NORTH ANNA POWER STATION UNIT 1
FIRST REFUELING STEAM GENERATOR INSPECTION REPORT

I. Introduction

North Anna Unit 1 began commercial operation on June 6, 1978, and operated at a capacity factor of 75.6 percent until shut down for refueling on September 25, 1979. Prior to the commencement of this refueling outage, a minor primary-to-secondary steam generator (SG) tube leak had been detected. Based on SG blowdown activity measurements, it was determined that 'C' SG had a barely detectable tube leak of about 2.08×10^{-3} gpm. The 'A' and 'B' SG's exhibited no detectable tube leakage.

II. SG Inspection Program

Based on the experience of other Westinghouse PWR's operating on Secondary Water AVT and using fresh water circulating water, no SG corrosion problems had been anticipated. The refueling outage SG inspection program was scheduled to comply with the requirements of the North Anna Technical Specifications.

A. Technical Specification Program

Technical Specifications Section 4.4.5 requires a sampling program inspection to include a minimum of 3 percent of the tubes in all steam generators. Since the preservice inspection was performed on all tubes in all three steam generators, it was planned to inspect 3 percent of the total number of tubes in all three SG's by inspecting approximately 4.5 percent of the tubes in each of SG's 'A' and 'C' during this outage. This is in compliance with Regulatory Guide 1.83.

Figures 1 and 2 show the SG tubes inspected as part of the initial Technical Specification inspection in SG's 'A' and 'C', respectively. A 400 KHZ eddy current (EC) probe was used to detect possible tube defects. A sample of approximately 440 tubes in SG 'A' and 480 tubes in SG 'C' were inspected with this probe. The sampling pattern was a pre-determined array chosen to investigate all areas of the tubesheet with additional tubes in the areas of greatest concern. This pattern was based on previous inspection experience of the SG vendor. No indications of defects were detected in SG 'A' with the 400 KHZ probe. Eddy current examinations confirmed defects in the two tubes in 'C' SG that were found to be leaking during pressure testing.

In addition to the required 400 KHZ inspections, it was planned to use a 7.5 KHZ probe on approximately 421 tubes in SG 'C' to determine if tube support plate corrosion had occurred during the plant's first cycle. These inspected tubes are shown in Figure 3. Of the 421 tubes inspected, 155 tubes exhibited indications of support plate corrosion or possible ligament cracking.

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Table 1

NORTH ANNA UNIT 1

EXPANDED SG INSPECTION PROGRAM

SG	EC Probe	Tubes Inspected	Indications
A	*400 KHZ	440	None
	100 KHZ (diff)	181 (rows 1 and 2)	None
	7.5 KHZ	370	132
B	400 KHZ	133	None
	100 KHZ (diff)	88 (row 1)	None
	100 KHZ (abs)	89 (row 1)	None
	7.5 KHZ	119	19
C	*400 KHZ	480	2 (leakers)
	400 KHZ	163 (cold leg)	None
	100 KHZ (diff)	178 (rows 1 and 2)	2 (same leakers)
	100 KHZ (abs)	***117 (vicinity of leakers)	2 (same leakers)
	**7.5 KHZ	421	155

*Initial Regulatory Guide Inspection

**Additional Initial Inspection

***117 tubes including leakers

Numbers are approximate and data are still being reviewed. A final report will be issued for retention in station records.

B. Expanded Program

Based on the results of the initial inspection program which identified support plate corrosion in SG 'C', a comprehensive inspection program was developed to identify tube or support plate anomalies in all three SG's. The resultant program is shown in Table 1. As can be seen, the inspection was expanded to include SG 'B' and additional eddy current probes of 400, 100 and 7.5 KHZ were utilized to determine the overall condition of all SG's. See Figures 4 through 12 for additional inspections performed during the expanded program.

The 100 KHZ absolute and differential inspections were performed to supplement information gained from the 400 KHZ probe. The use of absolute and differential probes provides additional information about tube conditions. The absolute probe uses a single coil in the probe whose signal is compared to a reference coil located outside of the SG. This allows the inspector to detect slow changes in tube properties such as wall thickness (wastage) or corrosion product buildup. The differential probe uses two coils in the probe itself, and these two signals are compared to identify rapid changes in tube properties. The differential probe is thus more sensitive to continuity defects. The 7.5 KHZ probe inspections were performed to define support plate integrity. The 400 and 100 KHZ inspections were performed to define a SG tube integrity.

All eddy current inspections performed during this outage were single-frequency inspections. No multi-frequency or multi-plexing was used.

III. Inspection Results

Figures 13 through 15 show the locations of indications of support plate corrosion or possible ligament cracking in SG's 'A', 'B' and 'C'. Table 1 provides a summary of indications by SG and probe type.

Note that the two leaking tubes in SG 'C' are identified in row 1 on Figure 15. In addition, one tube in SG 'C', row 46, exhibited signs of minor denting and would not pass a 700 mil probe. Tube nominal ID is 775 mils. A 650 mil probe passed the restriction; however, this tube and its mirror image were plugged.

A. SG 'A' Results

No indications of tube defects were observed with the 400 KHZ and 100 KHZ EC probes. Approximately 36 percent of the tubes inspected with the 7.5 KHZ probe exhibited signs of tube/support plate intersection corrosion and/or possible ligament cracking. See Figure 13.

B. SG 'B' Results

No indications of tube defects were observed with the 400 KHZ and 100 KHZ EC probes. Almost 16 percent of the tubes inspected with the 7.5 KHZ probe exhibited support plate corrosion or possible ligament cracking. See Figure 14.

C. SG 'C' Results

Two leakers were detected in row 1, columns 50 and 61 in SG 'C'. One restricted tube was detected in row 46, column 41. Approximately 37 percent of the tubes inspected with the 7.5 KHZ probe showed indications of support plate corrosion or possible ligament cracking. See Figure 15.

