ATTACHMENT

REPORT ON THE STEAM GENERATOR TUBE LEAK AT PVNGS UNIT 1

Revision 0
February 1987

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I. Introduction

A. Purpose of Report

This report describes the steam generator tube leak event and describes the inspections which were conducted on the PVNGS Units 1 and 2 steam generators. Additionally, the report provides an evaluation of each of the significant inspection findings. These evaluations, which are described on a summary level in this report, provide the basis for ANPP's determination that power operation of PVNGS Units 1 and 2 may be safely resumed.

B. Description of Event

On January 17, 1987, an indication of primary to secondary leakage was received in the PVNGS Unit 1 control room. The indication was in the form of a high radiation alarm from the steam generator blowdown system radiation monitor associated with steam generator #1. Subsequent to receipt of the alarm, the control room staff performed a Reactor Coolant System (RCS) inventory balance calculation and determined that the primary to secondary leak rate was approximately 0.2 gpm. Additionally, the RCS inventory balance calculations for the previous three days had indicated a trend of slowly increasing unidentified RCS leakage. The primary to secondary leak was closely monitored by mass balance and secondary radiochemical techniques and the leak increased to approximately 0.4 gpm by the morning of January 18, 1987. At this time, due to the increasing leakage trend, ANPP decided to shutdown the unit. It should be noted that the leakage requirements of Technical Specification 3.4.5.2 were not exceeded prior to shutdown of the reactor.

C. Description of the System 80 Steam Generator

The System 80 steam generators (Figure 1) are of the recirculating U-tube design. The tube supports employ the CE eggcrate design which provides maximum open flow area. The major difference between the System 80 steam generators and earlier CE steam generators is the incorporation of an integral economizer (Figure 2). The economizer uses the lower portion of the cold leg half of the tube bundle to preheat incoming feedwater to saturation conditions, resulting in a more efficient heat transfer process.

The integral economizer is an axial flow design. Feedwater is introduced into a water box (Figure 3) that forms a half-ring around the cold leg side of the tube bundle. Discharging uniformly around the half-circumference through ports in the bottom of the water box, feedwater flows radially inward across the tube sheet beneath the flow distribution plate. The flow distribution plate is designed to achieve uniform axial mass velocity over the cross section of the economizer.

The economizer is formed by mounting a 2-5/8 inch thick divider plate in the tube lane (Figure 3) between the hot and cold leg sides of the tube bundle (Figure 4). The divider plate is attached to the steam generator shell and the center support cylinder and extends up past the third tube support. The divider plate completely isolates the cold and hot leg sides in the lower portion of the steam generator.

At the top of the economizer section (economizer section extends to the top of the divider plate as shown in Figure 4), the saturated feedwater from the economizer section mixes with recirculating water introduced through a 16-inch entrance window extending 180° around the cold leg side half-circumference (Figure 2).

Recirculating water on the hot leg side is introduced into the tube bundle below a flow distribution plate, which forces flow radially inward across the tube sheet to achieve uniform axial velocity

through the distribution plate. Axial flow through the flow distribution plate occurs through the 0.025 inch diametral clearance annulus formed by drilled holes in the flow distribution plate and the tubes passing through the plate. There are no holes in the flow distribution plate without a corresponding tube passing through it.

The steam generator tubes are 0.75 inch outside diameter with 0.042 inch thick walls. The steam generator tubes are made of Inconel 600. The eggcrate tube supports and the flow distribution plates are made of ferritic stainless steel.

D. Development of Inspection Plan

PVNGS Unit 1 was shutdown on January 18, 1987, and over the next several days, the RCS was cooled down to cold shutdown conditions in preparation for inspection of the steam generators. ANPP elected to perform the Technical Specification required initial inservice eddy current inspection of the PVNGS Unit 1 steam generators. The initial inspection plan included approximately 3,000 tubes in each of the PVNGS Unit 1 steam generators. It should be noted that the selected inspection plan was very conservative and was well in excess of the Technical Specification required 3% sample (3% corresponds to 331 tubes).

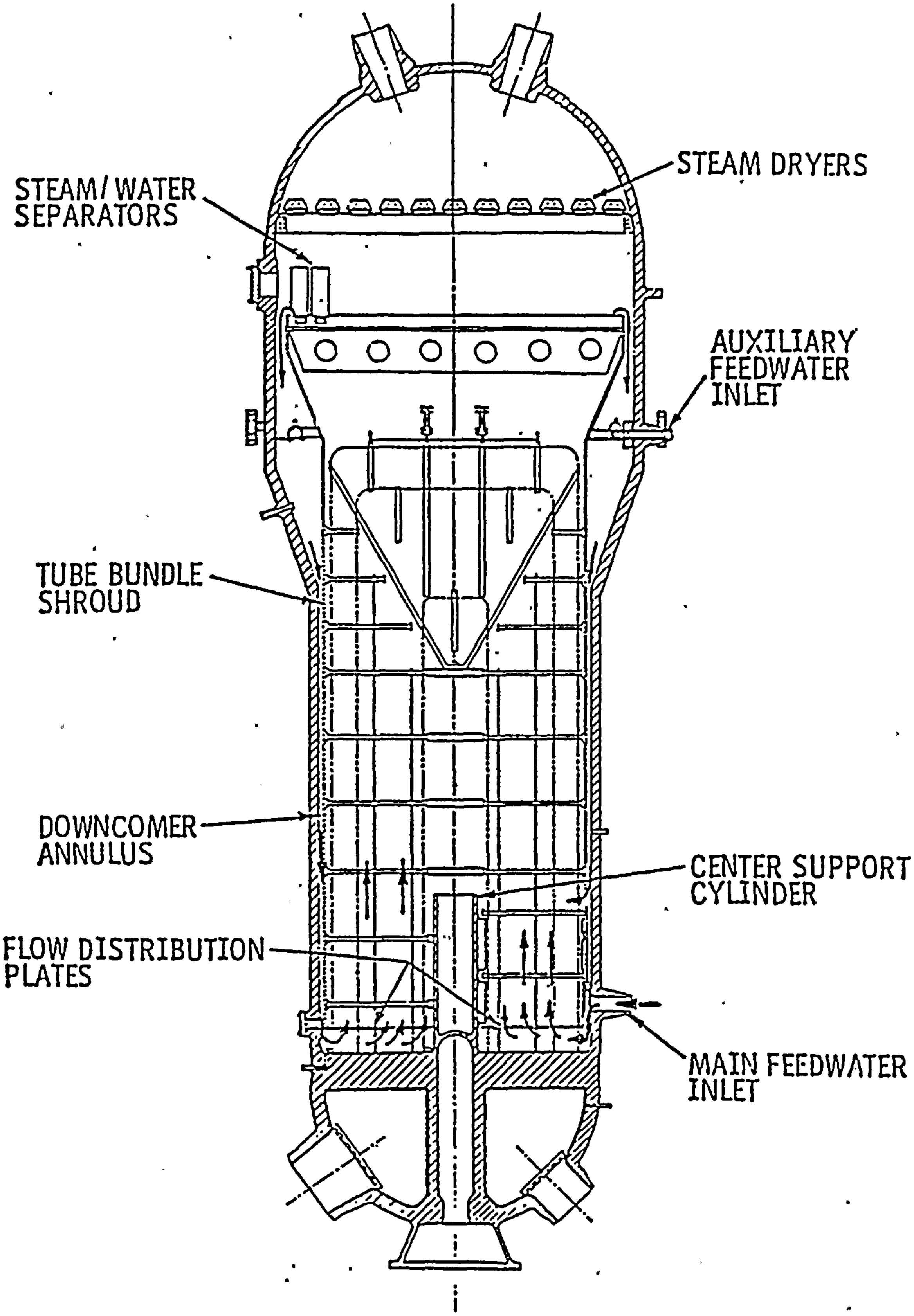
On January 24, 1987, the primary manway was removed for visual inspection of steam generator #1. The secondary side of steam generator #1 was in wet layup. When the primary manway was removed, dripping water was observed on the cold leg side and indications were that the leaking tube was near the outer periphery of the tube bundle near the divider plate. Eddy current testing (ECT) on January 27, 1987 confirmed the leak to be adjacent to the first eggcrate support on the row 3, column 2 tube. Continued ECT inspections discovered additional tubes with wear indications in the cold leg corners (tube bundle periphery by the cold leg-hot leg divider plate) of the steam generators. At this time, ANPP decided

to increase the inspection scope to include additional tubes in the cold leg corner regions. The final Unit 1 inspection pattern is indicated by the shaded regions of Figure 5.

At the time of the steam generator tube leak in PVNGS Unit 1, Unit 2 was in cold shutdown for a surveillance testing outage. Following evaluation of the initial eddy current inspection results from the Unit 1 steam generators, ANPP decided to also inspect the areas of interest in the Unit 2 steam generators. The Unit 2 initial inspection pattern involved approximately 40 tubes per steam generator in the cold leg corner regions. Due to the random nature of the wear indications in the steam generators, the inspection area was expanded to approximately 80 tubes per steam generator to clearly bound the affected region. The final inspection areas for the Unit 2 steam generators are shown by the outlined areas of the cold leg corners in Figures 8 and 9.

The eddy current examinations were performed using the standard bobbin coil Zetec MIS-18 Digital Data Acquisition and Analysis System. The MIS-18 utilizes 4 channel multi-frequency (10 KHz to 1 MHz) differential and absolute coil techniques. The 100% preservice examinations of the PVNGS Units 1 and 2 steam generators were performed using the Zetec MIS-12 analog system. The inspection system used during the most recent steam generator inspections is significantly more sensitive than the previous system.

