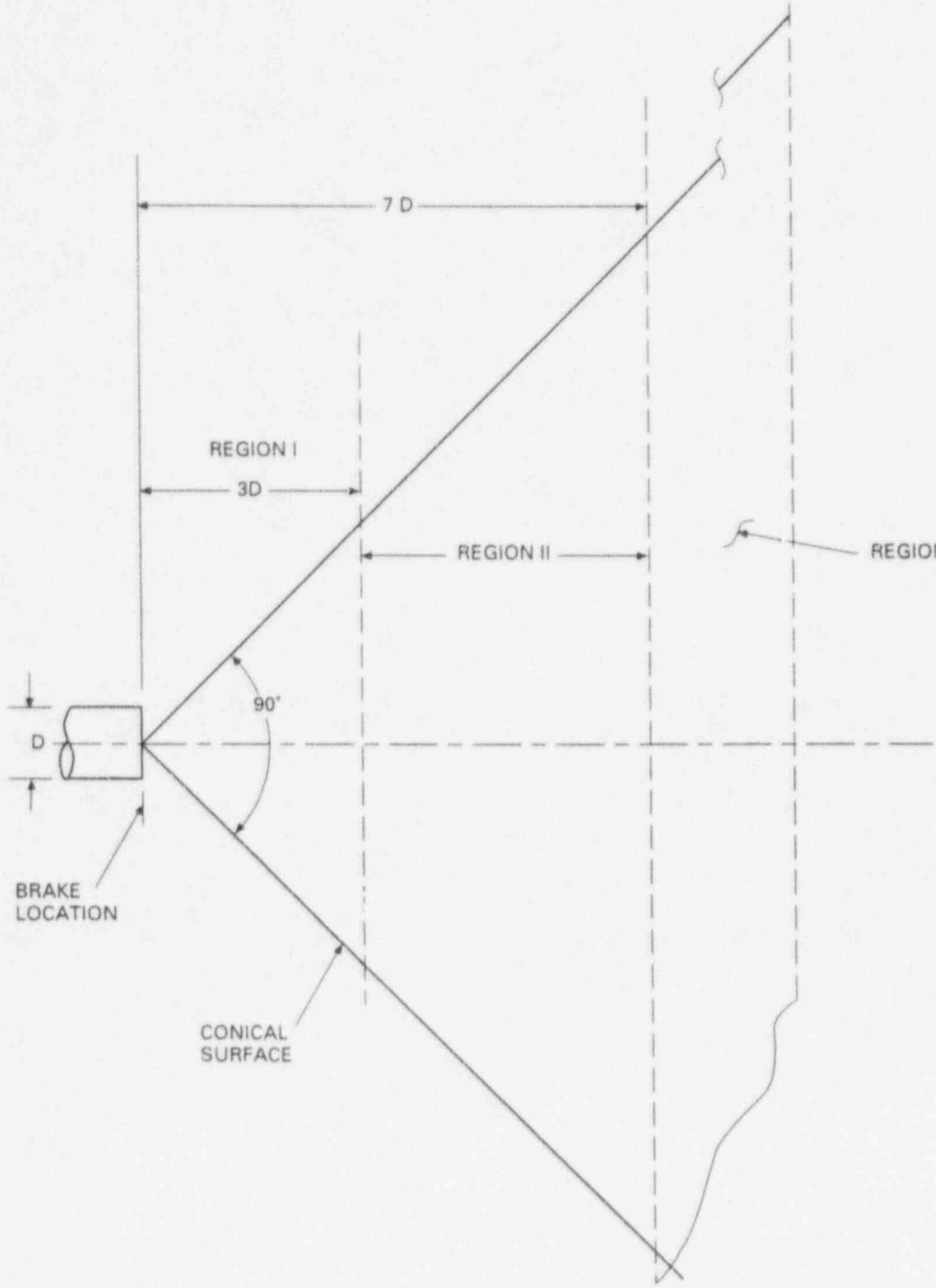


Figure 3 - Schematic of LOCA Jet-Cone Model