D. Inspection Results Summary

Of the approximately 1070 tubes inspected in three SG's with the 400 KHZ probe, 2 tubes were identified as leakers.

Approximately 34 percent of the 910 tubes inspected with the 7.5 KHZ probe in three SG's indicated support plate/tube intersection corrosion and/or possible ligament cracking. Most of the tubes inspected with the 7.5 KHZ probe showed some indication of minor support plate/tube intersection corrosion.

One tube in SG 'C' was found to be slightly restricted in Row 46, column 41. It would pass a 650 mil probe, but not a 700 mil probe. Tube nominal ID is 775 mils.

IV. Interpretation of Inspection Findings

A. Leakers

While the actual failure mode of the two leaking tubes cannot be known without removal and additional inspection, tube leaks identified on the inner row have been attributed to residual manufacturing stresses created during tube bending. The maximum stresses are located at the apex of the U-bend and quickly lead to tube failures in the presence of severe support plate corrosion and subsequent hourglassing and flow slot closure. This phenomenon has been extensively treated in previous work. The first failures have, in the past, been in tubes located at the middle of the flow slots, since these tubes are the most affected by hourglassing due to support plate distortion. Tubes located between flow slots, i.e., in hard spots, are not exposed to extensive support plate distortion and thus are not likely to exhibit U-bend failures as a result of hourglassing.

The leaks identified in this inspection are located not at the apex of the U-bend, but at the tangent region. At this point, residual stresses are less than at the apex and are thus less likely to contribute to failure. Additionally, the two leakers identified in SG 'C' are not located adjacent to flow slots and are not subject to bending stresses due to the hourglassing effect of support plate distortion. Indeed, photographs taken of the flow slots show no detectable closure or distortion. Therefore, no effects of hourglassing has been observed in the tubes most likely to be stressed by this phenomenon and the tubes identified as leakers, being located in hard spots, are even less likely to be affected by the hourglassing phenomenon.

It is not apparent that the leakers are failures due to any identifiable mechanism, and it is not clear that these failures are related to first row failures in SG's affected by hourglassing. Two possible mechanisms are residual stress corrosion cracking and/or manufacturing defects. The fact that the tubes failed in the tangent region where residual stresses are substantially less than in the apex region of the U-bend, lends credence to the argument that these two failures are random events caused by manufacturing defects.

Thus, while the failure mechanism resonsible for these 2 tube leaks is not definitely known. There is no indication that it is related to tube failures caused by hourglassing of the flow slots.

B. <u>Tube Support Plate Corrosion</u>

The extensive inspections performed with the 7.5 KHZ EC probe indicated minor corrosion in the tube to support plate annuli. The corrosion observed appears to be the very early stages of the denting phenomenon affecting some other plants, especially those with salt water cooling.

This corrosion process has been attributed to secondary water chemistry in other plants, and the primary causal agent has been chlorides. The chloride source is commonly condenser in-leakage for plants using brackish or seawater for cooling. This is not the cause of the corrosion observed at North Anna 1 during this inspection. While some condenser in-leakage was observed during a portion of the first cycle, the use of fresh water cooling precludes introduction of sufficient chlorides into the secondary water to contribute to SG corrosion to the extent it has been observed to occur.

In light of this, a review of plant chemistry data was performed by Westinghouse and Vepco personnel. It was observed that a major discharge of resins from the Powdex polisher into the steam generators occurred in February, 1979. Three subsequent smaller discharges of resin into the secondary water were also noted. Details of the February, 1979, incident are included as Appendix A. It is known that the ion-exchange resins decompose at SG

operating conditions and produce sulfuric acid. A summary of the chemistry of this process is included in Appendix B. Laboratory studies performed by Combustion Engineering under contract to EPRI show that acid sulphates produce support plate corrosion and subsequent denting similar to the denting caused by acid chloride impurities.

Although the effects of sulphates on SG chemistry were not well understood at the time, it appears that the Powdex polisher resins may have contributed or/are responsible for the tube support plate corrosion seen at North Anna 1. This conclusion is supported by a substantial decrease in pH and an increase in cation conductivity of the SG blowdown during these occurrences. The decision was made to operate at load following this major resin discharge and to cleanup the SG's by blowdown. It was not expected to take long to cleanup the system because cation conductivity was continuously trending downward and pH was being adjusted upward. However, the slower-than-anticipated cleanup efforts extended the period of operation with SG contamination. During a return to power in May, 1979, the effects were also clearly observable in plant chemistry parameters as a result of chemical hideout return.

A report of plant chemistry before, during and following the resin discharge contamination is included as Appendix C.

V. Corrective Actions

A. Condensate Polishers

The Powdex units will be operated as filters or in the bypass mode until an evaluation of modifications to prevent additional resin discharges can be completed. Installation of resin traps and other possible system changes will be considered in our review.

B. Condensers

A condenser in-leakage abatement program will be initiated to minimize condensate contamination. Before returning to full power, condenser inspection and maintenance will be performed as required to eliminate in-leakage. A review of additional potential sources of contamination, such as the chiller air ejector condenser, will be conducted and inspection and maintenance will be performed as necessary to preclude contamination from these sources.

C. Steam Generators

Maintenance of steam generator chemistry within recommended values will be assured through a three step program.

1. Dissolved salts - Since the observed contamination is due to sulphates, a fill and drain procedure with nitrogen agitation will be performed during the present outage. During startup, the plant will be held at 450°F to facilitate further cleanup prior to power operation. A hideout return will be induced several weeks following return to full power by a load reduction to 50 percent followed by system cleanup before return to full power. During subsequent load reductions, the chemistry will be cleaned up to 0.5 - 1.0 umho cation conductivity prior to returning to full power.