Figure 1



INTEGRAL ECONOMIZER STEAM GENERATOR

AXIAL FLOW

Figure 1

Figure 2

ECONOMIZER ELEVATION VIEW

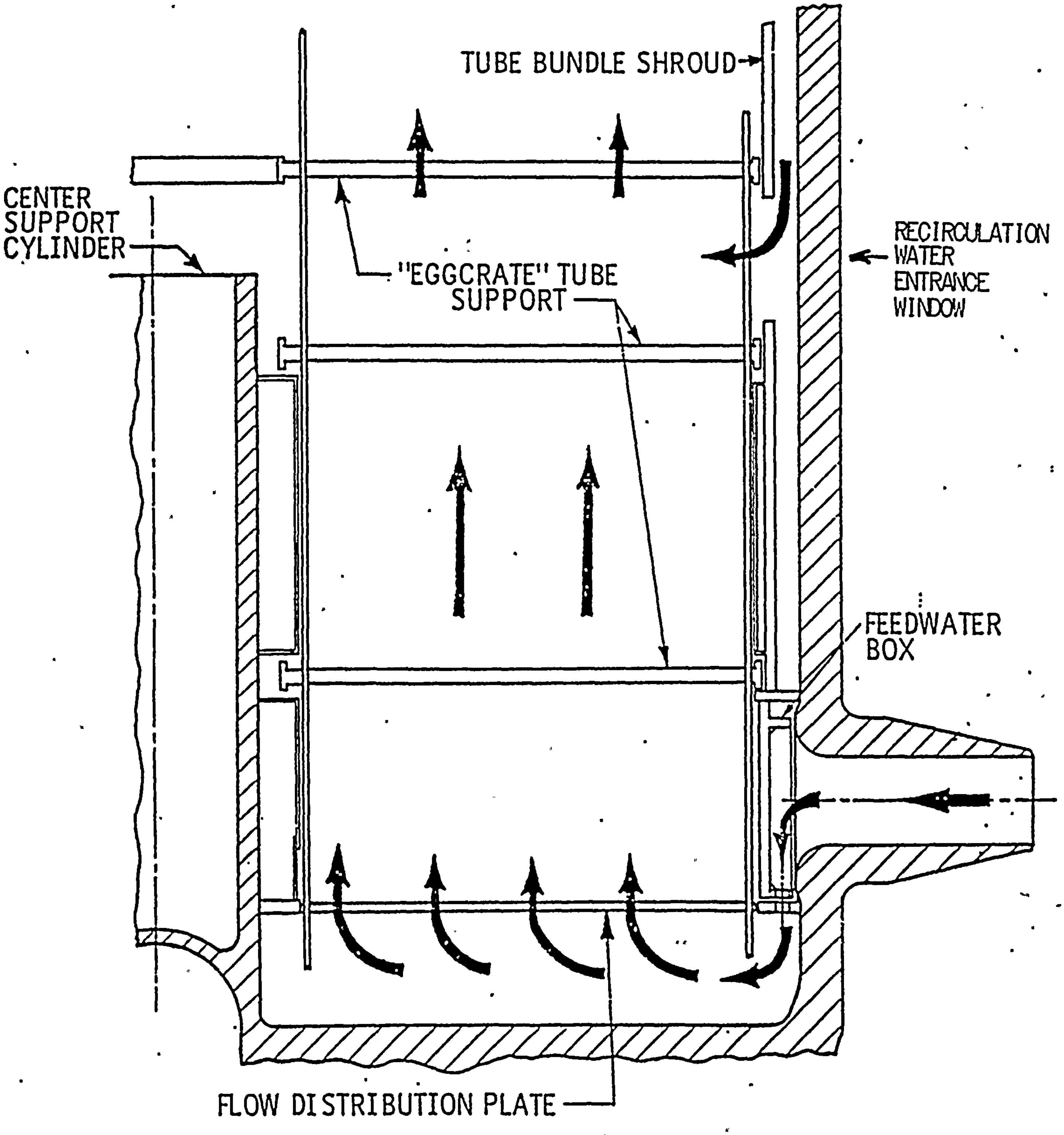
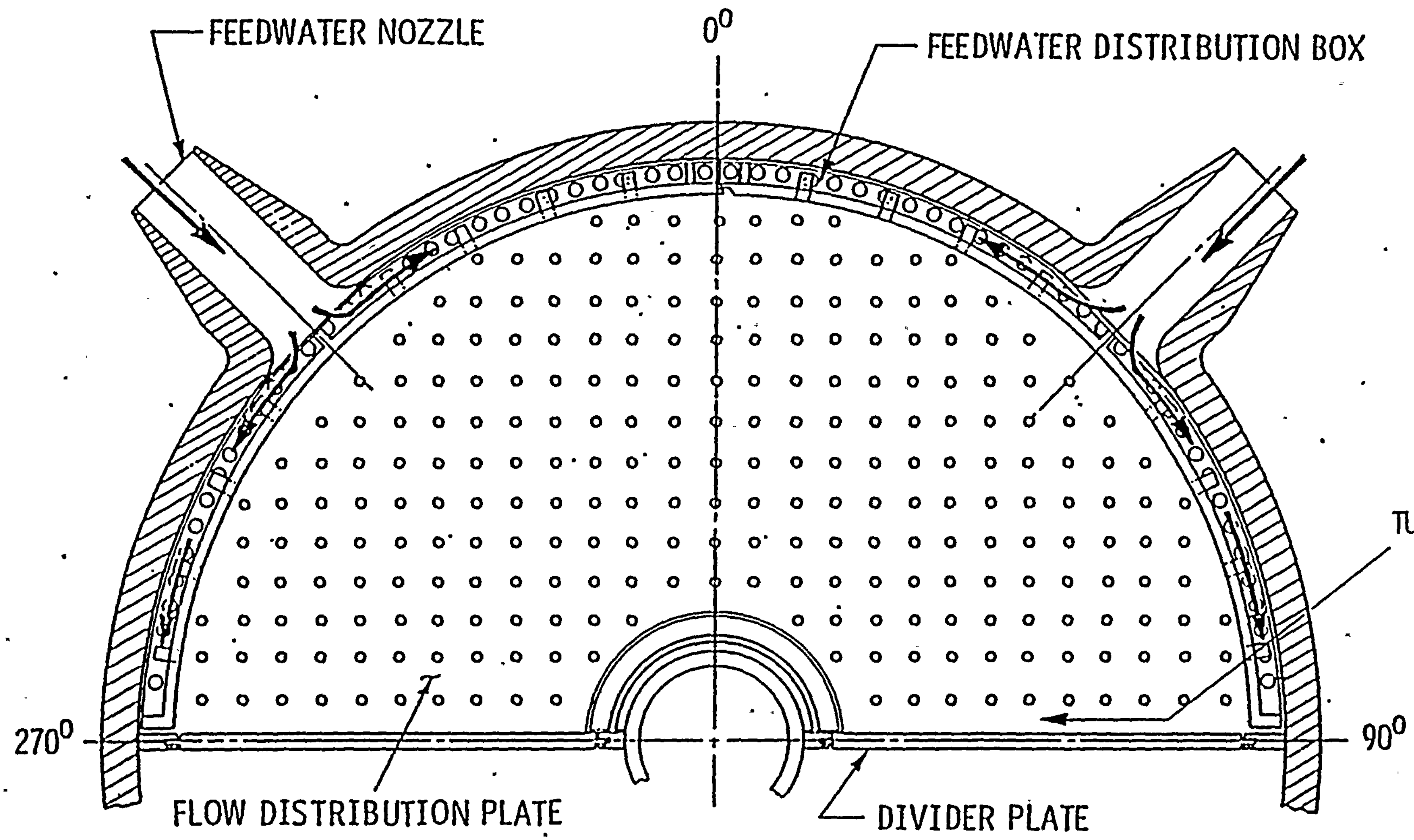


Figure 2



ECONOMIZER PLAN VIEW

Figure 3

gure 4

ECONOMIZER REGION

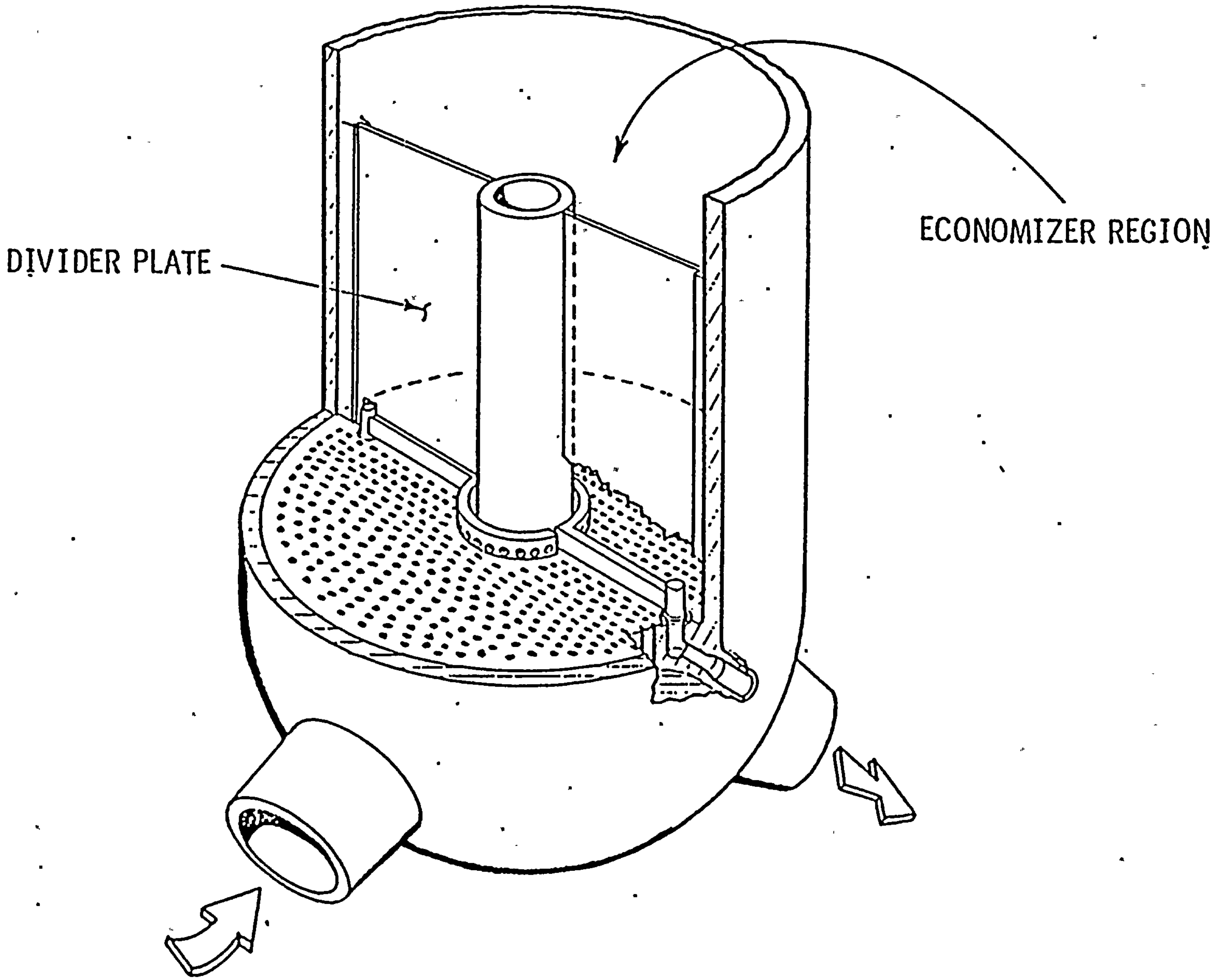


Figure 5

Steam Generator Inspection Pattern
For Unit 1 (Shaded Regions)

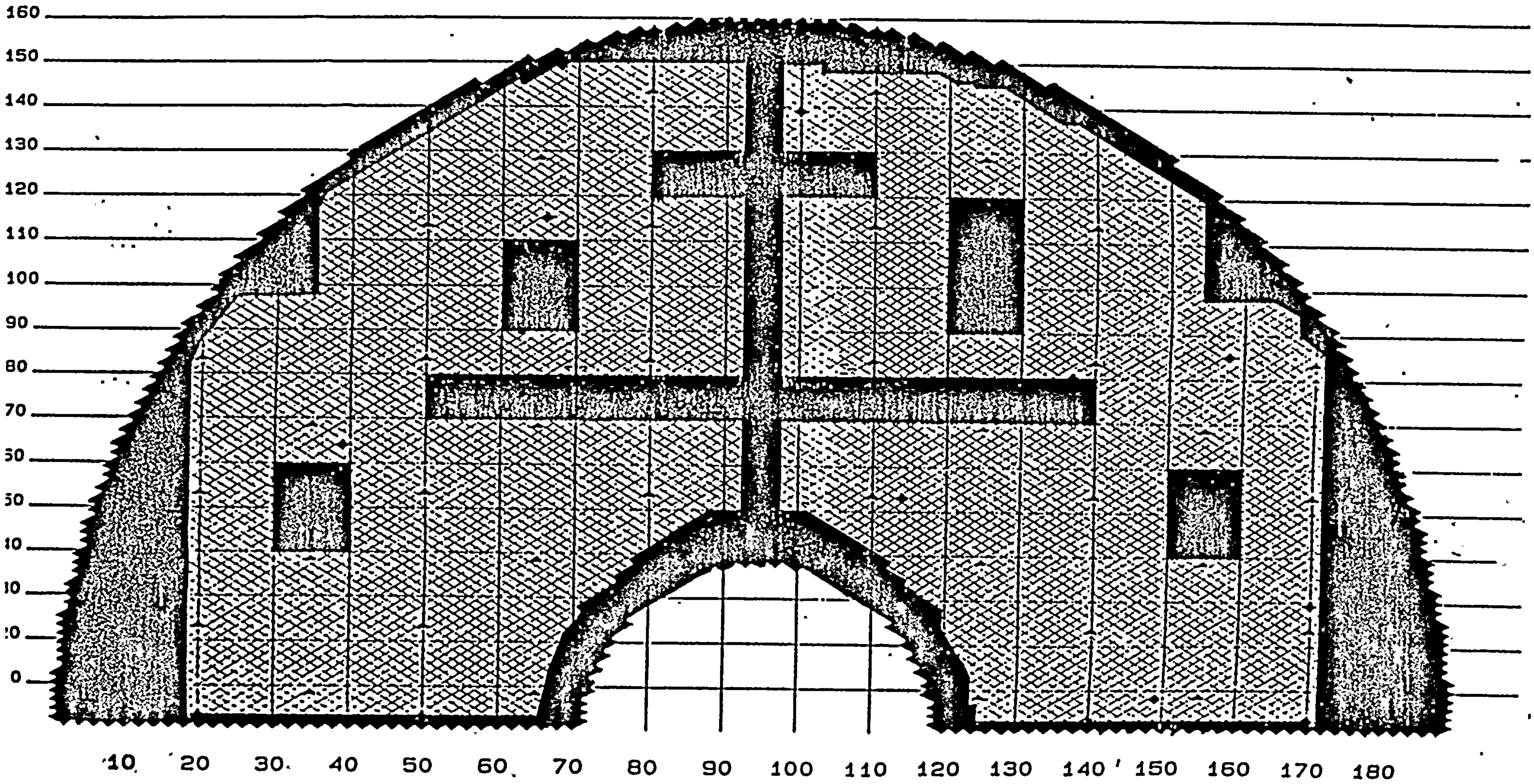


Figure 5

II. Results of Steam Generator Inspections

The PVNGS Units 1 and 2 steam generators were inspected by use of eddy current testing techniques during the months of January and February 1987. This section of the report summarizes the results of these inspections. The eddy current inspection results consist of the following types of indications.

A. Steam Generator Tube Wear

Indications of tube wall thinning were found on several tubes (Table 1) of steam generators 1 and 2 in both Units 1 and 2. These worn tubes are confined to a particular region of the steam generator (Figures 6 through 9). The region where tube wear has been observed is referred to as the cold leg corner region. The cold leg corner region is located on the outer periphery of the tube bundle adjacent to the economizer divider plate on the cold leg side of the steam generator. There are two cold leg corner regions in each steam generator. The indications of worn tubes are located at the second through sixth tube supports (first through fifth eggcrate supports) on the cold leg side of the steam generator.

Table 1 - Summary of the Number of Worn Tubes

Range of Wear Depth	Unit 1		Unit 2	
(% Through Wall)	SG #1	SG #2	SG #1	SG #2
<20	1	4	7	4
20-39	5	1	4	2
40-59	4	3	9	13
60-79	2	1	9	2
80-100	1	0	1	0
TOTALS	13	9	30	21

B. Dented Steam Generator Tubes

In steam generator #1 of PVNGS Unit 1, the tubes on the cold leg side in row 1 at columns 48 through 64 (a total of 9 tubes as shown on Figure 10), exhibited indications caused by

deformation of the tube at the top surface of the flow distribution plate (first tube support). Deformation of the tube at column 58 prevented passage of the 0.540 inch outside diameter eddy current probe. Therefore, no eddy current data was available for this tube. The other tubes that showed indications of denting were eddy current tested. There were no indications of wear or loss of tube wall for any of the inspected dented tubes.

