Evaluation of Drywell Insulation Debris Effects on ECCS Pump Performance

Hope Creek Generating Station
Public Service Electric & Gas Company

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1 INTRODUCTION

1.1 PURPOSE

There is a concern that the insulation debris created by a high energy line break in the primary containment will collect on the Emergency Core Cooling System (ECCS) suction strainers and impair the pump performance. These debris considerations are part of Unresolved Safety Issue A-43, Containment Emergency Sump Performance.

The Hope Creek Generating Station (HCGS) was evaluated to determine the maximum quantity of insulation debris that might be generated by a LOCA. The evaluation includes transport of this debris to the ECCS suction strainers and the effect on ECCS pump operation. Only the low pressure coolant injection (LPCI) and core spray (CS) pumps are evaluated because only large pipe breaks can generate significant quantities of insulation debris. Neither the high pressure coolant injection nor the reactor core isolation cooling pumps are able to operate after a large break LOCA.

The only insulation debris in the drywell that might enter the vent pipes, and eventually the suppression pool, are small pieces of shredded fiberglas because of the small openings in the jet deflectors. Whole and torn blankets are assumed to be retained by the drywell internal obstructions and the vent jet deflectors.

1.2 SUMMARY OF RESULTS

It has been determined that the postulated fibrous insulation debris generated by a high energy line break will not jeopardize ECCS pump operation at HCGS. This is based on evaluation of the transport of the worst case shredded debris generation in the drywell. The volume of shredded debris and its transport to the ECCS strainers has been conservatively evaluated. The head loss due to the accumulation of the debris concurrent with the conservative NPSH available conditions does not cause the NPSH available to drop below that required by the ECCS pumps. The NPSH available to the ECCS pumps is at least 10 ft greater than the required 7.5 ft for the LPCI and 3.5 ft for the core spray pumps. The results of the analysis are shown on Table 3-1.

2 BASES

2.1 HCGS is a BWR with a Mark I containment design.

2.2 The ECCS pumps take suction from the suppression pool water inventory following a LOCA. The suppression pool is located in the torus surrounding the base of the drywell. The fluid from a LOCA is released into the drywell and the steam-water-gas mixture is conducted to the suppression chamber by the eight vent pipes and the vent/downcomer header system in the torus. When the liquid level on the floor of the drywell reaches the elevation of the vent pipe openings this liquid also flows to the suppression pool through the vent system.

The ECCS suction strainers are located above the bottom of the torus in eight different sections. Figures 2-1 through 2-5 show the general arrangement.

2.3 The only thermal insulation used in the drywell is Owens-Corning "NUKON", stainless steel jacketed fiberglas. The fiberglas is totally enclosed in woven fiberglas covers with glass fiber stitching. The blankets are held on with velcro fasteners and protected with 22 gage stainless steel jackets with seismically qualified mechanical latches.

3 METHOD OF ANALYSIS

3.1 IDENTIFICATION OF PIPE RUPTURE LOCATIONS (PRL)

3.1.1 The PRLs for analysis are based on the locations identified in the pipe break analysis discussed in FSAR Section 3.6 (Reference 4.4).

3.1.2 The break locations analysed were chosen in the large diameter lines with greatest potential for generating significant quantities of insulation debris. The PRLs analysed are in the following lines:

1. Reactor Recirculation Pump Suction
2. Main Steam Line
3. Feedwater Line
4. RHR Supply Line

3.1.3 The pipe break is postulated to be circumferential. The broken pipe is not assumed to shadow the jet cone although pipe movement is restricted by whip restraints. This will result in a conservative estimation of the affected insulation. Slot breaks were not evaluated as the resulting jet would have a smaller zone of influence and would therefore generate less insulation debris.

3.1.4 Extensive use of pipe whip restraints and separation of lines eliminates pipe whip and pipe impact as significant mechanisms for insulation debris generation. The debris generated by these mechanisms would be in the form of the manufactured whole blankets. This form of debris is retained in the drywell and does not affect the ECCS suction strainers.

3.2 DEBRIS GENERATION

3.2.1 The pipe break is postulated to produce a jet from each end of the break. Each jet cone is assumed to expand at an angle of 45 degrees from the pipe centerline as recommended in NUREG 0897 (Reference 4.1). The direction of the cone is along the original pipe centerline because the pipe movement is limited by the whip restraint.

3.2.2 Each jet cone is separated into two regions. Region I is the portion from the break to the plane where the jet thrust divided by the jet area is 20 psig. All insulation in Region I is assumed to be shredded into small fragments by the jet impingement forces. Region II is the portion of the jet cone extending from Region I to the plane where the jet thrust divided by the jet area is equal to 0.5 psig. The insulation in the region is assumed to be dislodged in the as-fabricated form.

3.2.3 The pipe whip restraints and large structural steel members inside the jet cone are assumed to cause "shadowing" of the jet (i.e., insulation in the "shadow" of the member is not assumed to be shredded). This is consistent with the criteria for modeling jet impingement forces in FSAR Section 3.6 (Reference 4.4) and SRP 3.6.2 (Reference 4.9).

3.2.4 The stainless steel jacketing on the insulation is assumed to provide no protection of the insulation blankets. This is a conservative assumption because it is expected that the steel jacketing will provide some protection against shredding of the insulation, especially where the jet pressure is between 20 and 60 psig.

3.2.5 A geometric analysis was performed to determine the volume of insulation that would be affected by the selected break locations. The volume of insulation exposed to jet impingement in Region I of the jet cone was quantified. The insulation dislodged in Region II of the jet cone was not quantified because the physical barriers in the drywell discussed in FSAR Section 6.2.2 (Reference 4.4) will prevent the insulation blankets from entering the suppression pool.

3.2.6 The break location generating the largest volume of shredded fibrous insulation is the Main Steam Line. The results of the analysis are provided below:

Main Steam Line Break (Line D)		Insulation
M. S. Line D	26"Ø	27.0 ft^3
M. S. Line C	26"Ø	6.75 ft^3
LPCI Line	12"Ø	12.0 ft^3
Recirc Pump Discharge	22"Ø	4.6 ft^3
		50.75 ft^3

The break location is shown in figures 3-1, -2 and -3. The same geometry applies to Main Steam Line A. Main steam lines B and C are less limiting.