2. Oxygen Control - Based on Westinghouse recommendations, oxygen will be controlled to 5 - 10 ppb at the condensate pump with a hydrazine residual of at least 10 ppb at the feed inlet to the SG.

3. Boric Acid Treatment - A program of boric acid treatments will be implemented during the upcoming startup to stop the support plate corrosion, followed by residual treatments to inhibit further deterioration. A boric acid soak at reduced power followed by continuous boric acid treatment during power operation will be implemented. It is theorized that the introduction of the boric acid into the SG's inhibits corrosion by chemically combining with the corrosion product magnetite to form borasite, a much less permeable compound. This effectively seals the corrosion site and prevents transport of corrosives into the annular region, thereby preventing formation of additional magnetite. The newly formed borasite is a dense, stable compound, no longer subject to corrosion. Maintenance of this borasite "seal" requires residual treatment with 5-10 ppm boron during operation until the corrosion process has been abated.

   As part of the boric acid treatment program, Vepco will purchase and install hydrogen monitors. These will provide an indication of the effectiveness of the corrosion abatement program.

   A copy of the Boric Acid Treatment Program is included for informational purposes as Appendix D.

D. Leakers

To preclude further U-bend tube leaks in the first row, all first row tubes will be plugged prior to startup. This action will be taken in light of the fact that two tubes have failed during the first cycle and that residual manufacturing stresses can contribute to additional tube failures. However, it is understood that there is no evidence that the leaking tubes identified during this inspection failed by a mechanism related to the residual stresses. To the contrary, the primary known contributor to U-bend tube failures, e.g., hourglassing due to flow slot closure, does not exist in the North Anna SG's. In addition, it is not obvious that the failures were caused by residual stress corrosion cracking

because the failures occurred in the tangent position of the U-bend where stresses are considerably less than at the apex. Most U-bend tube failures occur at the apex. We believe that the two observed failures are attributable to isolated tube defects present since fabrication.

Due to the lack of information concerning the tube failure mechanism, a conservative decision to plug first row tubes, will effectively preclude additional first row tube failures during subsequent operation. This is based on the fact that both leaking tubes detected during this inspection were first row tubes. Experience at other plants has indicated that similar first-row failures have occurred and that first row tubes are the most likely to fail.

F. Inspection Ports

It is currently planned to install inspection ports in the North Anna Unit 1 Steam Generators during the second refueling outage. These ports will be similar to those installed at Surry and will allow inspection of the upper tube support sheet and tube U-bends.