Fiberoptic inspection of the internal diameter of three tubes (row 1 - columns 56, 58 and 60) verified the eddy current results and determined that the eddy current indications were slight indentations of approximately 1/16 to 1/8 inches. In addition to the indentation, one tube also exhibited an even slighter indentation around a partial circumference of the tube. The fiberoptic instrument, which has an outside diameter of 0.50 inches, was able to pass through the tube at row 1 - column 58. However, the eddy current test probe, which has an outside diameter of 0.540 inches, was not able to pass through the tube at row 1 - column 58.

C. Indications of Potential Loose Parts

The use of a multi-frequency eddy current probe allows for the detection of potential loose parts or other anomalies when using the lower frequency range of the eddy current probe. As reported by our eddy current inspection team, potential loose part indications were found at the locations described in Table 2 and shown in Figures 11 and 12.

Table 2 - Unit 1 Potential Loose Parts Indications

Steam Generator Number	Tube Number
#1	Row 1, Column 48
	Row 1, Column 50
	Row 1, Column 52
	Row 1, Column 54
	Row 1, Column 56
	Row 1, Column 58
	Row 1, Column 60
	Row 1, Column 62
	Row 1, Column 64
	Row 26, Column 113
	Row 25, Column 114
	Row 125, Column 100
	Row 127, Column 100
	Row 129, Column 100
#2	Row 39, Column 4

D. Sludge Accumulation

The eddy current inspection revealed signs of sludge accumulation in the Unit 1 steam generators in small areas of the tube sheet. The deepest accumulation of sludge is approximately 1-inch thick. The sludge thickness rapidly decreases in depth as you move away from the area of the deepest accumulation. The affected area encompasses approximately 35 tubes on the cold leg side of the steam generator as shown in the attached tube map of Unit 1 steam generator #1 (Figure 13). Unit 1 steam generator #2 indicated small areas of sludge, on both the hot and cold leg sides of the steam generator, of depth less than 0.8 inches and encompassing approximately six tubes (Figures 14 and 15).

E. No Tube Explansion (NTE)

The tubes in the System 80 steam generators are explosively expanded ("explanded") into the 23.5 inch thick tube sheet. CESSAR Section 5.4.2.4.1 described the expansion of the tubes into the tube sheet. The purpose of explansion is to preclude the entry of impurities to the crevice that would otherwise exist between the steam generator tubes and the tube sheet. Such impurities could concentrate and potentially, over a sufficient length of time, cause degradation of the affected steam generator tubes. Explansion is not required to meet the primary coolant pressure boundry integrity requirements. Pressure boundry integrity is assured by a tube-to-tube sheet weld located on the primary side of the tube sheet.

In Unit 1, there were 16 tubes in steam generator #1 and 14 tubes in steam generator #2 with indications that the tubes were not fully explanded into the tube sheet. The indications of non-explanded tubes were randomly scattered across the tube sheet area on both steam generators. The inspection equipment used during the preservice baseline examination was not sensitive enough (i.e., single frequency analog system) to identify non-explanded tubes.

F. Foreign Residue in Steam Generator Tubes

During the course of the eddy current inspection of Unit 1 steam generator #1, the eddy current probe became obstructed/restricted while probing certain peripheral tubes (Figure 16).

The eddy current probe, which started from the cold leg side, passed up the cold leg side and began to traverse the long horizontal portion of the U-tubes. The probe, at various lengths depending on which tube was being probed, then began to encounter a resistance to its travel at various starting points. The resistance would cause the ECT machines to stop

pushing at some point in the tube, either in the horizontal run or in the hot leg side of the tube. At no time did the probe come to an abrupt halt. Rather, the probe would gradually slow down until the probe would not push any farther in the tube. When this was reported, a decision was made to bound this phenomenon (i.e., determine the extent of tubes which may have deposits). As the eddy current inspection team returned to this area for bounding these indications, the inspections were successful in probing the full tube length with a 0.610 inch outside diameter probe, cold leg to hot leg, with no further resistance. The probe did pick up some material which was retrieved and sent to Battelle Northwest Laboratories for analysis. The results of the laboratory analysis are discussed in Section III.F of this report. After finding no further tubes in this area exhibiting this problem, the eddy current inspections returned to the task of completing the required steam generator tube inspection.