3.3 INSULATION DEBRIS TRANSPORT

3.3.1 <u>Short Term Transport</u>

3.3.1.1 The short term is the period during initial blowdown from the postulated pipe break. The blowdown lasts for about 1.5 minutes for the main steam line break cases. The insulation is transported by the jet force from the break and flow of the spilled fluid to the drywell floor. As indicated earlier, pipe whip and impact are not considered in the analysis.

3.3.1.2 It is conservatively assumed that all of the insulation in Region I of the jet cone is shredded and transported to the drywell floor by the jet forces. In reality, a portion of the shredded insulation would be distributed and retained on the structural steel and on the grating and components in the drywell. Only a portion would reach the floor and be available for transport to the torus. The shredded insulation is assumed to be uniformly mixed in the turbulent liquid collecting on the containment floor. When sufficient liquid has collected on the floor to reach the level of the vent pipes, it overflows and is carried to the suppression pool by the vent header. It is conservatively assumed that all of the shredded insulation in the drywell floor pool, except that in the sumps and inside the cylindrical vessel pedestal, is transported to the suppression pool with the overflowing liquid. The area under the vessel pedestal has only one opening at the elevation of the drywell flooding so this volume of water will become stagnant when the equalibrium flooding level in the drywell is reached. The sumps in the drywell are below the floor so that after they are filled and the drywell flooding level is above the top of the sump they become stagnant pools.

3.3.2 <u>Long Term Transport</u>

3.2.2.1 The long term is the period starting with the end of the initial blowdown from the postulated pipe break. The transport of insulation is caused by the operation of the ECCS pumps. It is assumed that all of the LPCI and core spray pumps are operating at their maximum flow rates. This results in conservatively high flow velocities for the transport analysis.

3.3.2.2 It is further assumed that the shredded insulation is uniformly mixed with the suppression pool water at the end of the short term/beginning of the long term. This assumption is based on the even distribution of the blowdown from the downcomers and the turbulent mixing within the suppression pool and is consistent with the uniform distribution of insulation in the drywell during the blowdown.

3.3.2.3 At the beginning of the long term the initial blowdown has ended. The discharge from the downcomers during the long term is due to the overflow of the ECC systems from the drywell. This flow is evenly distributed by the vent header system and results in local turbulence near each downcomer. The containment spray and torus spray modes for the LPCI are used for long term containment cooling following a large break LOCA. The sprays provide an even distribution of fluid returning to the suppression pool causing only shallow surface turbulence. The bulk of the water in the suppression pool is subject to bulk flow velocities due to the removal of water by the ECCS pumps.

3.3.2.4 The suppression pool has ring girders approximately 2 feet deep at each mitered joint and at the mid cylinder of each section. The transport test data in NUREG/CR-2791, (Reference 4.3) indicates that a flow velocity exceeding 0.3 ft/sec is required to entrain fibrous insulation shreds lying on the bottom of the suppression pool. The maximum flow velocity at the bottom of the suppression pool due to the bulk flow near each strainer is less than 0.3 ft/sec. Any insulation debris that sinks to the bottom outside the sections containing the strainers will not be transported to the strainers. The insulation that settles in the section between ring girders containing a strainer is conservatively assumed to collect on the strainer.

3.3.2.5 The maximum ECCS flow rate is used to determine the flow velocities. This minimizes the time available for settling of the debris and maximizes the flow velocities. The evaluation is based on the simultaneous operation of LPCI and core spray pumps at their runout flow rates.

4 LPCI pumps at 11,000 gpm/pump

4 core spray pumps at 4,015 gpm/pump

The resulting bulk flow velocity in the region near each strainer is 0.037 ft/sec toward each LPCI strainer and 0.014 ft/sec toward each core spray strainer.

3.3.2.6 Based on data in NUREG/CR-2791 (Reference 4.3), there are three types of shredded fibrous debris:

1. Debris that immediately sinks
2. Debris that slowly sinks
3. Debris that floats

The discussion in NUREG/CR-2982 (Reference 4.2) indicates that the debris absorbs water more readily and will sink faster in hot (120°F) water than water at ambient temperature.

3.3.2.7 Tests performed by Owens-Corning on fibrous "NUKON" fragments discussed in Topical Report OCF-1, Reference 4.5, indicate that the fragments will readily sink after absorbing water and becoming saturated. The shredded debris that enters the suppression pool will be in contact with hot water. This debris is also mixed with the blowdown water and enters the suppression pool below the water surface. The rate of water absorption is also more rapid when the insulation is hot, which is the case for insulation from high temperature lines. Therefore, it is expected that most fragments will rapidly become saturated and settle. Also, because the fragments are thoroughly wetted in transport to the suppression pool, both the floating and slow sinking debris are considered to be slow sinking. Thus, for conservatism no credit is taken for floating debris preventing transport to the strainers.

3.3.2.8 Although there is considerable test data supporting the conclusion made in Section 3.3.2.7, that most "NUKON" fragments will rapidly settle to the bottom of the torus, it is acknowledged there is no specific LOCA test data available describing the post-LOCA buoyancy characteristics of "NUKON". In the absence of specific LOCA test data for "NUKON", the conservative approach is to assume less than all the "NUKON" fragments rapidly settle. In order to arrive at a credible and conservative factor for the lesser amount of debris that rapidly settles, comparable test data contained in Section 4.7.2 of NUREG/CR-2791 (Reference 4.3) describing the post-LOCA buoyancy characteristics of mineral wool insulation was used in the analysis. This data is considered conservative because fragments of as-manufactured fiberglas insulation, and "NUKON" in particular, will become wet and sink faster than mineral wool (i.e., fiberglas has a greater tendency to sink compared to mineral wool). This conclusion is based on data contained in NUREG/CR-2982 and Topical Report OCF-1, (References 4.2 and 4.5). There is no reason to believe LOCA effects would change the buoyancy characteristics of "NUKON" debris so that it would be more buoyant than mineral wool. NUREG/CR-2791 (Reference 4.3) states that 40% to 50% of the fibrous insulation (mineral wool) dislodged by a LOCA can be expected to immediately sink. The calculation, therefore, used the conservative factor of 40% to determine the amount of "NUKON" fragments that rapidly settle. The remaining 60% of the debris in the suppression pool was assumed to be slow settling.