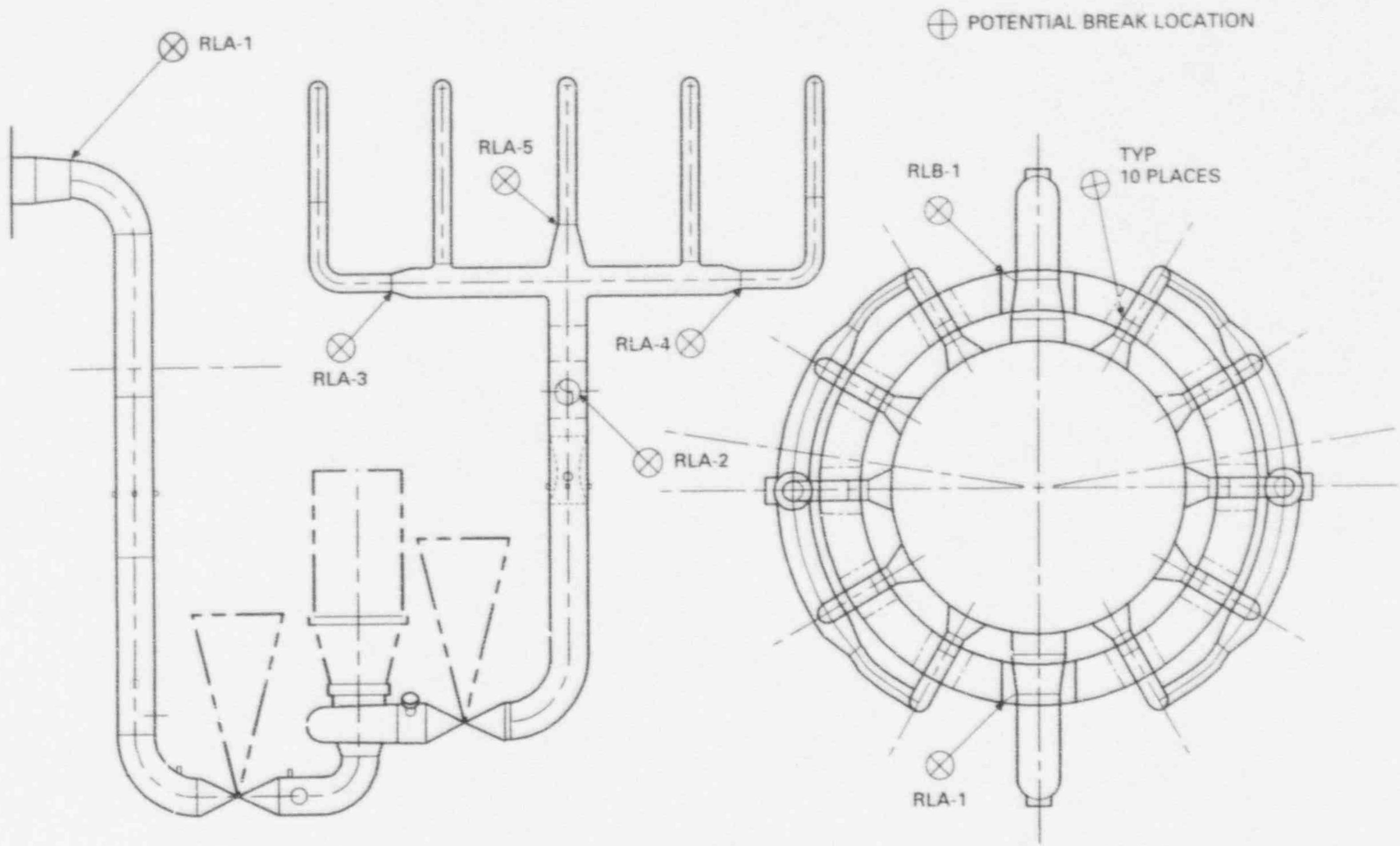


Figure 4. Potential Break Locations