Figures 1 through 15

Steam Generator Inspection Maps

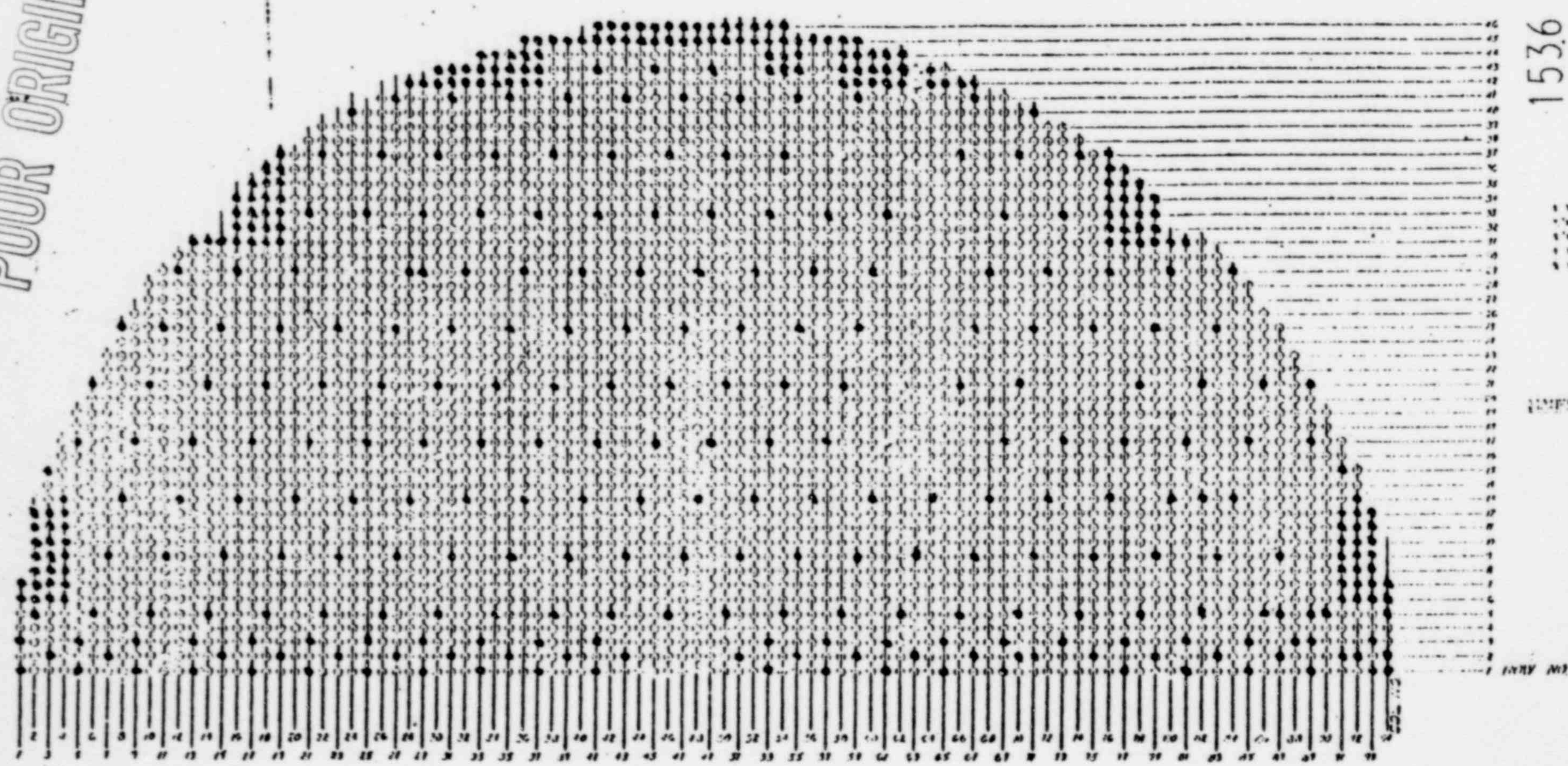
North Anna Unit 1 First Refueling

1536 219

POOR ORIGINAL

1536 220

FIGURE 1



1A STEAM GENERATOR

400 KHZ HoT leg 440 tubes

.700 .610 .540