Figure 6

Unit 1, Steam Generator #1 Tube Wear

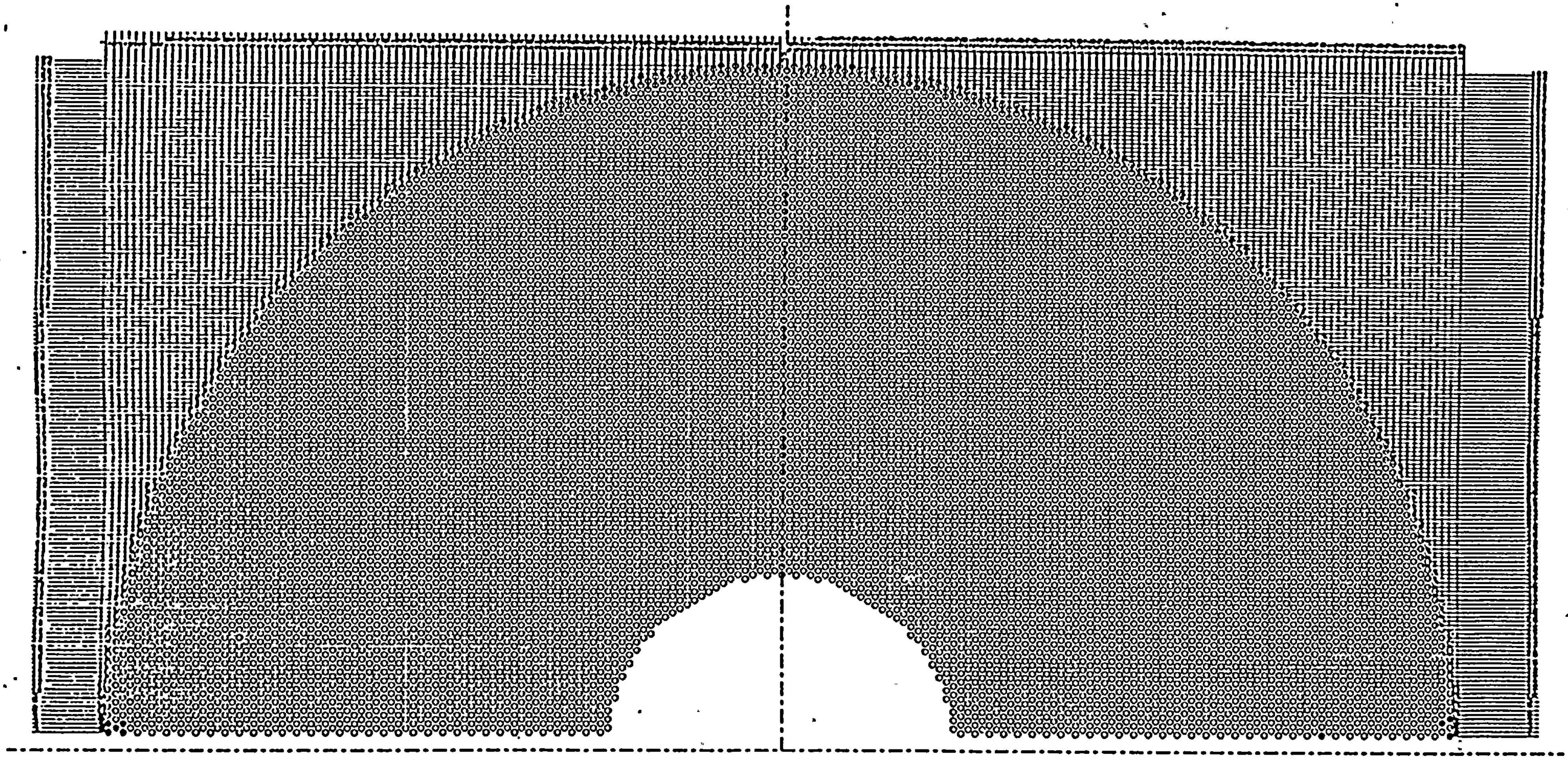


Figure 6

Figure 7

Unit 1, Steam Generator #2 Tube Wear

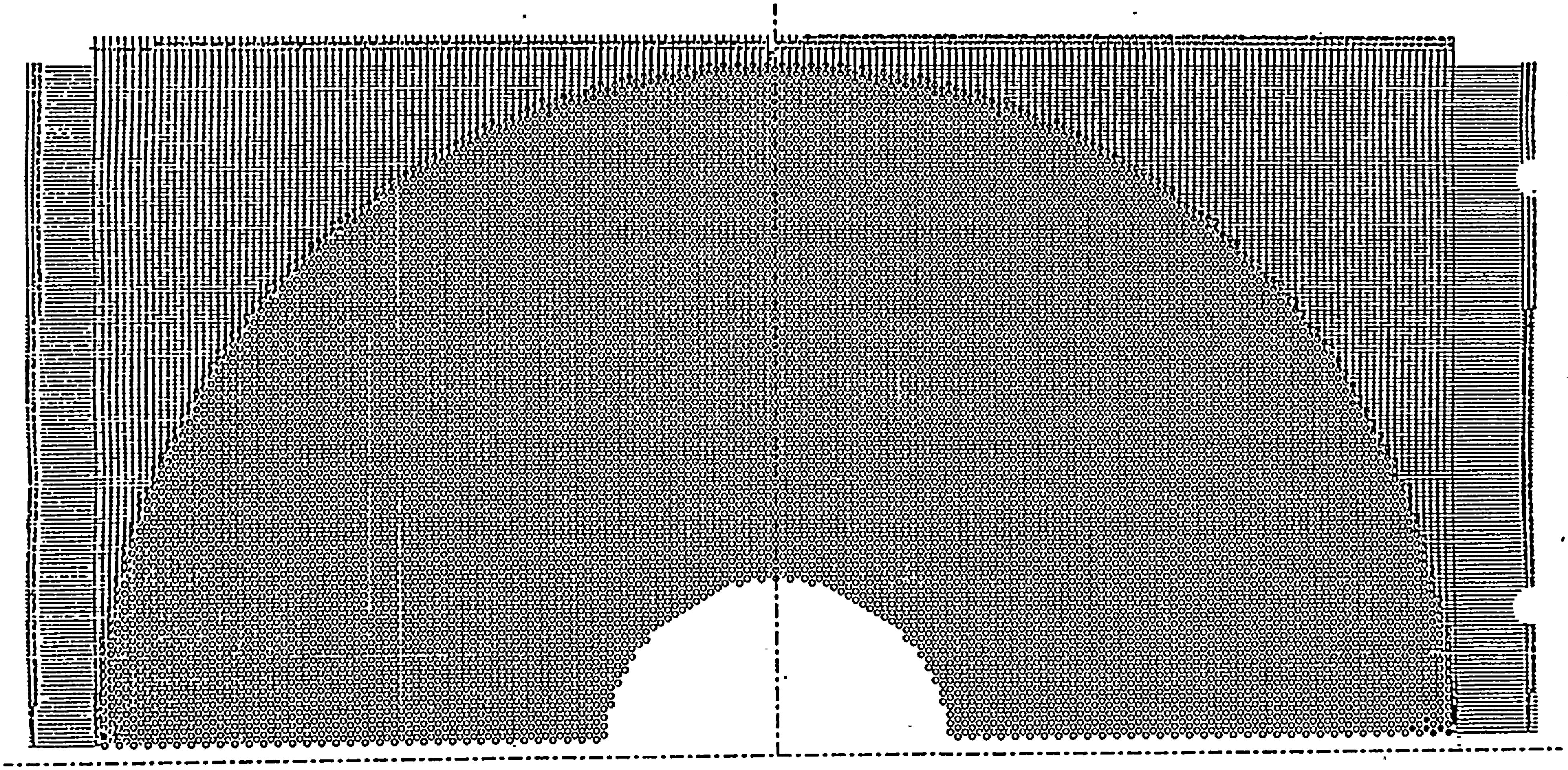


Figure 7

Figure 8

Unit 2, Steam Generator #1 Tube Wear and Inspection Plan

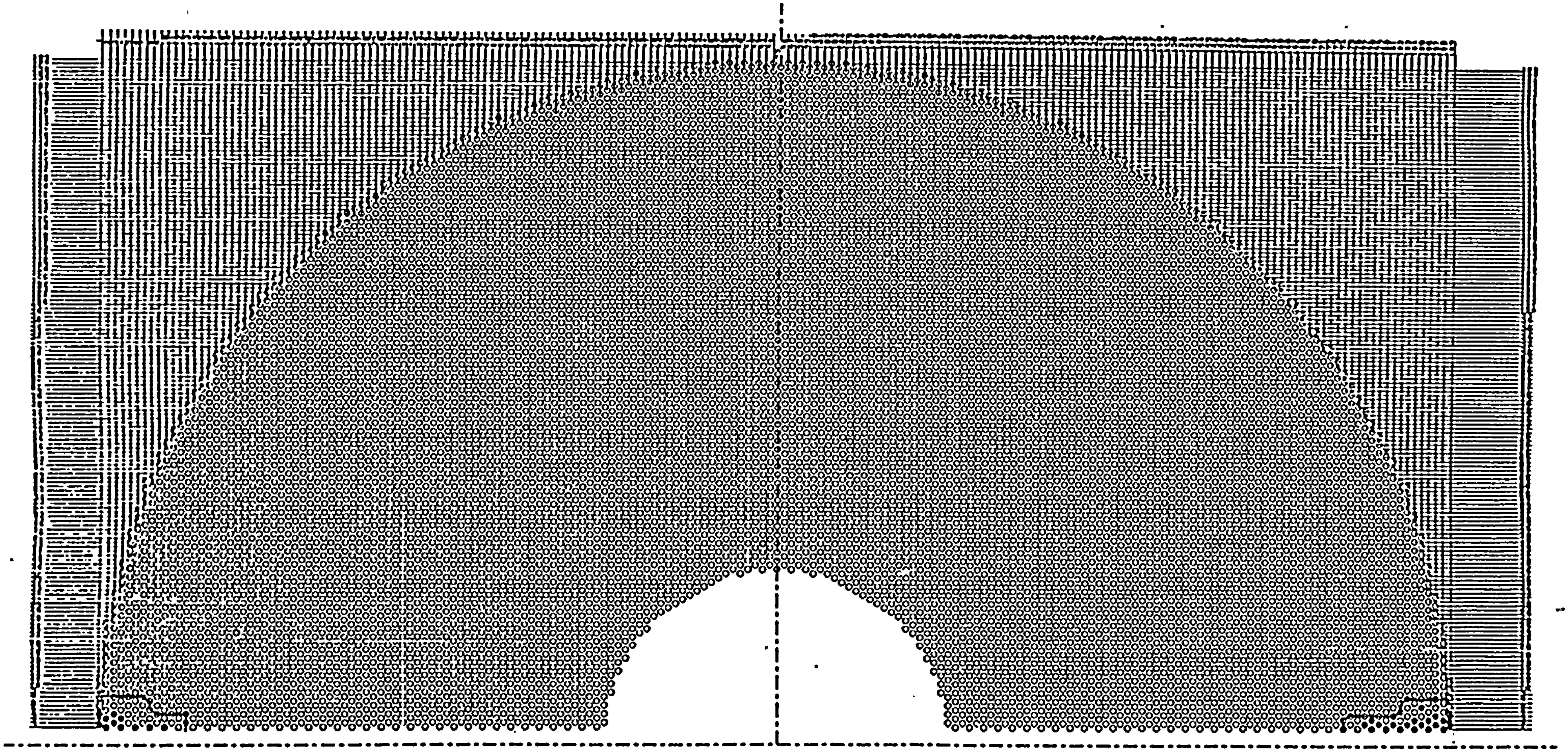


Figure 8

Figure 9

Unit 2, Steam Generator #2 Tube Wear
and Inspection Plan

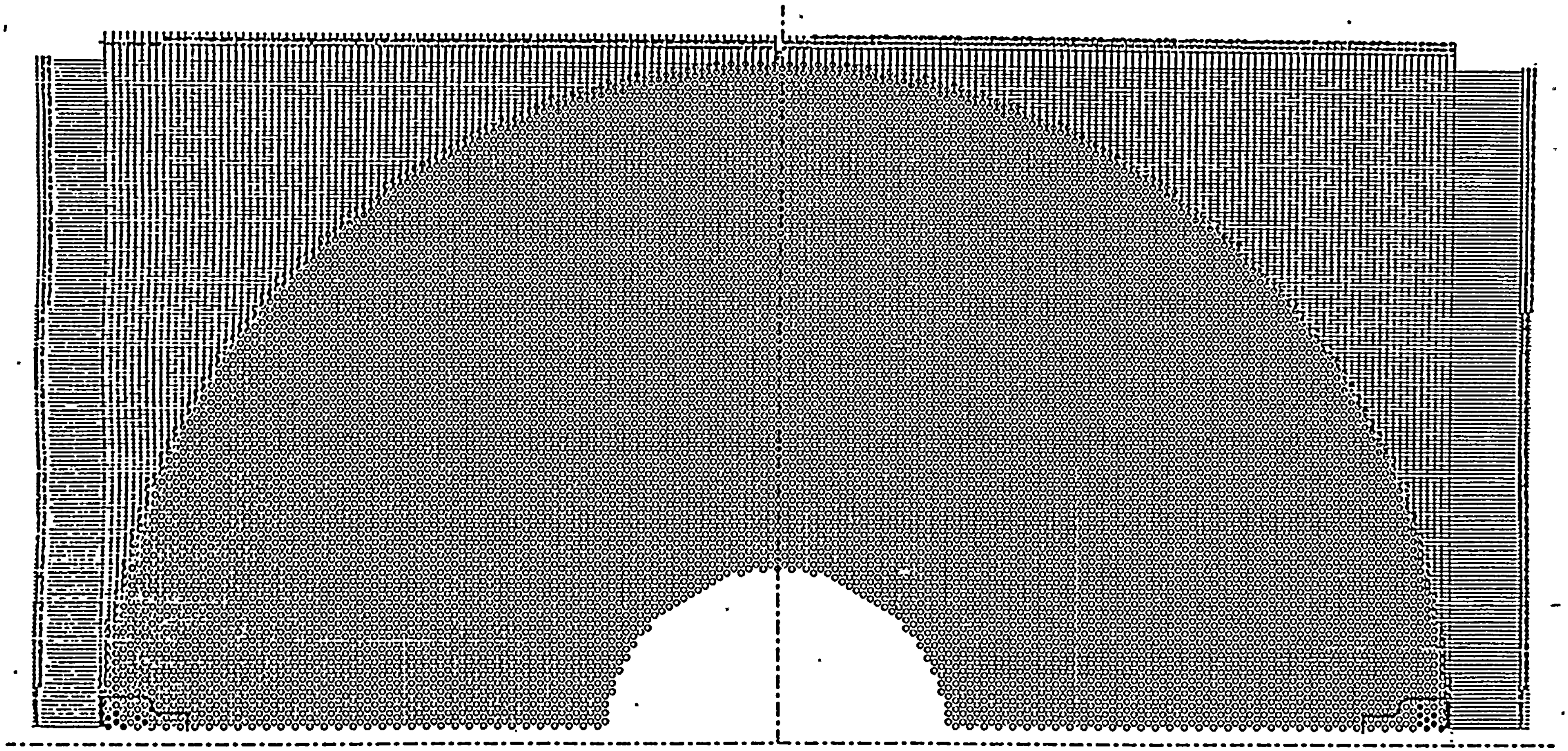


Figure 9

Figure 10

Unit 1, Steam Generator #1 Dented Tubes

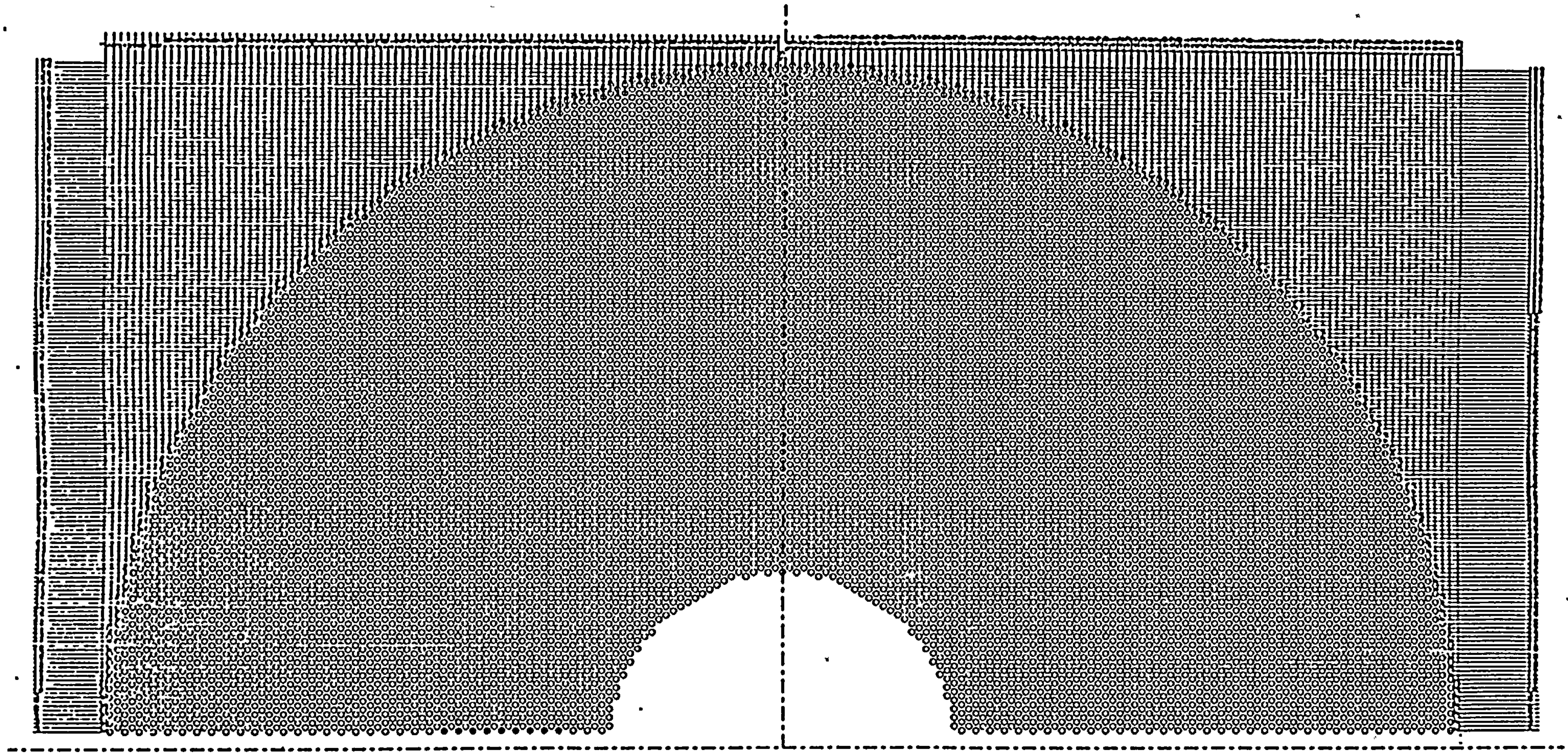


Figure 10

Figure 11

Unit 1, Steam Generator #1 Potential
Loose Parts Indications

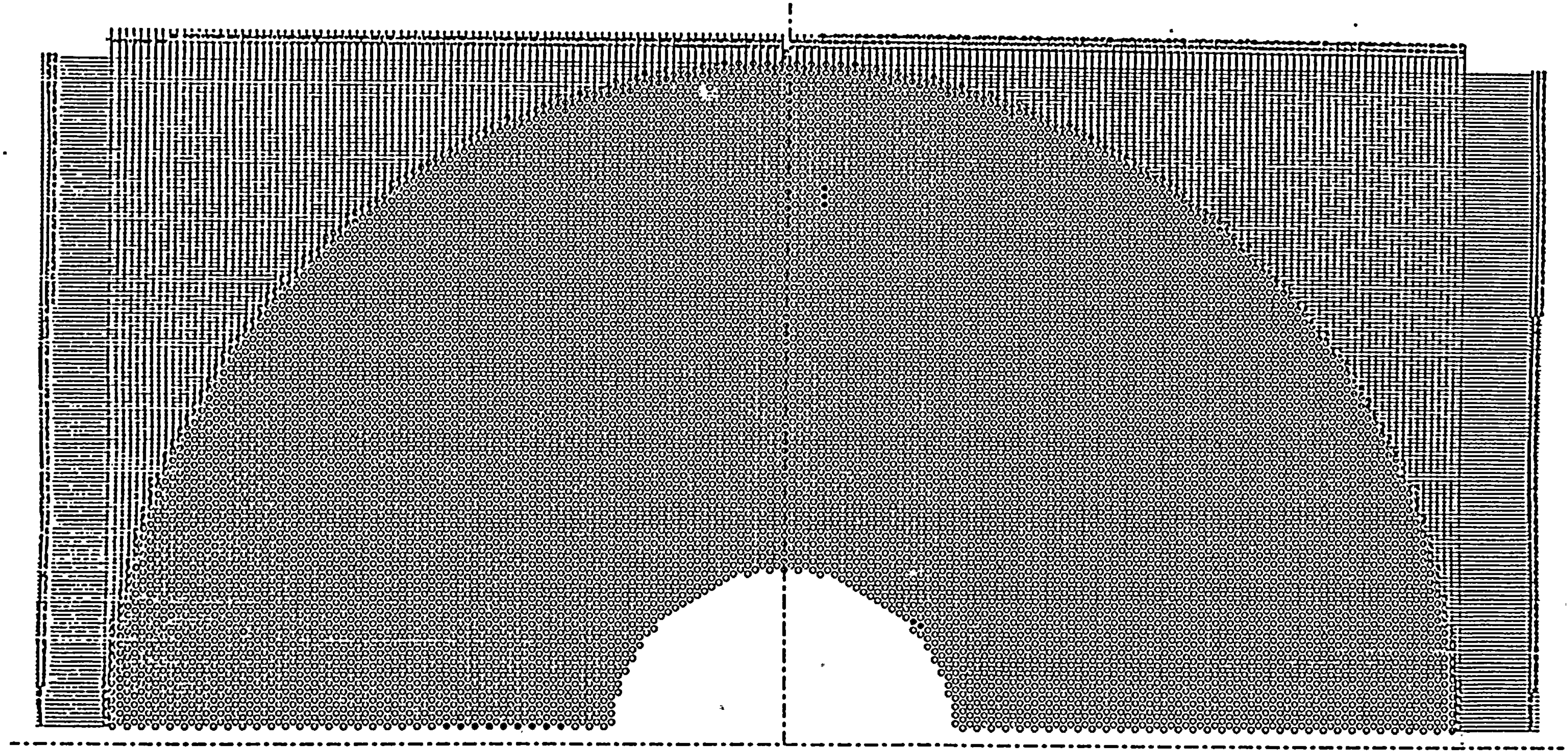


Figure 11

Figure 12

Unit 1, Steam Generator #2 Potential
Loose Parts Indications

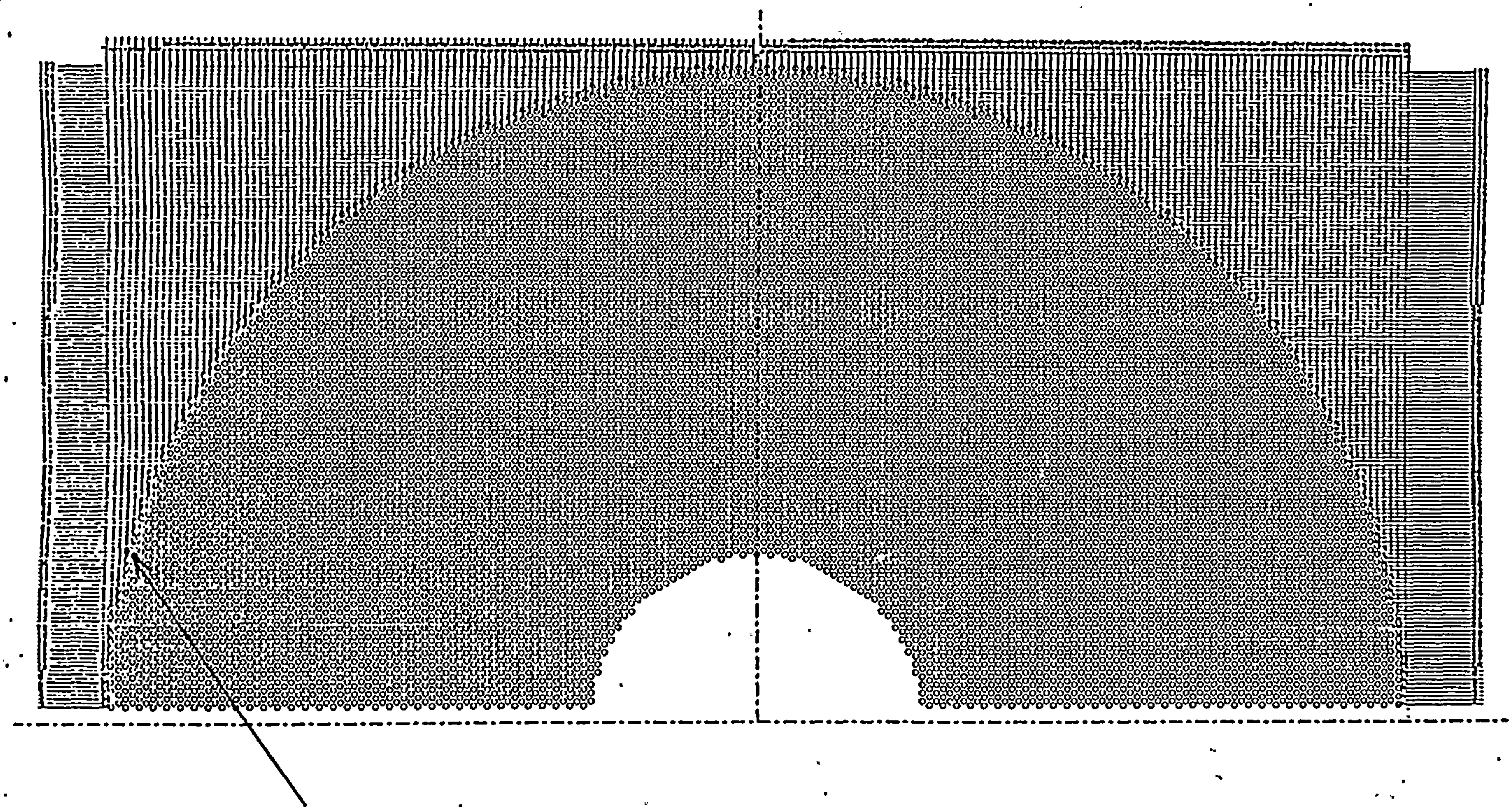


Figure 12

Figure 13

Unit 1, Steam Generator #1 Cold Leg
Side Sludge

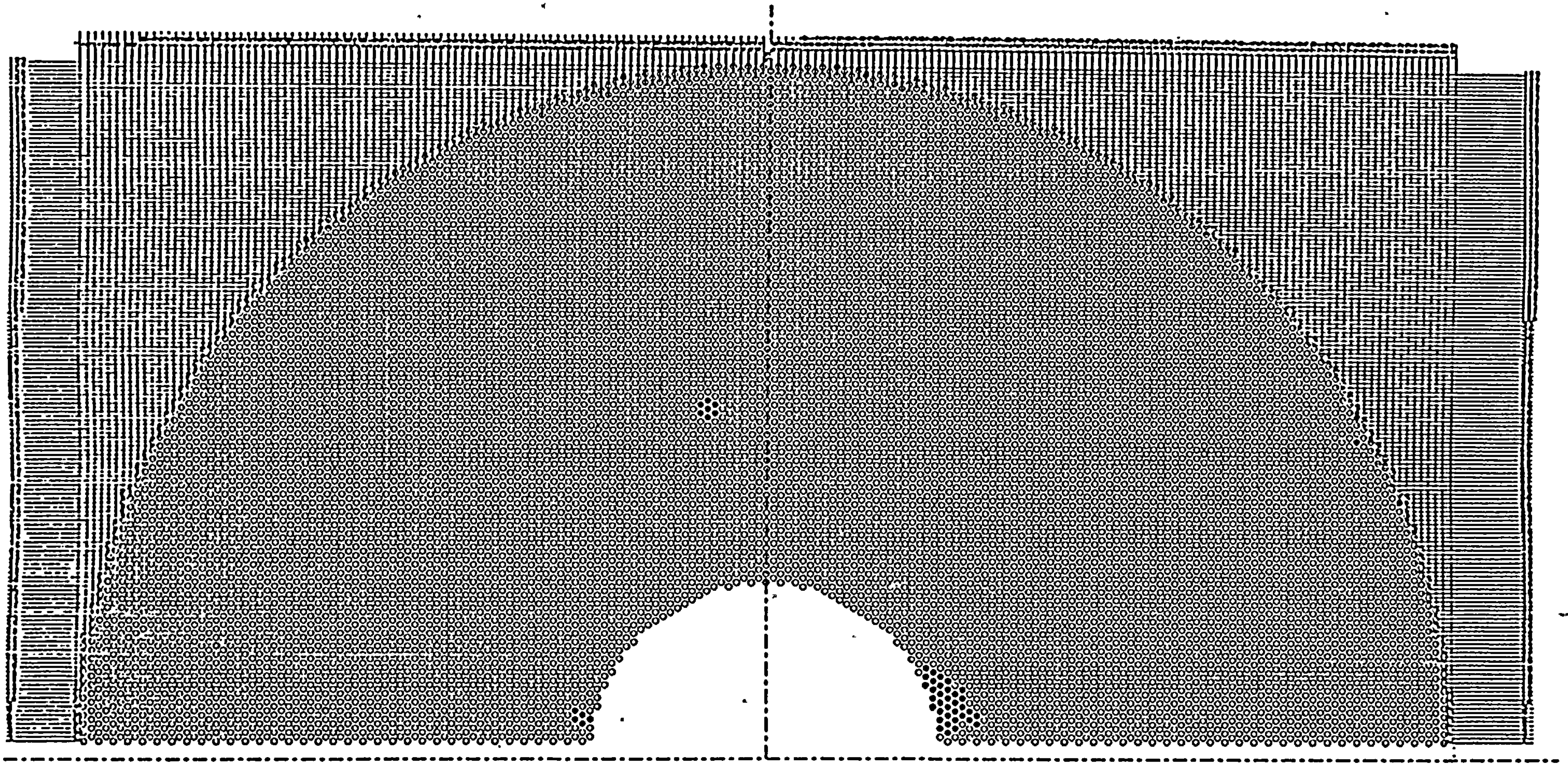


Figure 13

Figure 14

Unit 1, Steam Generator #2 Cold Leg
Side Sludge

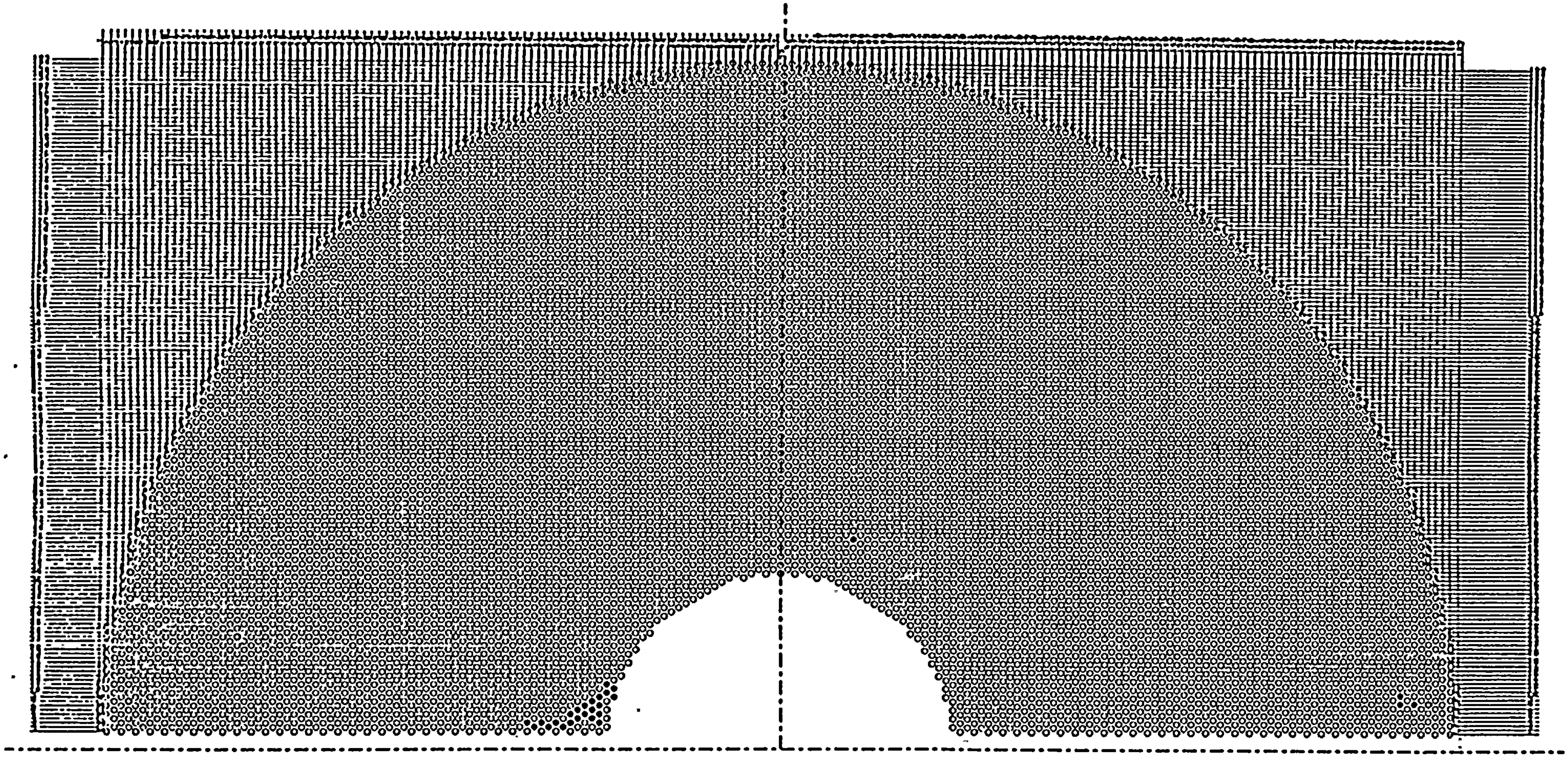


Figure 14

Figure 15

Unit 1, Steam Generator #2 Hot Leg
Side Sludge

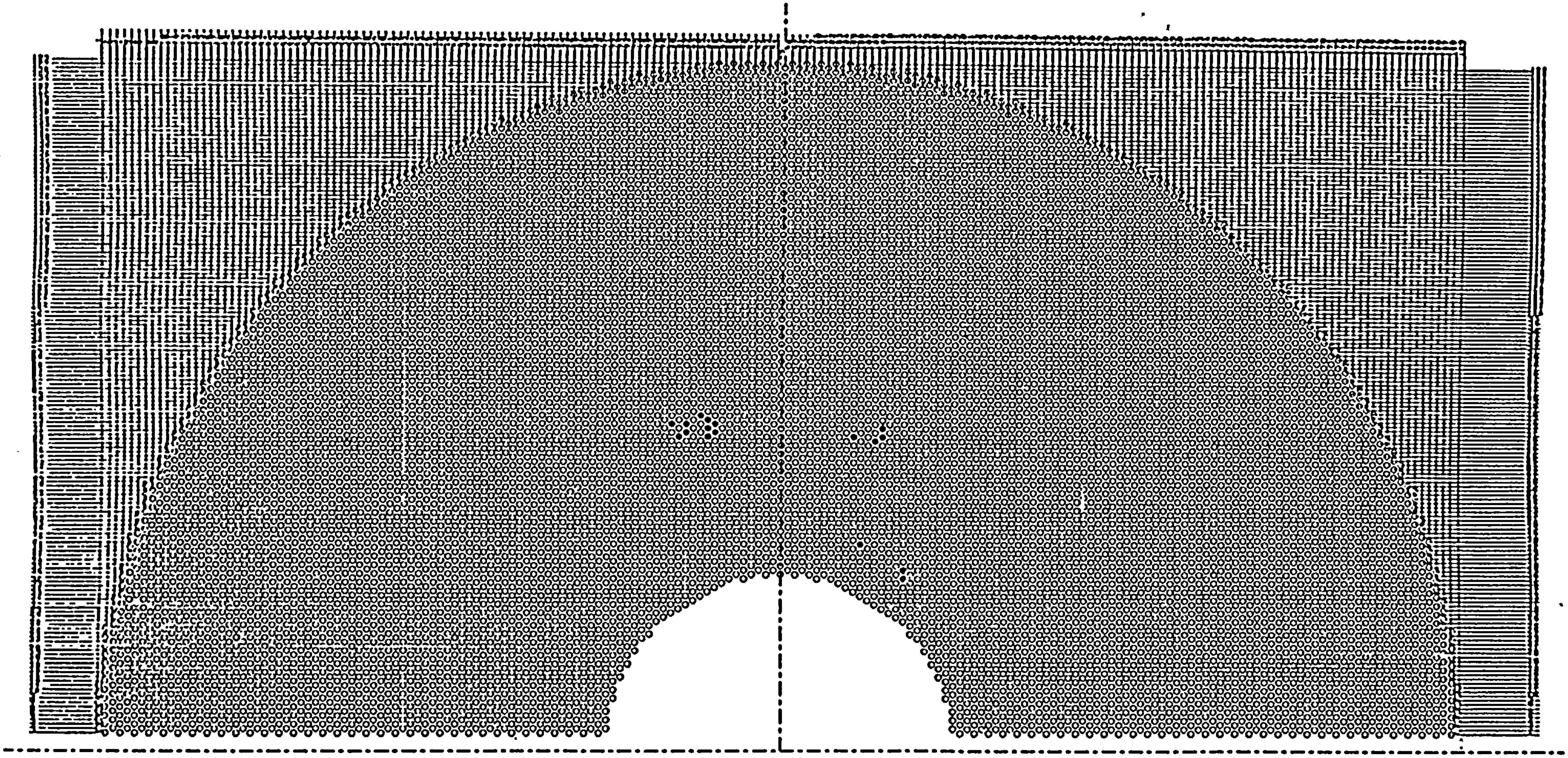


Figure 15

Figure 16

Unit 1, Steam Generator #1 Foreign Material Locations

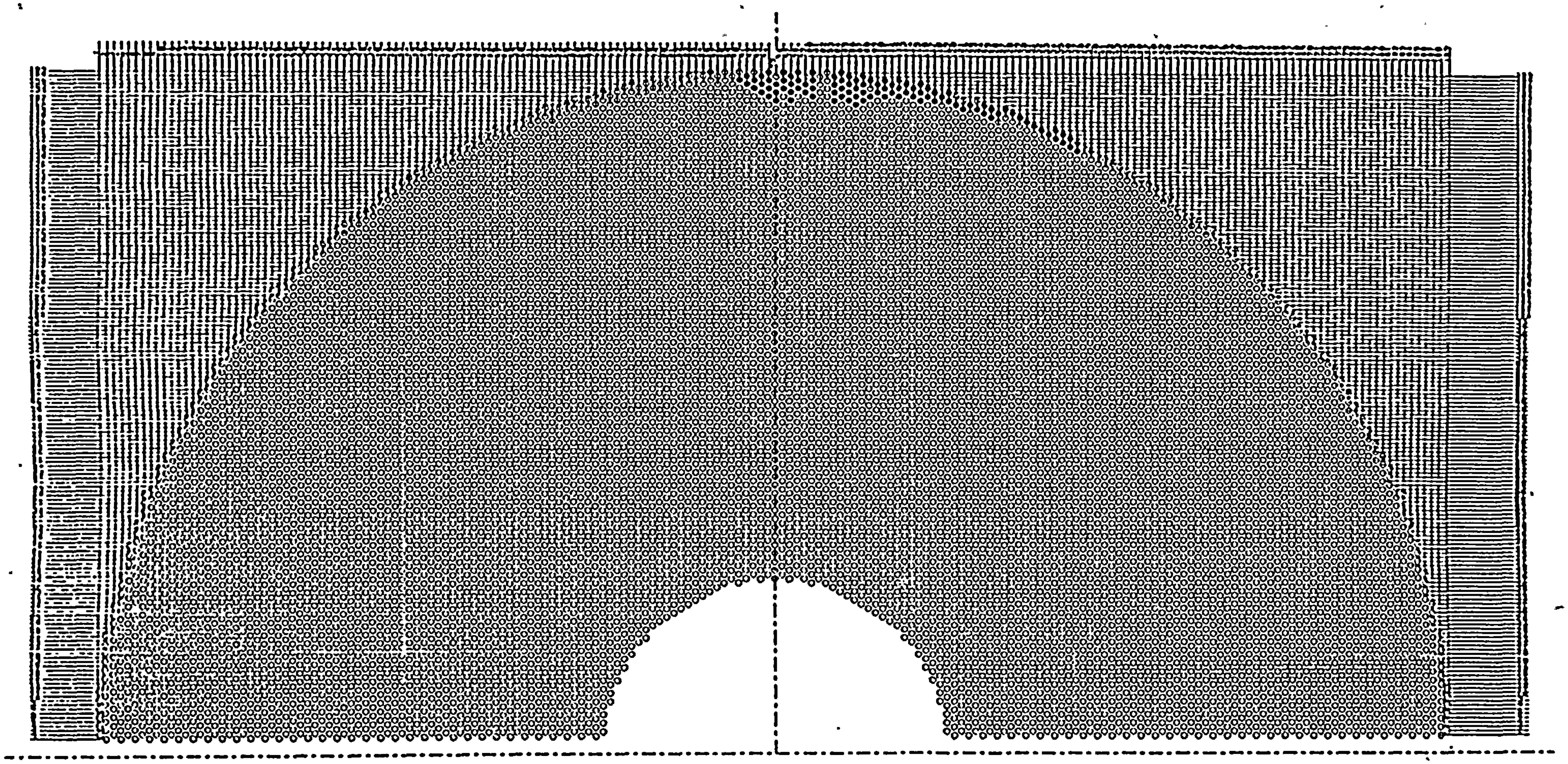


Figure 16

III. Evaluation of Inspection Findings

The eddy current inspection results outlined in Section II were evaluated by ANPP personnel and by Combustion Engineering. In addition, samples of the foreign material were analyzed by Battelle Northwest Laboratories. The results of these analyses will be summarized in this section of the report.

A. Steam Generator Tube Wear

An evaluation of the eddy current test data determined the indications to be typical of that caused by tube-to-support wear resulting from tube vibration. The cause of the tube vibration is postulated to be local high radial velocity flow streaming of entering recirculating fluid.

In the CE System 80 steam generators (Figure 1), the downcomer recirculating flow enters the cold leg side tube bundle above the integral economizer between the second and third tube supports (Figure 2). At the intersection of the recirculating water entrance window and the tube lane, a unique condition exists wherein the downcomer recirculating water can preferentially seek the low flow resistance open tube lane (Figure 17). This results in high local radial cross flow velocities. These velocities are believed to be of sufficient magnitude to cause tubes along the tube lane near the recirculating water entrance window to vibrate within the eggcrate supports, resulting in the observed tube wear.