3.3.2.9 The rapid settling debris is assumed to be dispersed uniformly in the suppression pool. The settling rate for this debris is .2 ft/sec based the average sink rate for saturated insulation in Topical Report OCF-1 (Reference 4.5). This settling rate and the bulk velocity of the suppression pool toward each strainer were used to determined the volume of rapid settling debris collecting on each strainer.

3.3.2.10 The slow settling debris is assumed to be dispersed uniformly in the suppression pool. The settling rate for this debris is .017 ft/sec based on the average sink rate for very small clumps of insulation in Topical Report OCF-1 (Reference 4.5). This settling rate and the bulk velocity of the suppression pool tow- d each strainer were used to determine the volume of slow settli.., debris collecting on each strainer.

3.3.2.11 Based on the transport analysis, the maximum expected shredded debris to collect on the RHR strainers is 28.8% of the amount reaching the suppression pool, and that collecting on the core spray strainers is 14.6% of the amount reaching the suppression pool. The total collecting on the strainers is 43.4% of that in the suppression pool or 29% of the total shredded insulation generated.

3.4 ECCS SUCTION STRAINER HEAD LOSSES DUE TO INSULATION DEBRIS ACCUMULATION ON THE STRAINERS

3.4.1 The volume of insulation debris that will accumulate on each strainer is calculated. Each pump has a separate suction line with a strainer located in the torus as shown on figure 3-1. The design and dimensions of the strainers is shown in figure 3-2. The effective surface area for each LPCI strainer is 15.2 ft^2. The effective surface area for each core spray strainer is 5.64 ft^2. The total ECCS strainer area is 83.4 ft^2.

3.4.2 The head loss calculated for accumulation of fibrous insulation debris is based on thickness of a uniform accumulation on the effective surface. Reference 4.8 provides a head loss formula developed for a bed of shredded "NUKON" insulation. It is noted that the maximum approach velocity tested in the reference is 0.5 ft/sec, while the strainer approach velocity for HCGS is near 1.5 ft/sec. Review of the data in the reference indicates that it is reasonable to assume that the straight line logrithmic relationship between head loss and approach velocity can be extended to approach velocities near 1.5 ft/sec. This was confirmed in discussion with the insulation manufacturer. Therefore, the "NUKON" specific head loss formula is used. This formula is provided below:

$$H = 63.8\ (t_i)^{1.07}\ (V)^{1.79}$$

where
H = head loss, ft of water
t_i = equivalent accumulation thickness, ft
v = screen approach velocity, ft/sec

3.4.3 The head loss due to the accumulation of insulation on the strainers is provided in Table 3-1.

3.5 EFFECT OF ACCUMULATION OF INSULATION DEBRIS ON ECCS PUMP NPSH.

3.5.1 The minimum NPSH is available when the suppression pool temperature is 212°F at 24,000 seconds. It is conservatively assumed that no noncondensables are added to the torus because of blowdown from the drywell and the noncondensables in the torus remain at the same temperature they were at prior to the blowdown. Therefore, the partial pressure exerted by the noncondensables is the same as existed prior to the LOCA.

3.5.2 Table 3-1 shows that the worst case insulation generation and the resulting accumulation on the strainers results in adequate NPSH for the ECCS pumps. The NPSH available for the LPCI pumps is 19.7 ft and the required NPSH is 7.5 ft. The NPSH available for the core spray pumps is 14.12 ft and the required NPSH is 3.5 ft. The NPSH required is taken from manufacturers certified performance data for the pumps. The required NPSH values in the FSAR and the GE Process Flow Diagrams contain a large safety margin above the requirement given by the pump manufacturers.

3.5.3 Non uniform distribution of the insulation in the torus was examined. The ECCS pumps have adequate NPSH available when 70% of the insulation debris reaching the suppression pool is distributed in one half the pool volume. The NPSH available was determined using the same assumptions as previously.

4 REFERENCES

4.1 Serkiz, A.W., "Containment Emergency Sump Performance," NUREG-0897 (for comment), NRC, April, 1983.

4.2 Brocard, D.N., "Buoyancy, Transport, and Head Loss of Fibrous Reactor Insulation," NUREG/CR-2982, SAND 82-7205, Alden Research Laboratory, November, 1982.

4.3 Wysocki, J.: Kolbe, R., "Methodology of Evaluation of Insulation Debris Effects," NUREG/CR-2791, SAND 82-7067, Burns & Roe, Inc., September, 1982.

4.4 Final Safety Analysis Report (FSAR), Hope Creek Generating Station, Public Service Electric and Gas Company.

4.5 Owens-Corning Fiberglas Corporation, "Topical Report OCF-1, Nuclear Containment Insulation System, NU'K'ON," January, 1979.

4.6 ANSI/ANS-58.2-1980, "Design Basis for Protection of Light Water Nuclear Power Plants Against Effects of Postulated Pipe Rupture".

4.7 ANSI/ANS-58.3-1977 (N182), "Physical Protection for Systems and Components Important to Safety".

4.8 Brocard, D.N., "Transport and Head Loss Tests of Owens-Corning NUKON Fiberglas Insulation, "Alden Research Laboratory, September, 1983.

4.9 NUREG-0800, "Standard Review Plan for Review of Safety Analysis Reports for Nuclear Power Plants", US NRC, July, 1981.

TABLE 3-1

Summary of Calculated ECCS Strainer Head Loss
Due to Accumulation of Fibrous Debris and
the Effect on ECCS Pumping $NPSH_A$

	ECCS STRAINER	PUMP FLOW gpm	DEBRIS GENERATED ft^3	DEBRIS VOLUME REACHING STRAINER ft^3 (1)	DEBRIS THICKNESS in.	DEBRIS HEAD LOSS ft	MINIMUM $NPSH_A$ WITH CLEAN STRAINERS ft	MINIMUM $NPSH_A$ WITH COVERED STRAINERS ft	$NPSH_R$ FOR PUMP ft
MAIN STEAM	LPCI	11,000	50.75	2.47	1.92	22.9	42.6	19.7	7.5
LINE BREAK	CS	4,015		1.21	2.52	30.13	44.25	14.12	3.5

(1) Value for a single strainer.