4

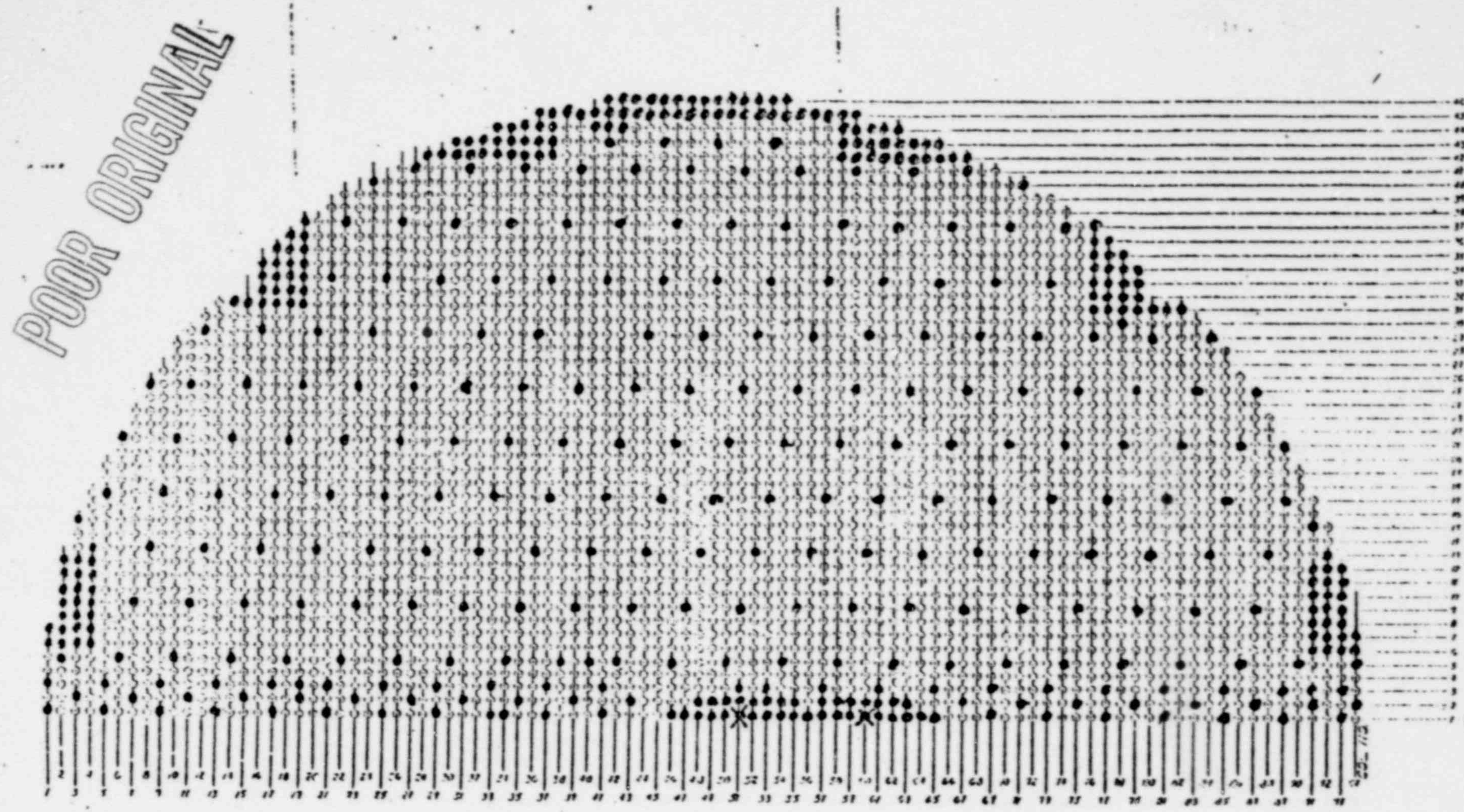


FIGURE 2

1536 221

1C STEAM GENERATOR

HOT leg 400KHZ

.700 .610 .540

480 tubes

x Leakers

480 7

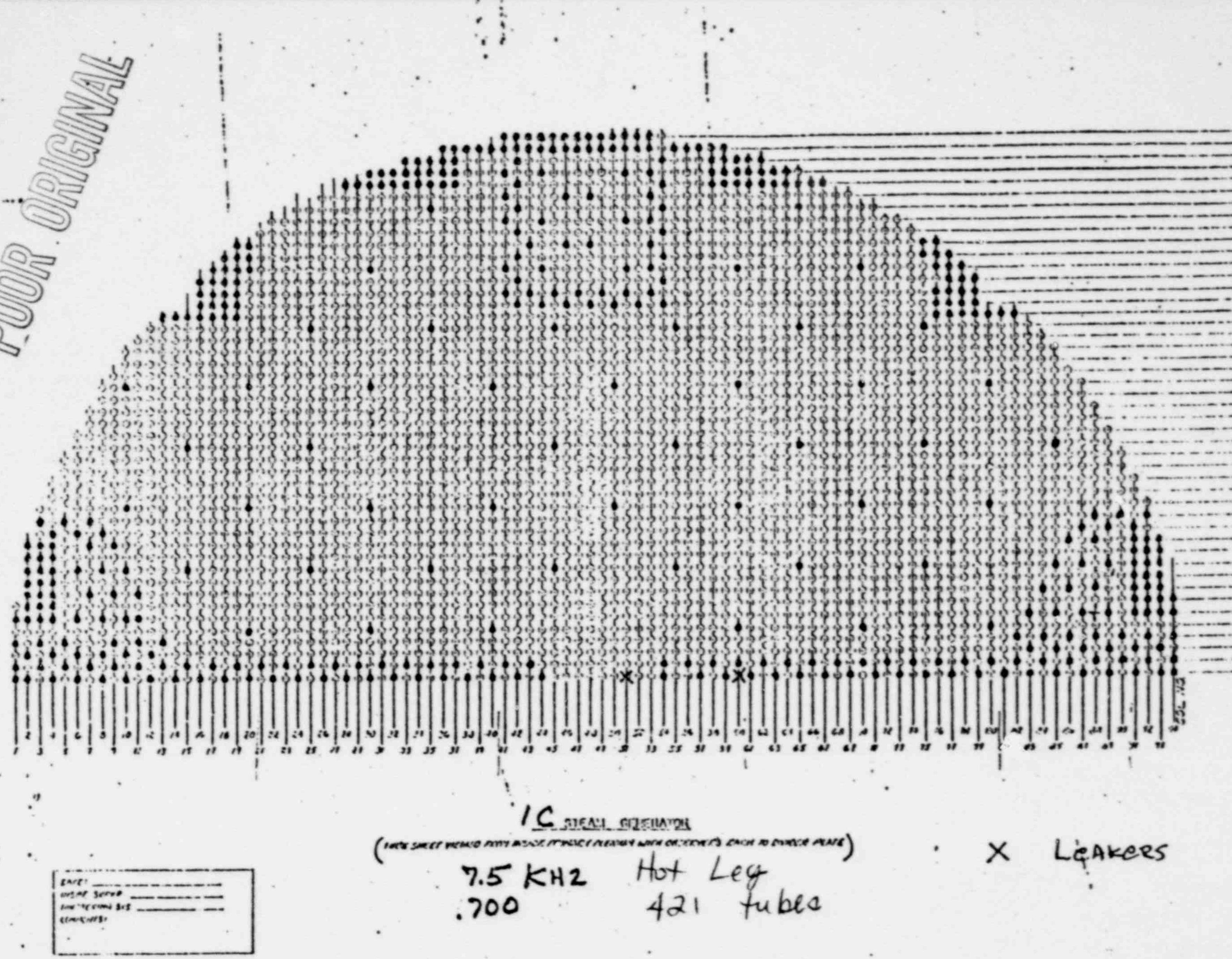
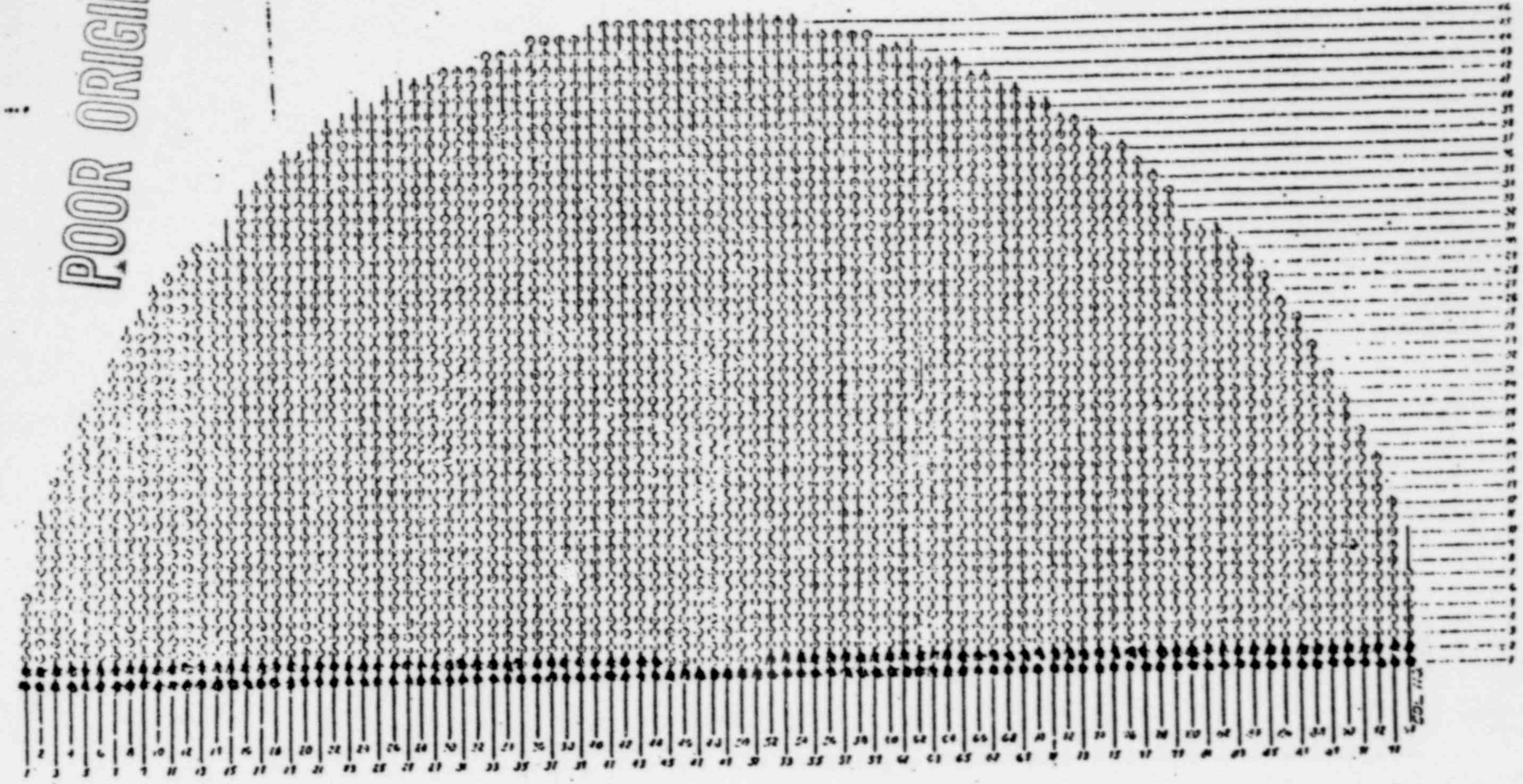