in the Pilgrim Recirculation Piping

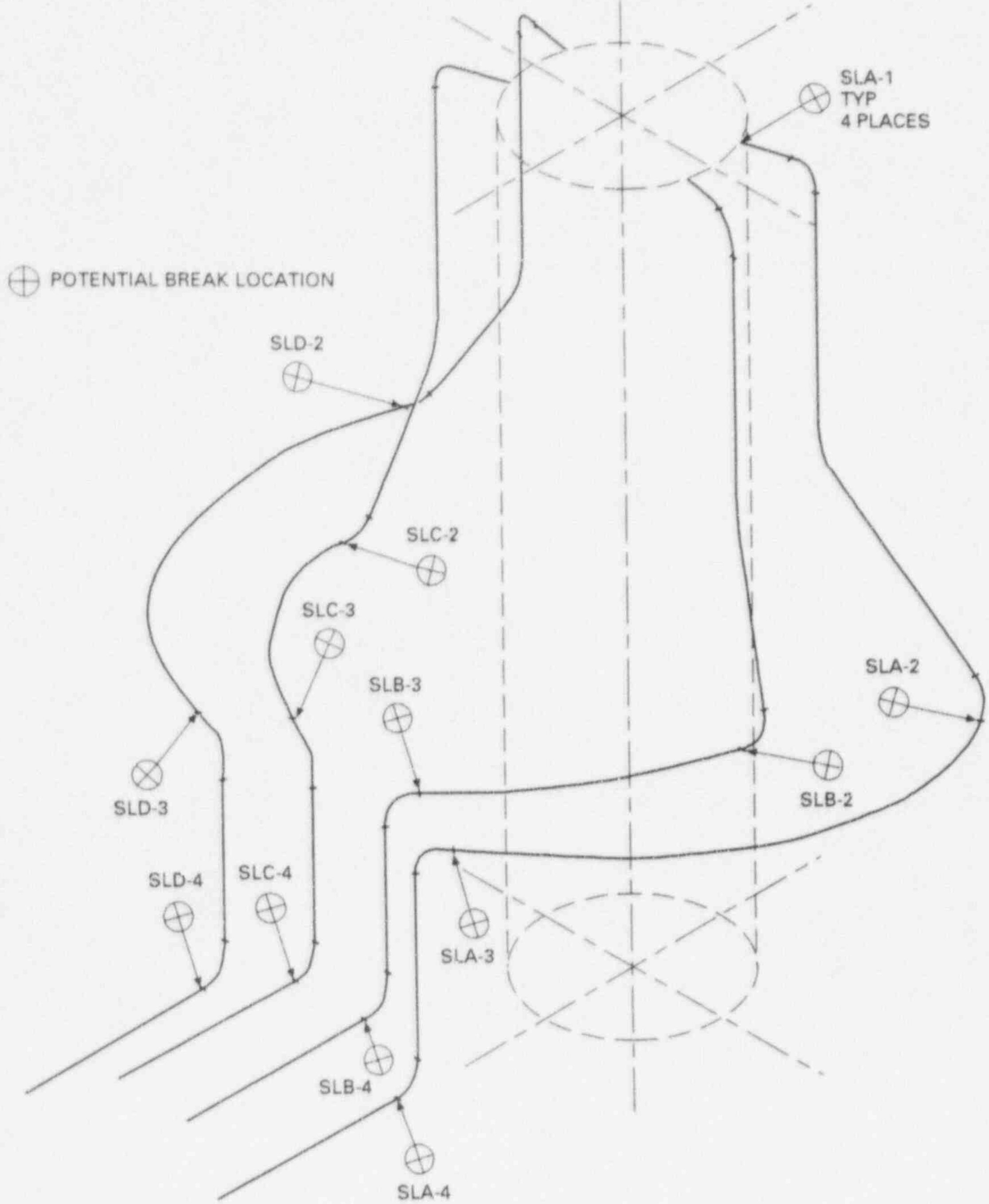