(2) Includes piping loss to the pump.

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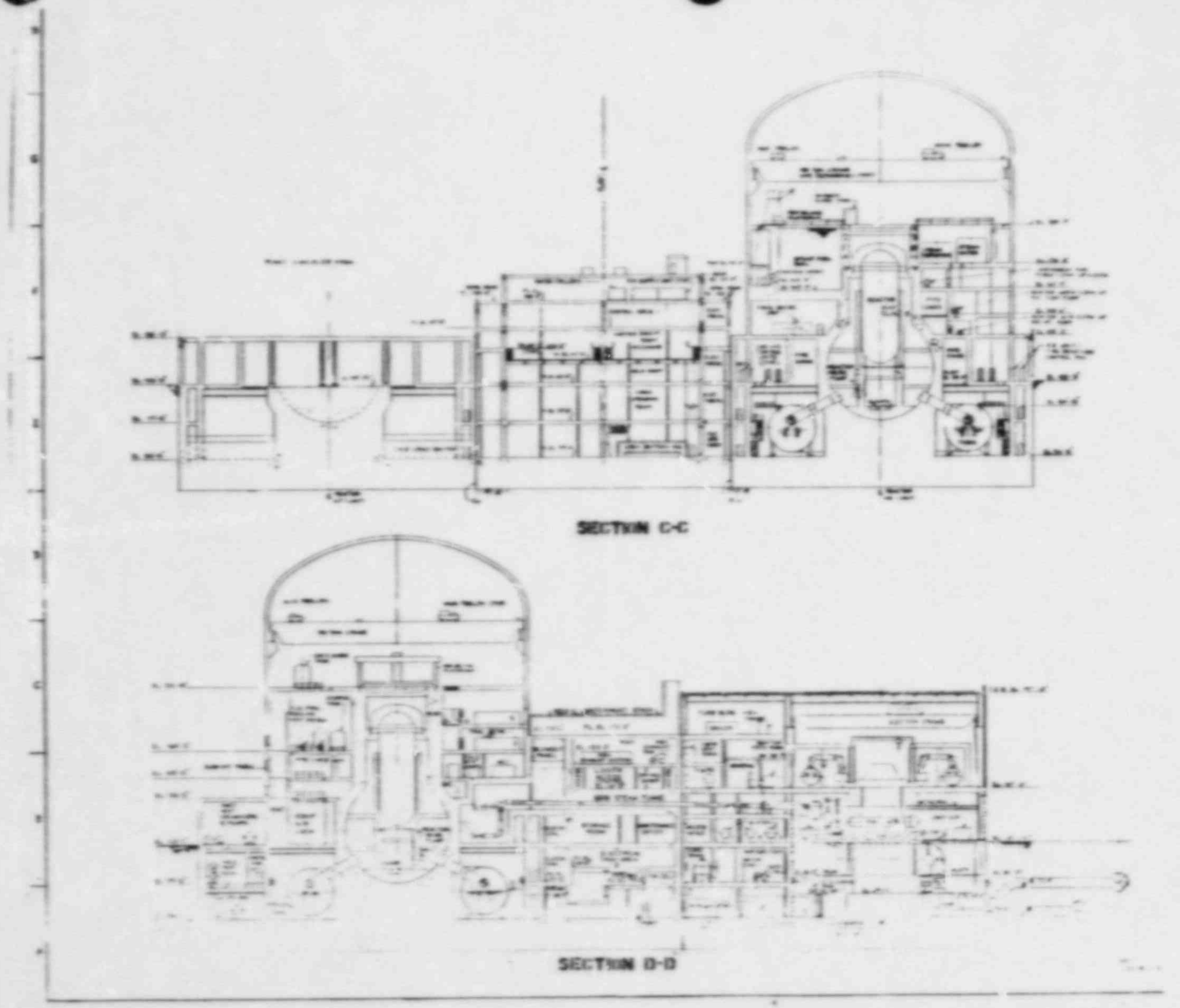