This unique condition is isolated to the small number of tubes at the intersection of the tube lane and the downcomer recirculating window. The previous thermal hydraulic design analysis was performed using a coarse mesh which does not model the tube lane/recirculating window configuration in detail. The need for a finer mesh to achieve a detailed flow model of this region was not previously realized.

Since radial flow is quickly converted to axial flow by becoming entrained with the upward flowing fluid from the economizer region and by the heat transfer process, the affected region extends only a limited distance down the tube lane. The general case of cold leg side recirculating fluid entering the tube bundle away from the tube lane was analyzed and tested during the design process and found to be acceptable. This was verified by eddy current inspection of the Unit 1 steam generators which showed no wear indications along the outer periphery of the tube bundle away from the tube lane.

Recirculating fluid on the hot leg side enters at the tube sheet as in all previous CE steam generators. No indications of wear were found on the hot leg side.

Variances in the number of worn tubes between steam generators 1 and 2 and between Units 1 and 2 is believed to be due to variations in the as-built dimensions of tube supports and tube support alignments, causing some tubes to be held firmly and more rigidly than other tubes. This variation has been demonstrated via examination of a prototypical sample of an eggcrate support as demonstrated to the NRC staff during a meeting on February 9, 1987.

This condition can be further aggravated near the outer periphery where the eggcrates are welded to the shroud support bars (Figure 18), potentially resulting in slight distortion of individual eggcrate members. The tighter held tubes are sufficiently stiff to resist vibration and, thus, exhibit no wear. Therefore, both conditions, loosely held tubes and high radial cross flow velocity must exist to cause this tube wear phenomenon.

The wear indications have similar wear scars to those experienced at other nuclear units with Combustion Engineering supplied steam generators such as San Onofre Units 2 and 3, Waterford 3, and St. Lucie Unit 2. At these plants, tube wear

occurred due to flow induced contact between the diagonal tube spacer strips ("batwings") and the tubes. To determine the safety significance of that condition, CE conducted leak/burst testing of tubes with wear patterns of the same nature as the wear patterns observed at San Onofre. The test results indicate that the wear characteristics are such that the tubes will develop small, but detectable, leaks that will remain stable during normal and postulated accident conditions. Tests were also conducted on tubes with 0.042 inch thick tube walls in anticipation of finding a similar "batwing" problem on System 80 steam generators. ANPP and CE consider these tests to be applicable to the PVNGS tube to eggcrate wear due to the similarity in the wear mechanism and the wear scars. As an additional note, the PVNGS Unit 1 steam generators were inspected in the "batwings" area of concern (tubes around the central stay cylinder) and no indications of tube wear were found.