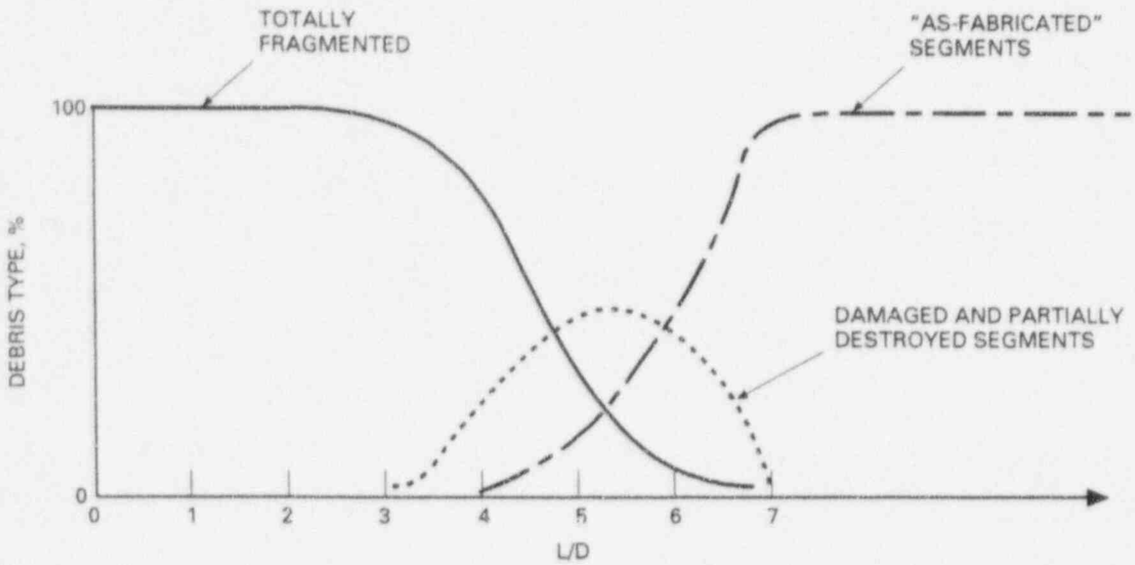
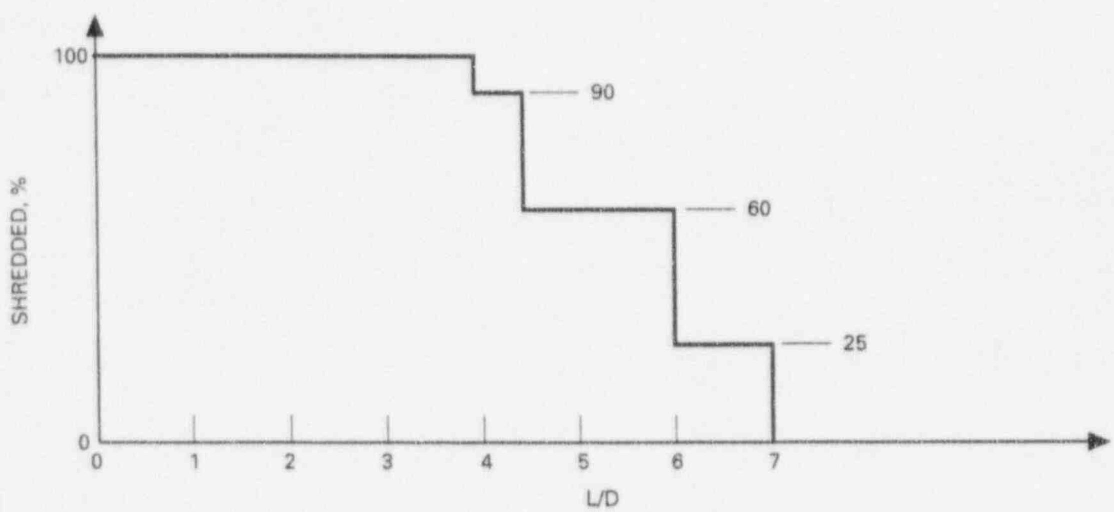