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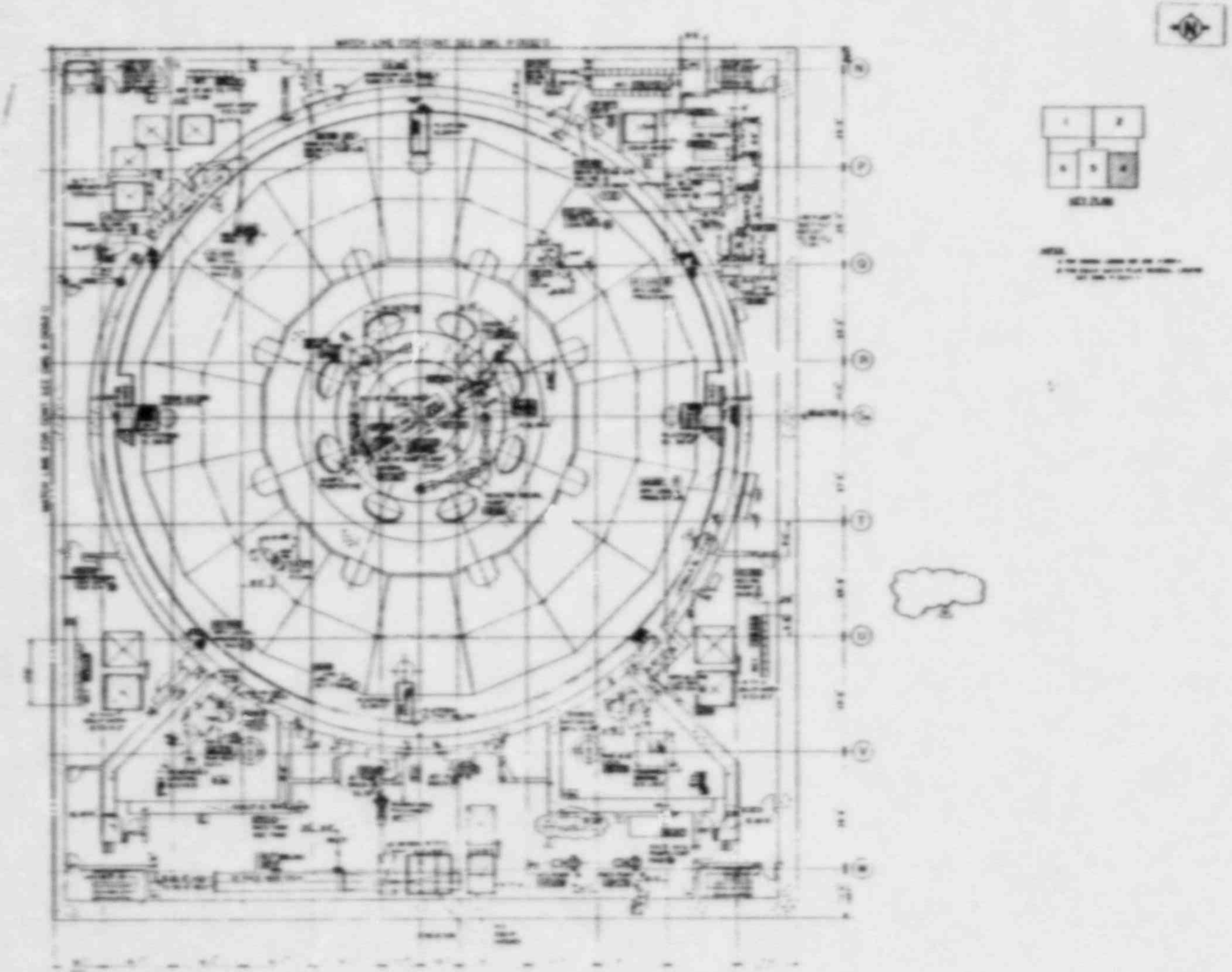
HOPE CREEK
GENERATING STATION