Since any leaks would be detected and monitored, appropriate actions, as required by Technical Specifications, would be taken to prevent development of a more significant condition. Technical Specification 3.4.5.2 requires that when primary-to-secondary leakage through all steam generators exceeds 1 gpm and 720 gallons per day through one steam generator, the plant must be placed in hot standby within 6 hours and in cold shutdown within the next 30 hours. Thus, this condition does not represent a significant safety hazard.

The root cause of this condition has been determined to be the unique condition at the intersection of the recirculating water entrance window and the tube lane where high radial flow velocities can exist. This configuration was not analyzed or tested during the design process. This condition did not exist in previous CE steam generators since only the System 80 design features cold leg side recirculating water entrance above the integral economizer.

Corrective Action

ANPP has plugged and staked all tubes with any indication of wear in the local high velocity region in Units 1 and 2. Those tubes with no wear to date are postulated to be sufficiently supported to preclude vibration and a mechanism by which this condition could change has not been identified. Therefore, these tubes will remain in service. All unplugged tubes in Units 1 and 2 in the region of interest will be reinspected during the next refueling outage to confirm that wear has not initiated in these tubes.

Combustion Engineering will perform a confirmatory flow analysis to more accurately model the recirculating water entrance to the open tube lane configuration. This analysis will be provided to the NRC Staff after ANPP review and acceptance of the analysis. It is expected this model will analytically predict local high radial flow velocities and thus confirm the postulated flow streaming phenomenon.

B. Dented Steam Generator Tubes

An evaluation was performed on row 1 tubes to determine the characteristics and probable cause of the deformation observed just above the cold leg flow distribution plate. In the process of verifying the location, magnitude, and characteristic shape of the deformation, a variety of frequencies were used as follows:

550KHz Absolute - this frequency was used to profile the inside diameter of the tube to determine the location, the relative magnitude, and the shape of the deformed region.