Figure 5 - Potential Break Locations in the Pilgrim Steamline Piping



(a) POSSIBLE VARIATION OF DEBRIS TYPES AND RELATIVE QUANTITIES IN REGIONS OF THE THREE-REGION JET MODEL (FROM REFERENCE 3)



(b) VARIATION OF SHREDDED DEBRIS USED IN ANALYSIS

Figure 6 - Shredded Debris Generation Model

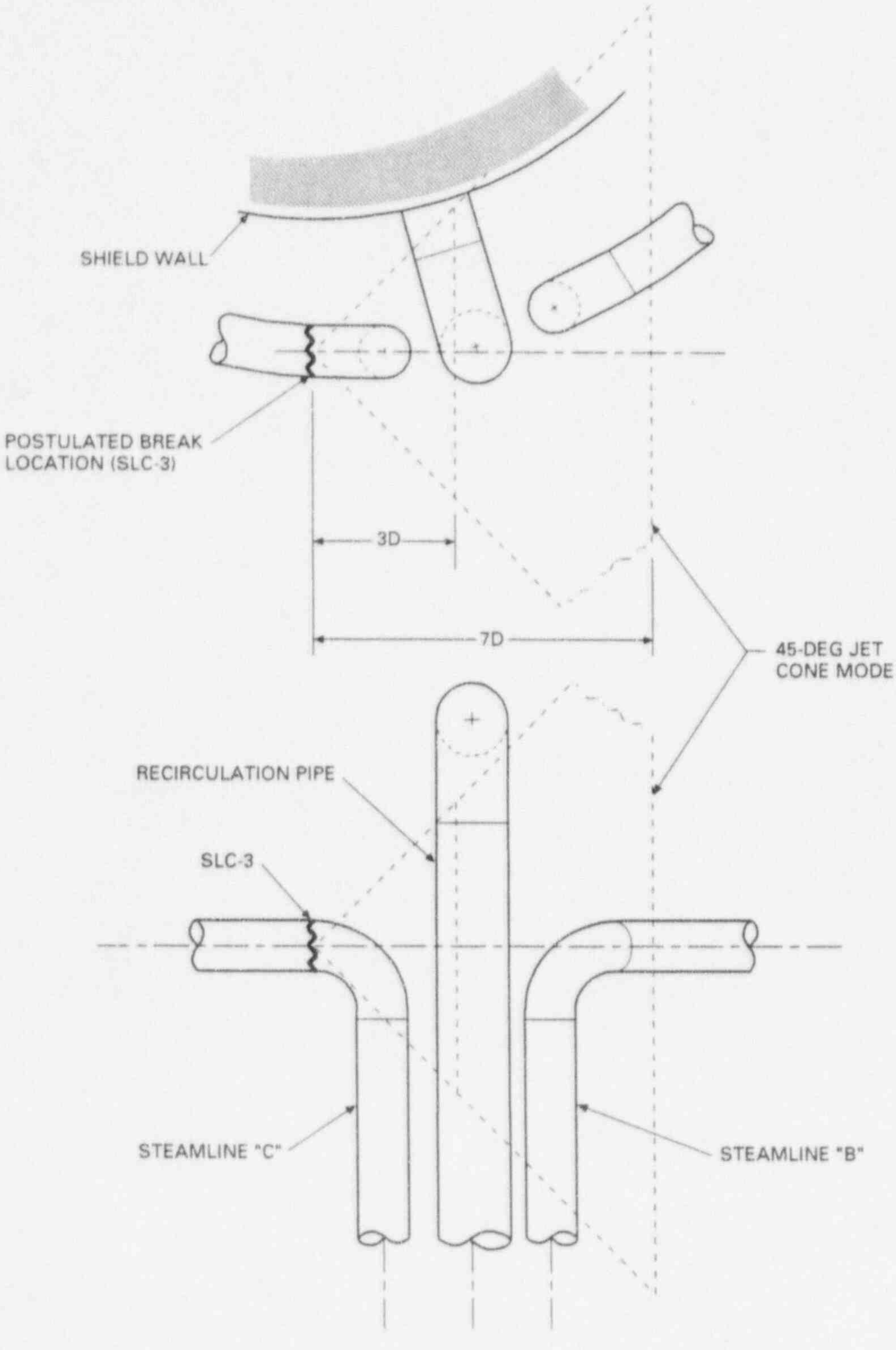


Figure 7 - Sketch of Worse Case Break Region

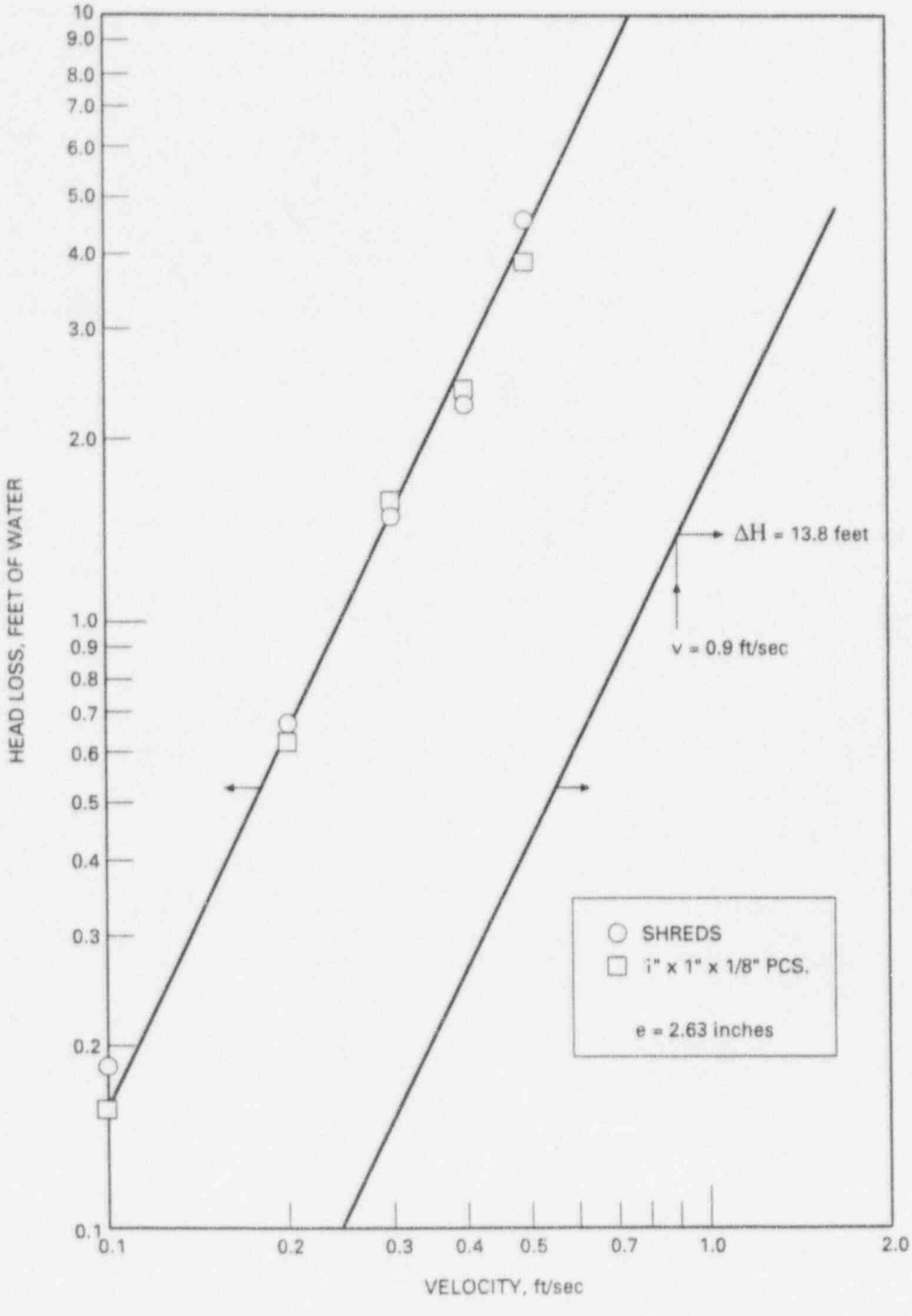