GENERAL ARRANGEMENT
SECTION C-C & D-D

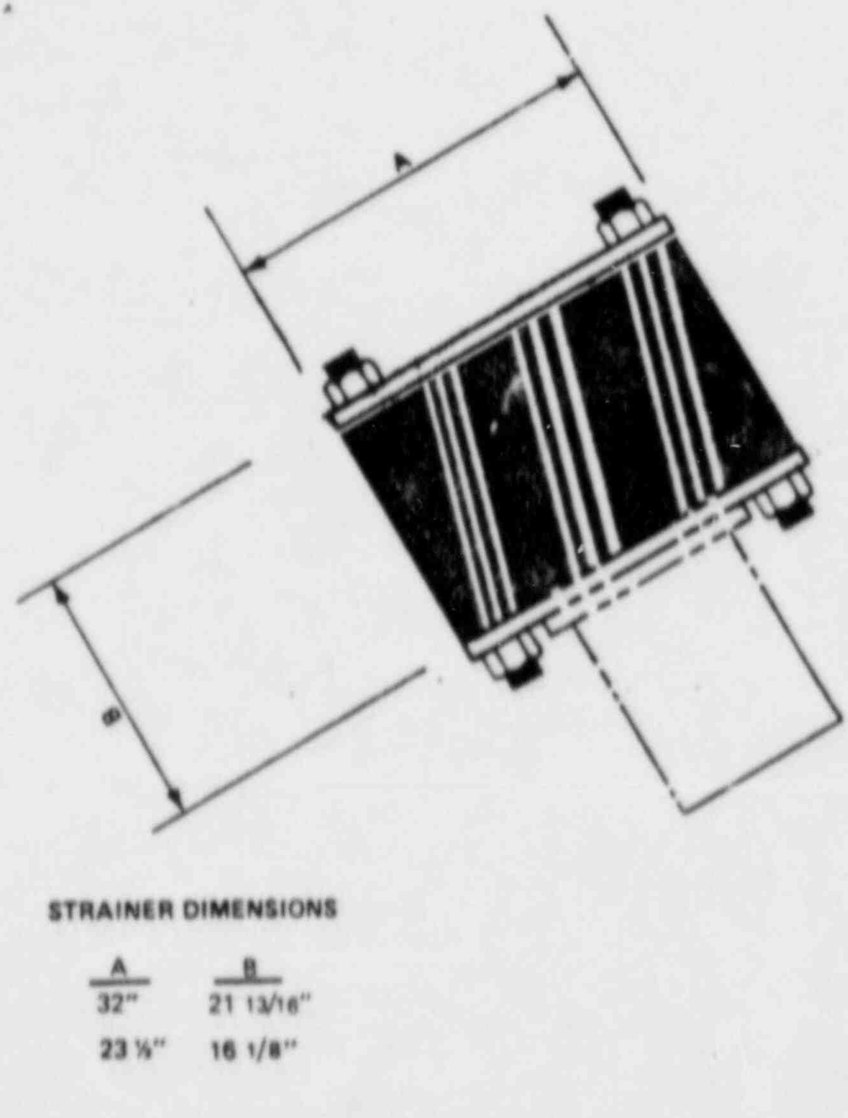
FIGURE 2.1



HOPE CREEK
GENERATING STATION

REACTOR BUILDING

FIGURE 2.2



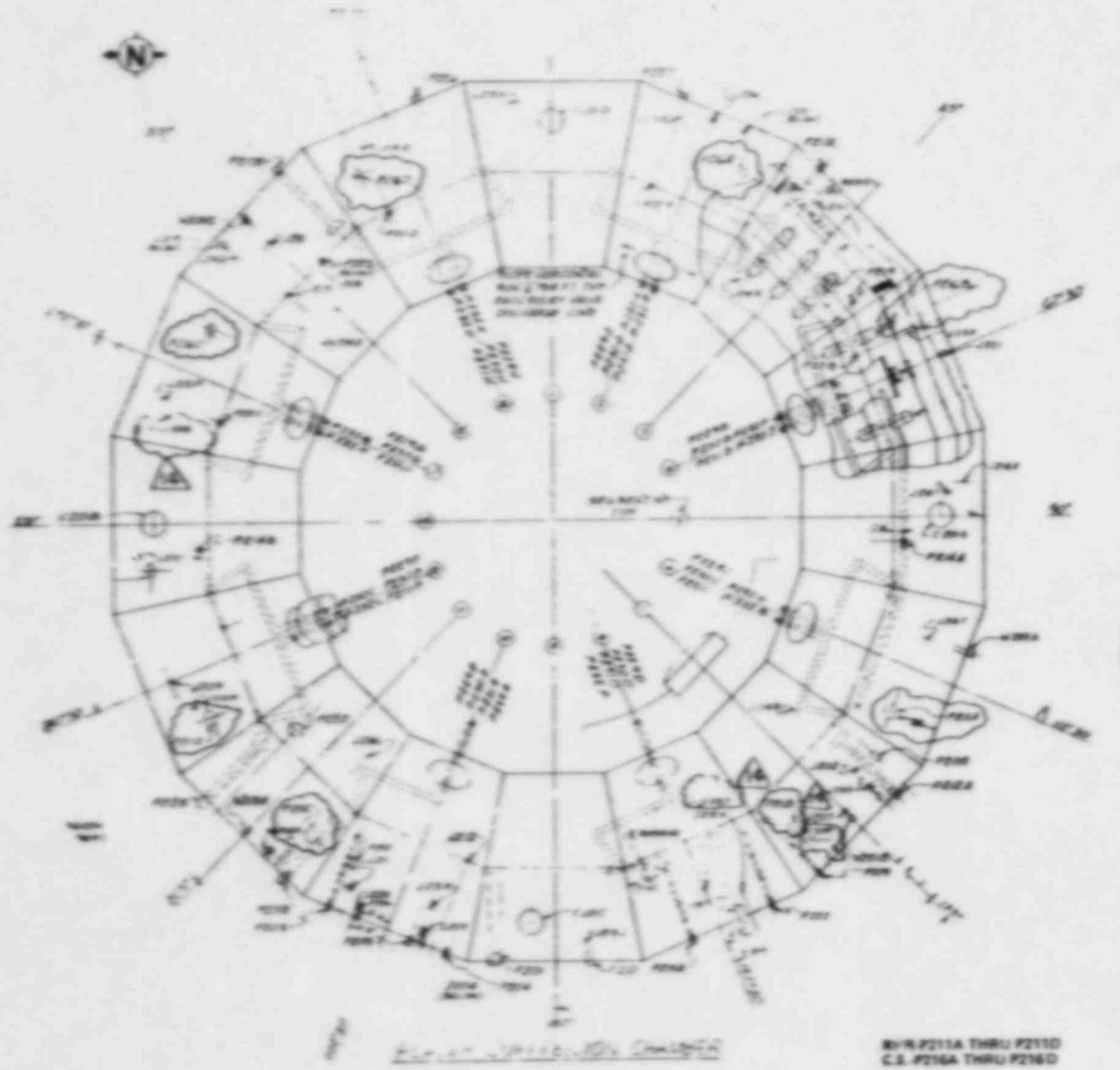
STRAINER DIMENSIONS

	A	B
LPCI	32"	21 13/16"
CS	23 ½"	16 1/8"