100KHz-550KHz(Mix) - these frequencies were used to eliminate the signal caused by deformation to determine if metal loss had occurred on the outside diameter of the tube. No metal loss was noted.

20KHz Absolute - this frequency was used to assist in the detection of foreign objects on the outside diameter of the of tube.

The review of the 20KHz data indicated the apparent presence of a foreign object at the same location as the higher of two dent indications at row 1 - column 60 and row 1 - column 62. Both of these tubes had two indications of deformation. Both tubes exhibited deformation at the top of the flow distribution plate and at several inches above the plate. All other tubes had deformation only at the top of the flow distribution plate. An additional review of the 20 KHz absolute signal revealed that a foreign object appeared to be adjacent to the single indication of deformation at the top of the flow distribution plate in row 1 - column 48 through column 56. This indicates that the object appears to be at least 12 inches in length, is lying on the flow distribution plate, and may be bent upward at the location of row 1 - column 60 and row 1 - column 62. The signal indicating the presence of the foreign object is similar to a signal that would be caused by a bar of ferritic stainless steel. No degradation such as would be caused by wear was evident on any of the dented tubes. A laboratory mockup, which tested various materials next to the tube, was used to correlate the eddy current signals with those observed in the field.

In light of the limited affected region and the detection of a metallic foreign object adjacent to the nine dented tubes, it is hypothesized that the deformation was caused by the wedging action of a metal "bar" between the economizer divider plate and the row 1 tubes during power operation. Since the flow distribution plate is made of 405 ferritic stainless steel, it has a lower coefficient of thermal expansion than the tube sheet. The relative temperature of the plate (secondary side, subcooled below saturation temperature) is also less than the tube sheet (RCS cold leg temperature). Therefore, the flow

distribution plate tends to move away from the economizer divider plate during heatup and power loading. The foreign object could then have worked into position above the flow distribution plate and wedged itself between the row 1 tubes and the divider plate. As the unit unloads and cools down, the flow distribution plate tends to move toward the economizer divider plate approximately 1/8 inch.

Since the foreign object was trapped and presumably non-compressible, the tubes absorbed deformation of up to 1/8 inch. A dent of 1/8 inch would not allow passage of a 0.540 inch ECT probe. The tube could be dented at the elevation of the foreign object or at the top of the flow distribution plate by the reaction force, or by the combination of both. A fiberoptics inspection of a dented tube tended to confirm the above hypothesis. A slight straight edged indentation was found above and opposite to a smaller partial circumferential indication. This would indicate a primary dent induced by a "bar-like" object causing a reactive dent on the opposite side of a tube caused by the reaction force at the top edge of the drilled holes in the flow distribution plate.

While precise identification of the foreign object cannot be made, one possibility is that a bar was introduced into the steam generator as a temporary shim during the installation and alignment of the lowest partial eggcrate tube support in the economizer region. That operation was performed in a horizontal position. During assembly, it is necessary to "block-up" the partial eggcrate to obtain optical alignment with the tube sheet and the previously installed flow distribution plate. Once alignment is achieved, support lugs, welded to the downcomer wrapper cylinder, secure the partial eggcrate support in position and all shimming stock should have been removed. Conceivably, a bar could have been overlooked and left in the steam generator. When the unit was lifted into the vertical position for the first time at the PVNGS site, the bar could have dropped down or it might have

occurred when the tube bundle moved away slightly from the divider plate during heatup as explained previously. Since nine successive tubes were dented and eddy current indications showed the presence of a foreign object, the object is expected to be 12 to 14 inches long. A means by which an object of this size could have been introduced into this region during maintenance or inspection has not been identified. Therefore, it is concluded that an object left in the steam generator from the manufacturing process is the most probable source of the indications.

Due to the location of the foreign object on top of the flow distribution plate, there is no way to get an inspection probe to that area. A possibility would be to remove the row 2 - column 61 tube by cutting just below the lowest eggcrate to create an inspection route for a partial view of the object and dents. Removal of a dented tube is not recommended because it could get stuck in the flow distribution plate or in the tube sheet. In addition, removal of a tube from the flow distribution plate would leave a flow hole in the plate approximately one inch in diameter. This unobstructed flow path would lead to higher local velocities in the area of the foreign object, and possibly lead to movement of the object. Thus, unless the object has a high probability of removal through the tube sheet, it would not be advisable to remove a tube.

The flow distribution analysis, performed during the design process, predicts velocities of approximately 1.5 ft/sec at the location of the foreign object. The flow direction is primarily vertically upward. The velocity adjacent to the divider plate at this radial position is likely significantly lower than 1.5 ft/sec. Since the fluid source for this area is incoming feedwater and since the radial flow can escape upwards between the flow distribution plate and the economizer divider plate, the flow at the position of the foreign object is quite low. The on-going flow distribution analysis review

of the economizer divider plate region is expected to support this conclusion. It should also be noted that there was no wear on the dented tubes.

A dent of 1/8 inch would produce a circumferential tensile strain of less than 8% on the tube inside diameter. The maximum tube inside diameter circumferential tensile strain of 8% is well below the 14% strain threshold required for "coriou" cracking (the cracking of alloy 600 tubing in high temperature PWR primary water due to a combination of high tensile stresses or strains and a susceptible microstructure). Steam generator tubes which have become dented within drilled plates (usually due to the formation of non-protective magnetite) can take an irregular cross section as a result of being constrained from expansion in all directions.

The irregular constrained cross section can produce high inside diameter circumferential tensile strains above 14% which could then lead to tube cracking. Since the denting in PVNGS Unit 1 steam generator is above the flow distribution plate, the irregular constrained cross section will not be formed and the high circumferential inside diameter tensile strains will not be produced. Axial inside diameter strains have not produced tube cracking based on industry experience. As such, denting of these tubes is not considered to be a safety concern.

Corrective Action

Since the foreign object is wedged in place and is in a relatively low velocity flow field, relocation of the object is not considered credible. Since the above hypothesis would indicate tube loading in a displacement controlled manner, the condition is not expected to worsen with time. Involved

procedures, such as tube pulling, do not seem warranted in light of ALARA considerations and no further anticipated tube damage. It is ANPP's and CE's opinion that tube plugging, regardless of method, is not necessary. Monitoring selective dented tubes during a future planned eddy current inspection would confirm the non-progression of the tube dents with time.

The condition of the wedged foreign object bears no resemblance to the phenomena of damage due to impact of "loose parts" which has led to tube rupture in a small number of operating steam generators. In the loose part scenario, repeated impacting of a loose part, accelerated by high velocity (as high as 15 feet per second, as referenced in NUREG-0909) and high density flows, imparts cold work to one side of a tube which ovalizes the tube cross section plus it subsequently collapses due to external pressure. The collapsed cross section then breaks under flow loading and beats against adjacent tubes which subsequently rupture due to gross metal loss. None of these phenomena are applicable to the wedged foreign object.

There is no evidence to suggest a generic aspect of the foreign object induced tube denting found in Unit 1. Historically, CE has been successful in precluding the introduction of foreign material in previous units.

C. Indications of Potential Loose Parts

The indications present in Unit 1 steam generator #1 are in the tubes at row 26 - column 113 and row 25 - column 114 and are located just above the tube sheet. The amplitude of the indications are too small to draw significant conclusions as to the origin of the indications.

Although the indications are too small to be well characterized, neither of the two tubes or any surrounding tubes show any sign of wear or tube wall degradation. Thus, the presence of these indications does not represent a safety concern.

The presence of a foreign object cannot be verified by fiberoptic inspection on the secondary side of the steam generator. Because the economizer divider plate is mounted in the tube lane, the tubesheet access port is offset 15 degrees away from the tube lane. Thus, fiberoptic equipment cannot access the tube lane and visual inspection along the lane cannot be accomplished.

The indication in Unit 1 steam generator #1 at rows 125 through 129 - column 100 and in steam generator #2 at row 39 - column 4 have been determined to be variations in the tubes themselves, such as the result of a permeability change in the tube. A multi-frequency mix of the eddy current signals indicates no tube wall degradation and no actual presence of foreign material. Therefore, these indications do not represent a significant safety concern.

Corrective Action

The indications of a loose part at the row 1 - columns 48 through 64 location are discussed in Section III.B of this report. Two of the three remaining areas have been determined to be other than loose parts. The possible presence of a small foreign object at the remaining location cannot be positively ruled out. However, if one does exist, its size and location is such that no damage has occurred and no corrective action is necessary. These and other surrounding tubes will be monitored in a subsequent eddy current inspection.

D. Sludge Accumulation

The very small amount of sludge found in the Unit 1 steam generators indicates that secondary chemistry control has been good. The locations of the largest deposits of sludge indicate that the sludge is being swept across the tube sheet to the area of the blowdown ring. This indicates that the blowdown system is operating as designed to prevent sludge accumulations from forming in the center regions of the tube bundle which have been a concern in previous steam generator designs.

The accumulation of sludge and its affects on the steam generator tubes is a well documented occurrence in the industry. The use of a recirculation-type steam generator coupled with an all volatile chemistry program has diminished tube thinning problems such that it is no longer a problem. The use of volatile chemistry control also reduces or eliminates the problem of chemical concentration since the high heat flux would only remove the volatile chemicals from the sludge.

Due to the inaccessability of the tube lane and tube sheet area on the System 80 steam generators, the sludge accumulation cannot be removed by use of sludge lancing equipment. The sludge accumulation is monitored each time the steam generators undergo an eddy current inspection.

E. No Tube Explansion (NTE)

The tubes in a System 80 steam generator are explosively expanded into the 23.5 inch tube sheet. Those tubes which exhibit NTE either had an undersized charge or the charge failed to detonate.

Localized corrosion of tubing material has led to steam generator tube leakage in some operating reactor plants where crevices exist. Examination of tube defects that have resulted in leakage has shown that two mechanisms are primarily responsible. The localized corrosion mechanisms are referred to as (1) stress assisted caustic cracking, and (2) local wastage. Both of these types of corrosion have been related to steam generators that have operated on phosphate chemistry. The caustic stress corrosion type of failure is precluded by controlling the steam generator water chemistry within Technical Specification limits. Localized wastage or beavering has been eliminated by removing phosphates from the chemistry control program.

The tubes with indications of NTE, as stated before, are in random locations throughout the tube sheet in both steam generators. ANPP does not consider it advisable to attempt a field expansion of these joints since impurities may already exist in the crevice. This possibility, and the additional stress to the tubing that would result from the expansion, would impose an increased risk to stress-induced corrosion (as well as non-stress induced corrosion) within the subsequently enclosed crevice.

This condition has occurred in other CE steam generators and has not resulted in unacceptable tube degradation. This is due to the fact that tubes in CE steam generators are purchased with a specified maximum tensile strength. Additionally, the tubes do not undergo a hard step roll into the tube sheet as in the steam generators provided by other NSSS vendors. These two conditions result in less residual stress in the tubes, making them less susceptible to stress corrosion cracking.

The potential risk of degradation to the affected steam generator tubes by not expanding the joints is considered acceptable. This is based on the successful operating history

over many years of recirculating steam generators with tube-to-tube sheet crevices that have invoked good chemistry control and impurity cleanup practices.

F. Foreign Residue in Steam Generator Tubes

Samples of the residue underwent chemical analysis by Battelle and ANPP. Battelle performed X-ray flourescence spectrometry, light optical microscopy, scanning electron microscopy, pyrolysis/gas chromatography, infrared spectroscopy, and neutron activation analysis. ANPP performed infrared spectroscopy, gamma isotopic analysis, boron analysis and low power light microscopy.

The steam generator tube deposits indicate that an organic material was introduced to the primary system. During thermal decomposition of the organic material, it became affixed to approximately one hundred tubes. The organic residue, along with crud and boric acid (precipitated during cooldown), composed the steam generator tube deposits. Chemical analysis results show a strong correlation between the tube deposit constituents and herculite (a yellow sheeting material used to cover components to maintain cleanliness and to prevent the introduction of foreign objects into systems) (yellow) ingredients. It is likely that this material was present in the hot leg piping or in the steam generator plenum prior to Unit 1 fuel load. A comparison of the tube deposits (less corrosion products) with the constituents of yellow herculite gave a reasonable assurance that the material deposits were from yellow herculite. This data also gave ANPP reasonable assurance that the material was limited to this region of the steam generator since the cadmium and barium (found in herculite) were not activated. Therefore, the material was not transported through the core.

The potential safety significance of the deposits is that residue in the RCS can cause detrimental effects to the components. The constituents chloride, lead, and sulfur, found in both tube deposits and their suspected parent, yellow herculite, are those which warrant the most concern in terms of materials degradation.

Chlorides have been associated with stress corrosion cracking of zircaloy and austenitic stainless steels at elevated temperatures. Based on historical RCS chloride levels during plant operations, the specified limit of 0.15 ppm has never been exceeded. This, combined with the low operating oxygen levels, eliminates the probability of stress corrosion cracking.

Lead, in significant proportions, can induce transgranular stress corrosion cracking in Inconel 600. Assuming all available lead was bleached from the herculite, its concentration in the. RCS would not be detectable. These levels are not considered significant enough to induce corrosion.