FIGURE 3

1536 22

FIGURE 4

1536 223



1A STEAM GENERATOR

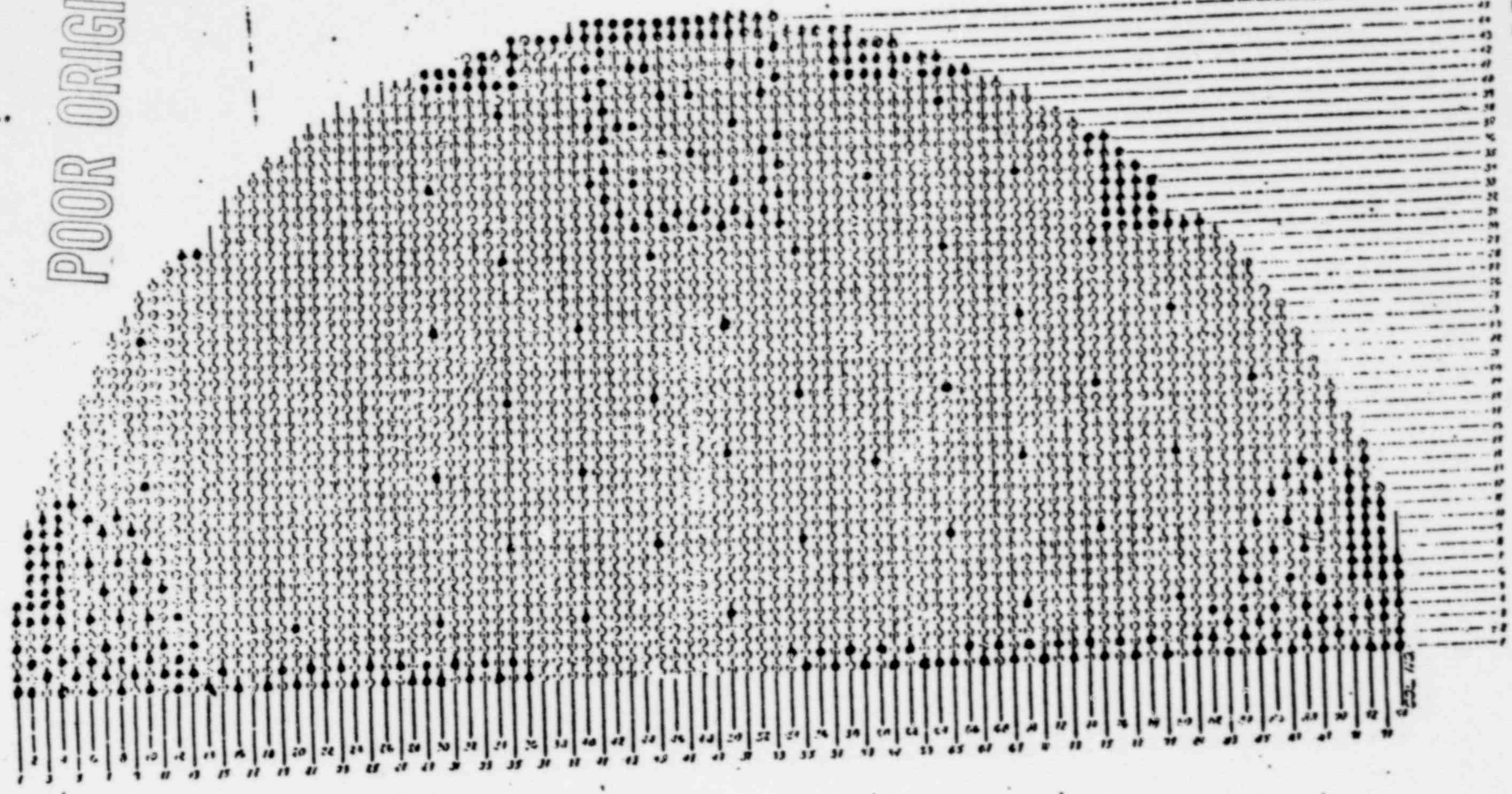
100 KHz Hot Leg DIFF.
.610 .540

181 tubes

POOR ORIGINAL

1536 224