HOPE CREEK
GENERATING STATION

SUPPRESSION POOL STRAINERS

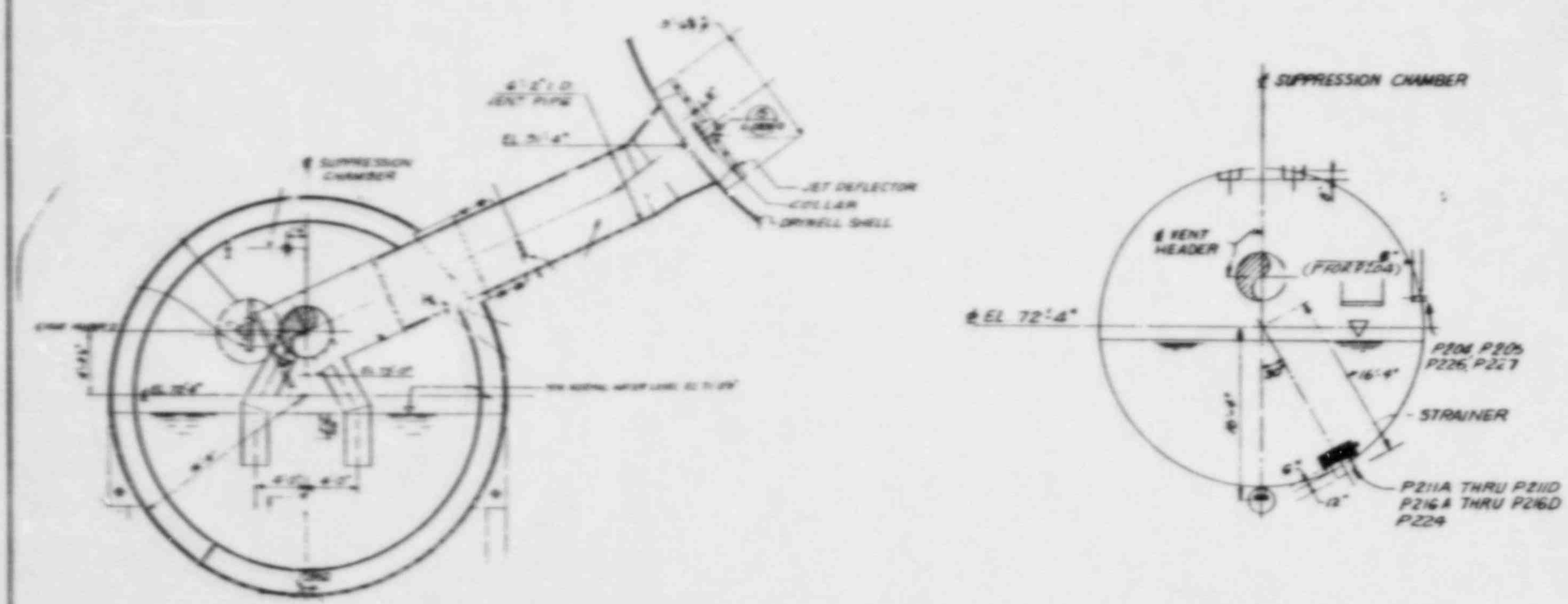
FIGURE 2-3



HOPE CREEK
GENERATING STATION

SUPRESSION CHAMBER

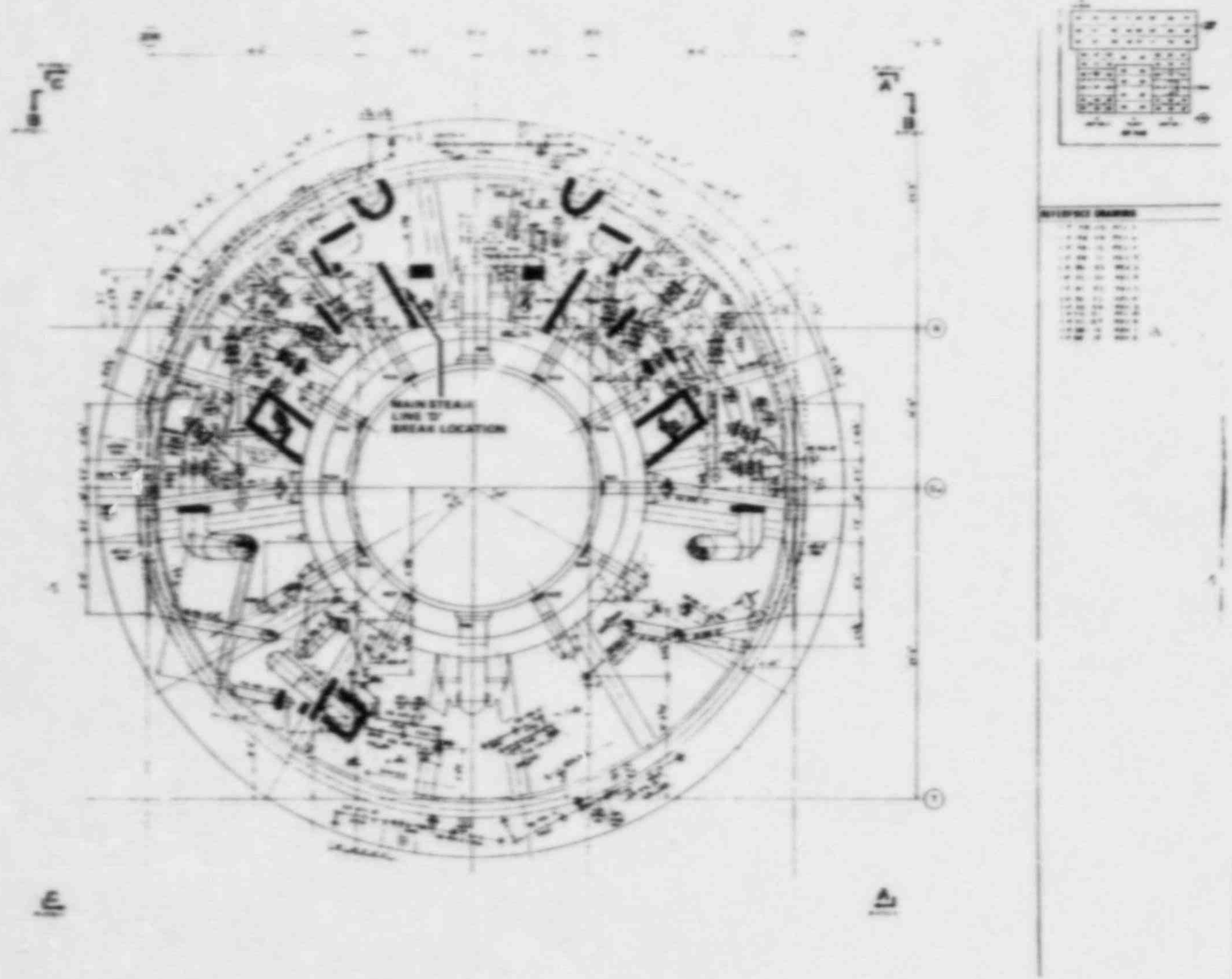
FIGURE 2.4



HOPE CREEK
GENERATING STATION

SUPRESSION CHAMBER
STRAINERS