Inconel 600 exhibits susceptibility to corrosion by sulfur in aqueous environments. In secondary environments, various toxic forms of sulfur can induce intergranular attack (IGA) and wastage (localized tube dissolution). The degree of susceptibility is due in part to its metallurgical treatment. Since sulfur appeared to be non-volatile during elevated temperature decomposition of herculite, the majority remained affixed to tube surfaces probably in association with a heavy metal or the decomposed herculite. Eddy current testing in the affected tubes showed no degradation.

The presence of non activated species such as cadmium and barium in steam generator tube deposit indicates that the organic residue found affixed to ID tube surfaces was not transported through the RCS. A comparison of chemical

analysis results between the tube deposit, aged herculite (a herculite sample heated in an autoclave at 575°F to agglomerate) and virgin herculite showed that some species such as lead and chloride were readily discharged into the RCS, but were effectively removed by purification. Continuous circulation of these would lead to their activation. No evidence of this was found. Pyrolysis of herculite leads to the evolution of gaseous products such as hydrogen chloride, carbon dioxide, and carbon monoxide. Their relative concentrations in the RCS however would be inconsequential. Therefore, the transportable species were effectively removed while a non violatile residue remained fixed on tube surfaces.

Corrective Action

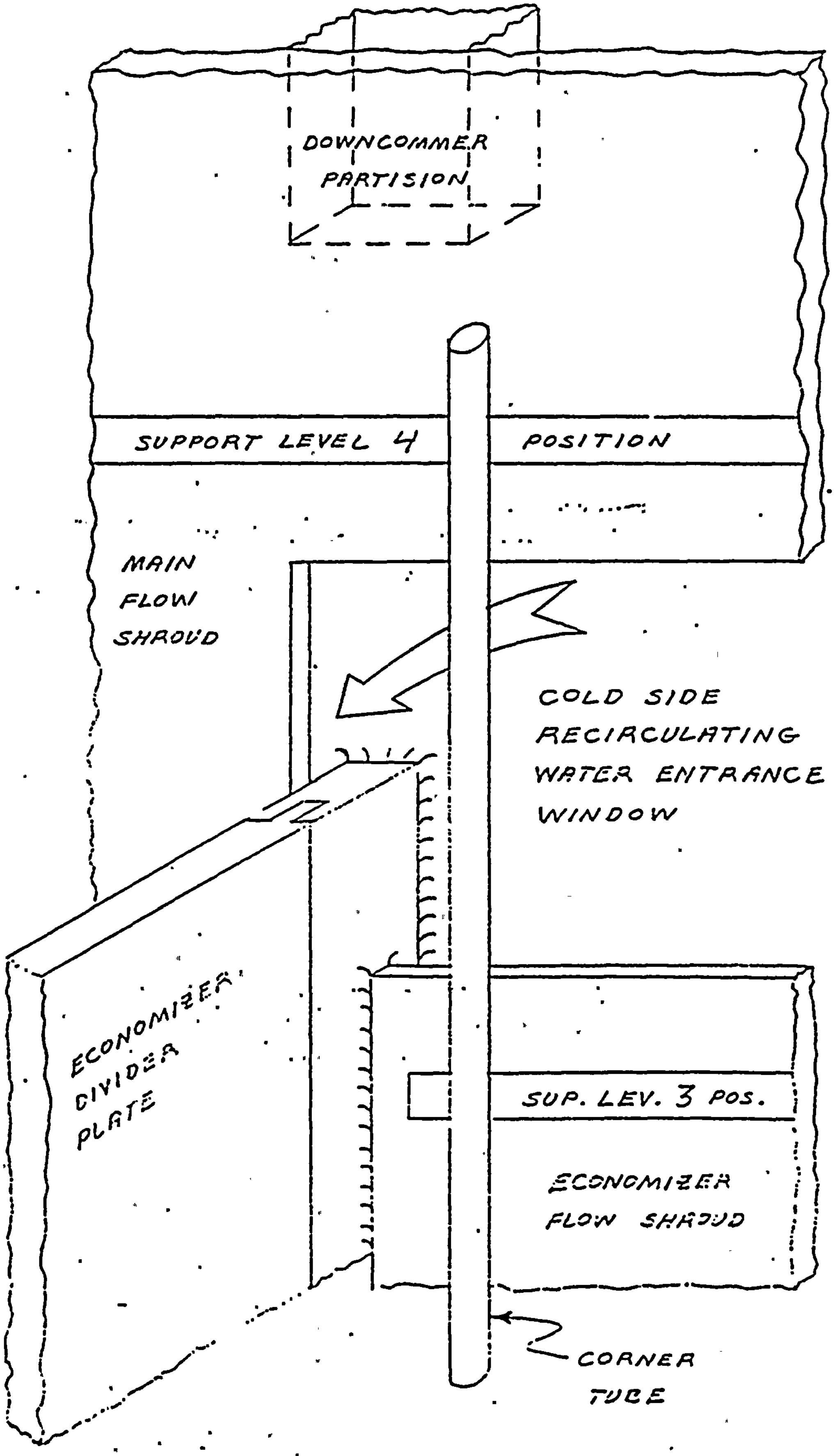
Based on videography results, affected tube surfaces are now relatively clean; a beneficial consequence of the ECT reinspection of the approximately 100 tubes. No further cleanup of the steam generators is required.

CE has concurred that tube deposits and impurity releases resulting from the decomposition of the herculite had no adverse affects on steam generator and RCS materials integrity. No RCS degradation is expected to occur.

A pebble-sized obstruction was discovered in Unit 1 steam generator #1 tube when a video probe, placed in a random tube to document the inside diameter tube deposits, encountered a blockage. The particle was an angular fragment with a light-colored appearance. It appeared as a solid 5/8" wide mass and showed little evidence of erosion. It is believed to have been transported through the system, became wedged, and was then coated with a soft, powdery material.

It was concluded to be non-related to the foreign residue in the steam generator tubes. Efforts to remove the obstruction from the tube were successful. However, retrieval of the particle for analysis using a vacuum device was unsuccessful. It is believed that the object was pulverized in the vacuum. This was the only case that any other material was found during the ECT examinations.

Figure 17



COLD SIDE TUBE BUNDLE ENTRANCE REGION

Figure 17

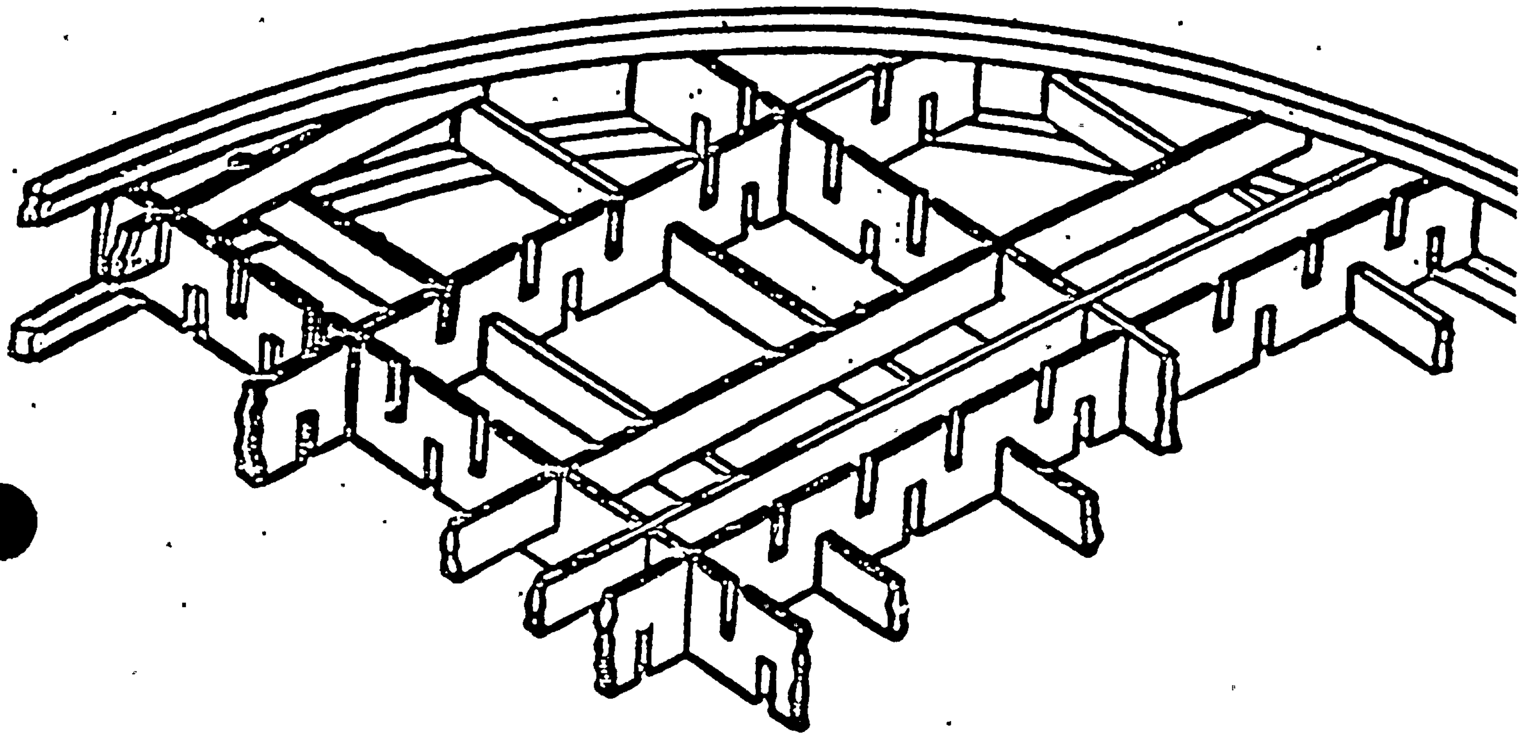


Figure 18

Horizontal Eggcrate Support

IV. Summary

An evaluation of the cause of the steam generator tube leak in the PVNGS Unit 1 steam generator and subsequent eddy current evaluations in Unit 1 and Unit 2 has led to the following corrective action:

- The tubes in PVNGS Units 1 and 2 that showed indications of wear due to flow induced vibration in the economizer section of the steam generator have been plugged and staked. The stakes were installed on the cold leg side to prevent severing or collapse of the tube. Each stake is 189 inches long, 1/2 inch diameter, braided stainless steel cable. The final number of tubes that were plugged is shown in Table 3.

Table 3
Summary of Tube Plugging

	Unit 1	Unit 2
Wear Indication	22	51
Dent Indication	6	--
Other*	6	--

*Five other defects not associated with support wear and one precautionary plug in the corner region. The one precautionary plug was installed in a good tube above the patch plate in the cold leg corner region. This precaution was taken due to ALARA considerations since plugs are difficult to install above the patch plate bolts.

- In addition, six of the nine tubes with indications of dents in row 1 of Unit 1 steam generator #1 have been plugged and staked.

- Removal of the identified part along the divider plate is not possible due to the inaccessability of the secondary side of the System 80 steam generators, both above the tubesheet and above the flow distribution plate. Since the foreign object is wedged, is in a relatively low velocity area, and bears no resemblance to the phenomena of loose parts impacting damage which has led to tube rupture, there is no immediate need to remove the object.

The following actions have been identified as confirmatory actions:

- An analysis will be made of the tube lane region to attempt to determine the local flow velocity in the region of the observed tube wear.

- Eddy current examinations will be conducted in Unit 1 during the first refueling outage in areas of concern such as the wear prone areas and in the tubes adjacent to the trapped part in steam generator #1.

- An augmented Technical Specification eddy current inspection will be conducted in Unit 2 during the first refueling outage, with an inspection scope similar to the Unit 1 steam generator inspection just completed.

In conclusion, based on the results of the evaluation and the corrective measures which have been implemented, ANPP has determined that power operation of PVNGS Units 1 and 2 can be safely resumed.

ANPP is currently considering the following alternative corrective actions for the PVNGS Unit 3 steam generators. ANPP will advise the NRC Staff of the chosen alternative at a later date.

- Based on the Units 1 and 2 tube wear findings, preventatively plug a sufficient number and pattern of tubes to allow operation of Unit 3 to the first refueling outage with no tube leakage.

- Determine the amount of time that Unit 3 can operate without preventative tube plugging and schedule a planned outage accordingly.

- Preventatively plug a limited number of tubes to allow operation of Unit 3 to a planned outage prior to the first refueling outage.

As an additional note, the NRC Staff has requested a reference to how Unresolved Safety Issue (USI) A-4 was addressed for PVNGS. The following discussion provides the ANPP response to this NRC Staff request. CESSAR sections 5.4.2 and 10.3.4 discuss the design of the steam generators and secondary water chemistry, respectively. The NRC review of CESSAR as it relates to USI A-4 is documented in Appendix C of the CESSAR SER and in Appendix C of Supplement 1 to the CESSAR SER. Additionally, the NRC has issued Generic Letter 85-02 which presented the NRC Staff's recommended actions for resolution of the USIs regarding steam generator tube integrity. ANPP responded to Generic Letter 85-02 in a letter from E. E. Van Brunt, Jr., ANPP, to Hugh L. Thompson, NRC, dated June 21, 1985 (ANPP-32869). Additionally, ANPP plans to revise the previous response to Generic Letter 85-02 to indicate the extent to which secondary side inspections of the steam generators can be conducted. This revised response will be provided to the NRC within 30 days.