FIGURE 5



1A STEAM GENERATOR

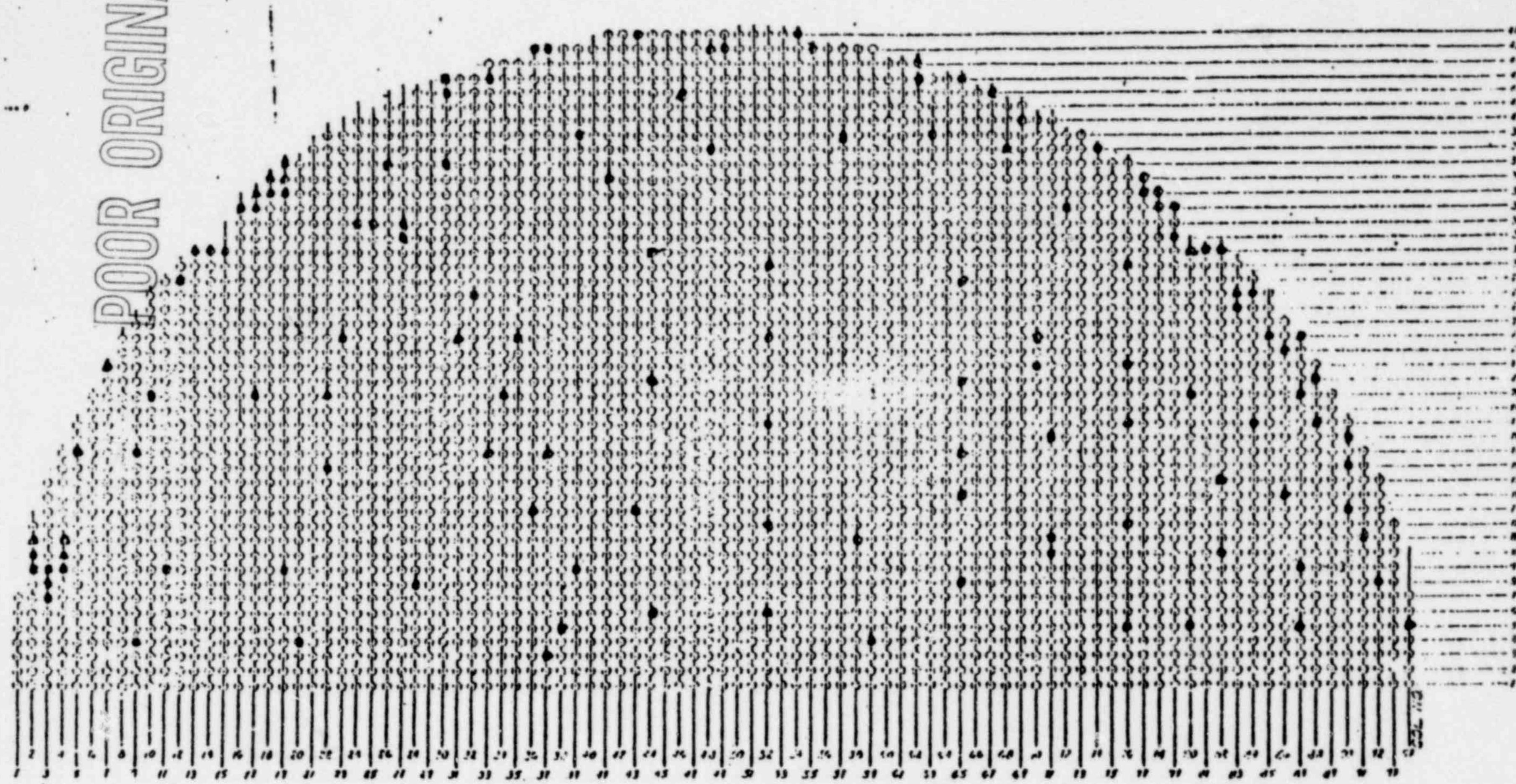
Hot Leg 7.5KHZ

.700

370 tubes

FIGURE 6

1536 225

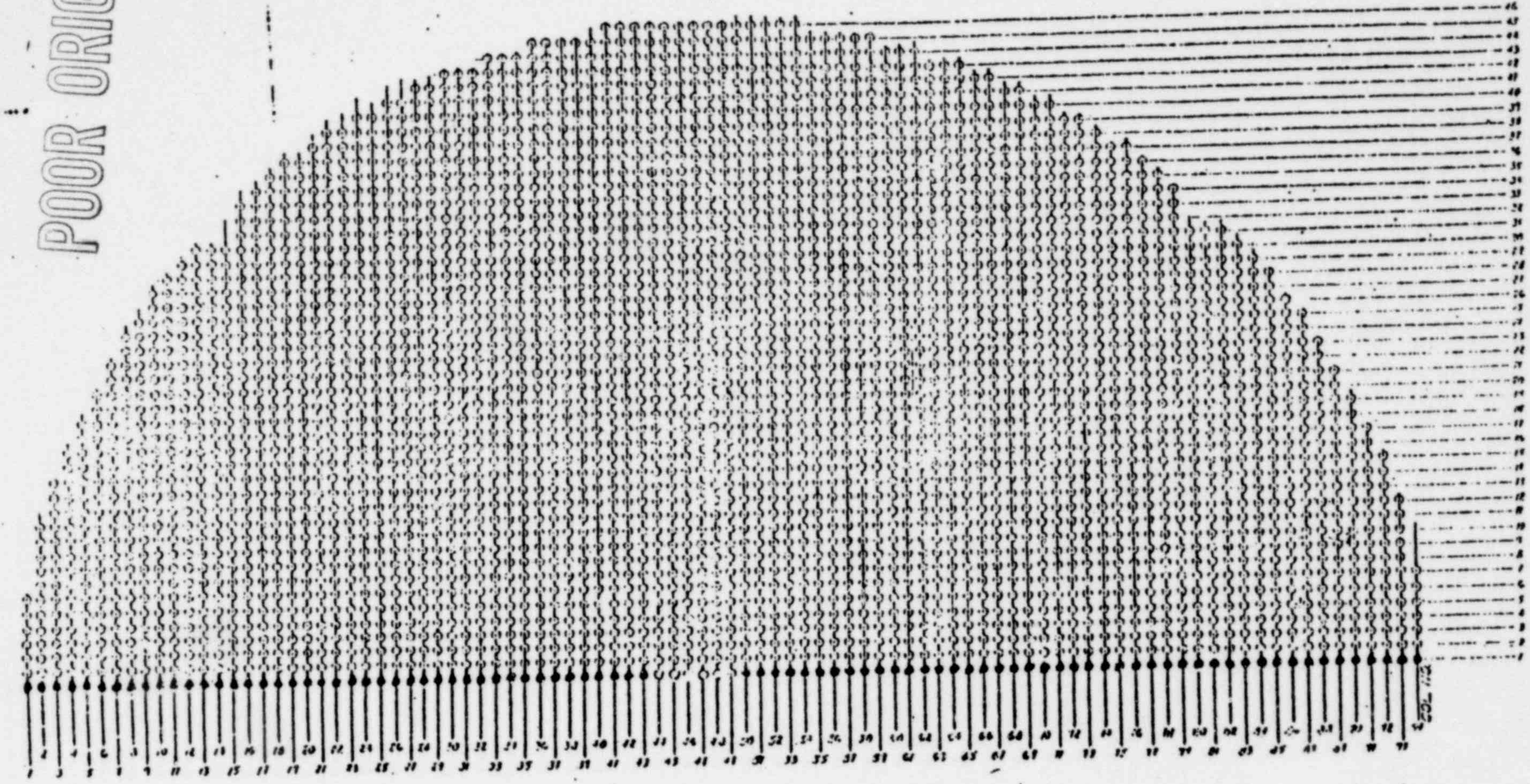


1B STEAM GENERATOR