Figure 8 - Extrapolation of Head Loss Data for RHR System

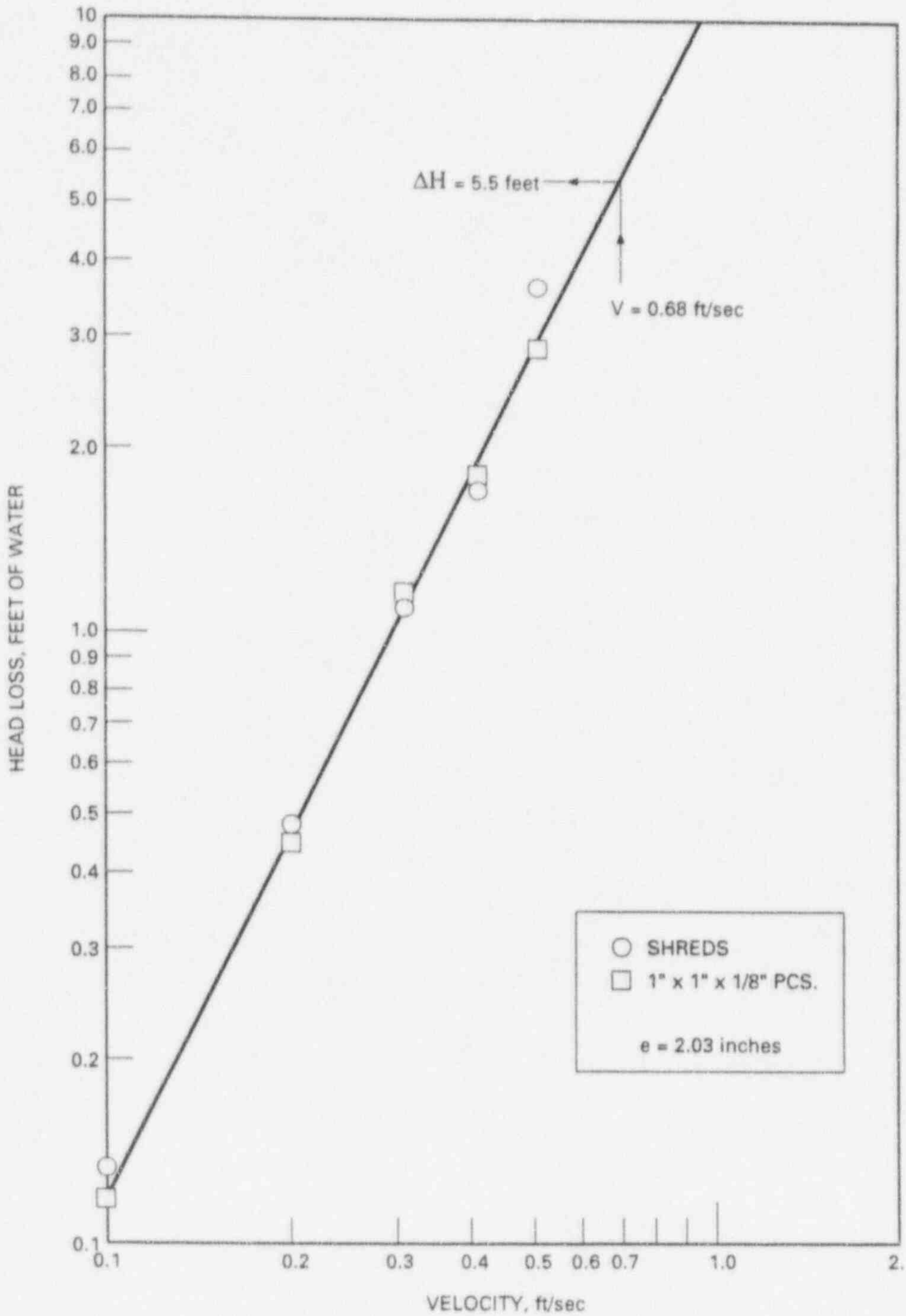


Figure 9 - Extrapolation of Head Loss Data for Core Spray System

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