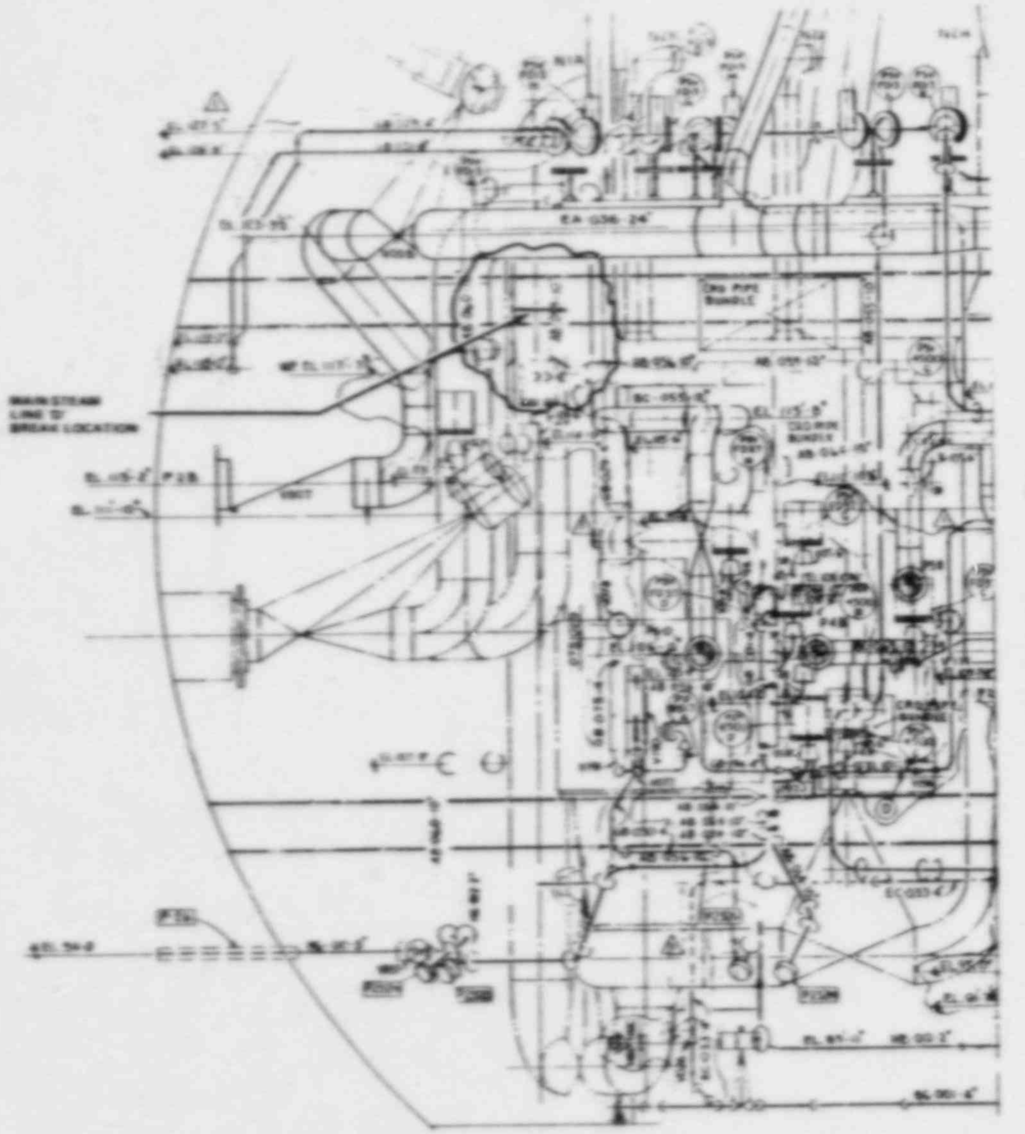
FIGURE 2-5



HOPE CREEK GENERATING STATION

BREAK LOCATIONS

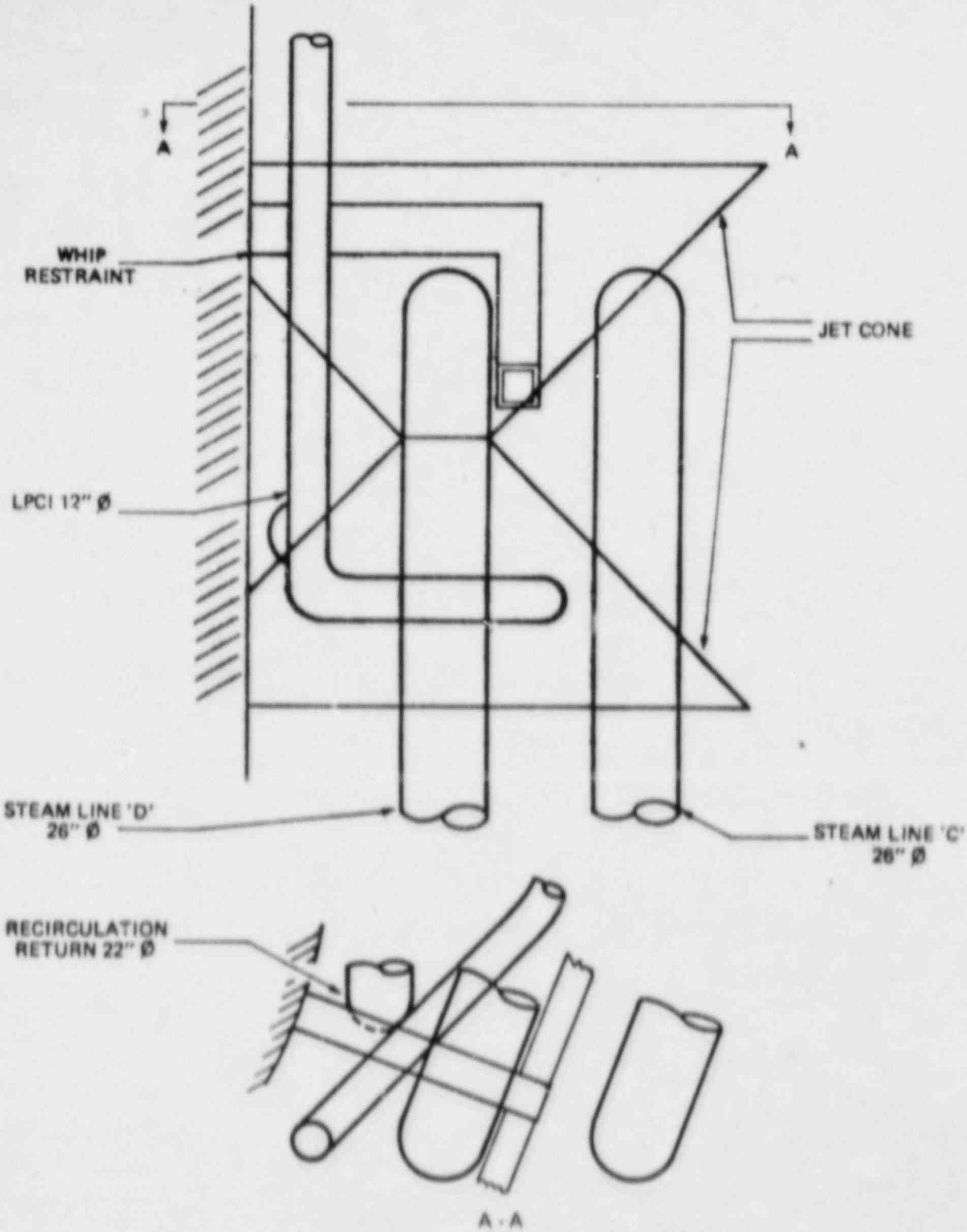
FIGURE 3-1



HOPE CREEK
GENERATING STATION

MAIN STEAM LINE

FIGURE 3-2



HOPE CREEK GENERATING STATION
MAIN STEAM "D"
FIGURE 3-3