400 KHZ Hot Leg

.700 133 tubes

FIGURE 7



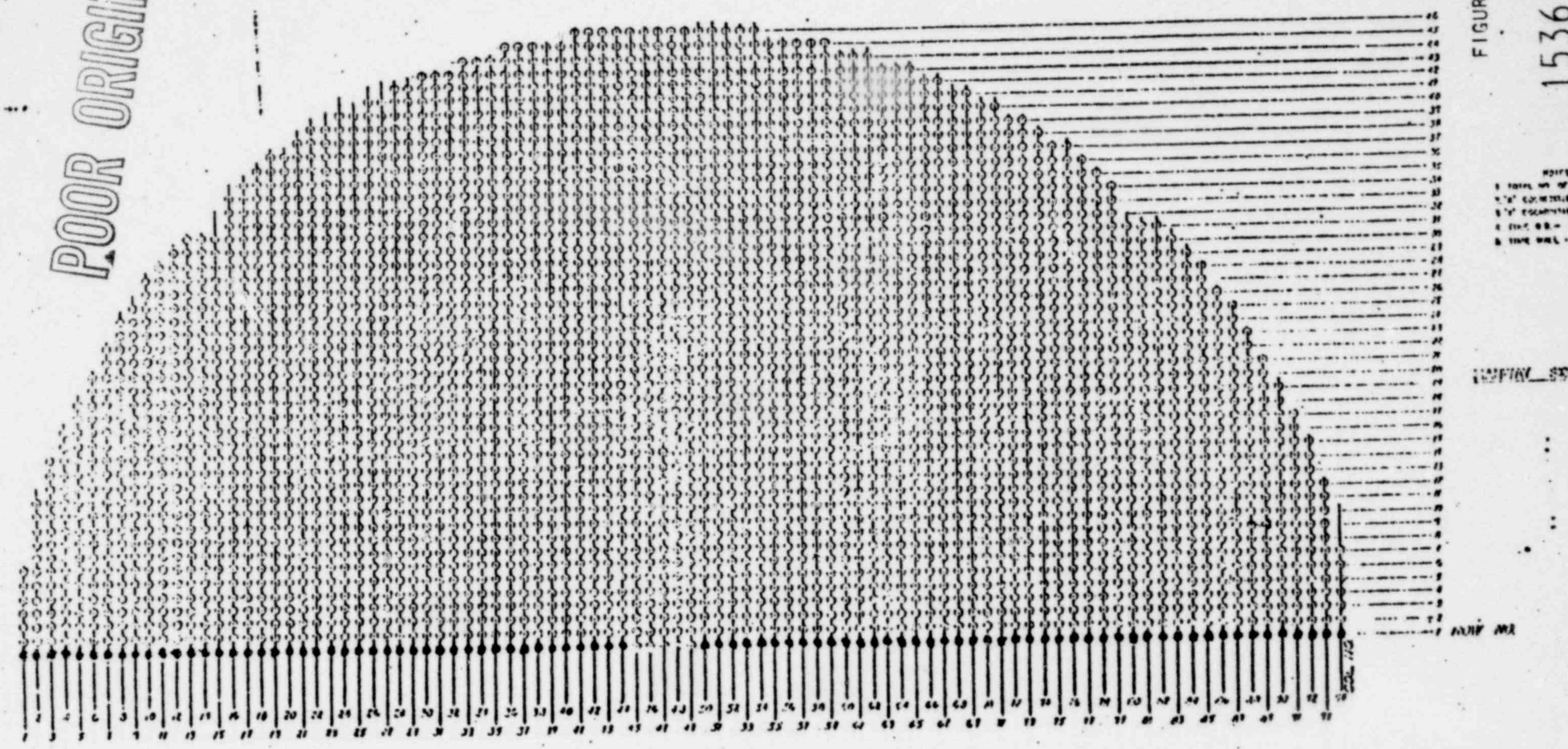
1B STEAM GENERATOR

Hot Leg 100 KHZ Dif

.540 88 tubes

1536 226

POOR ORIGINAL



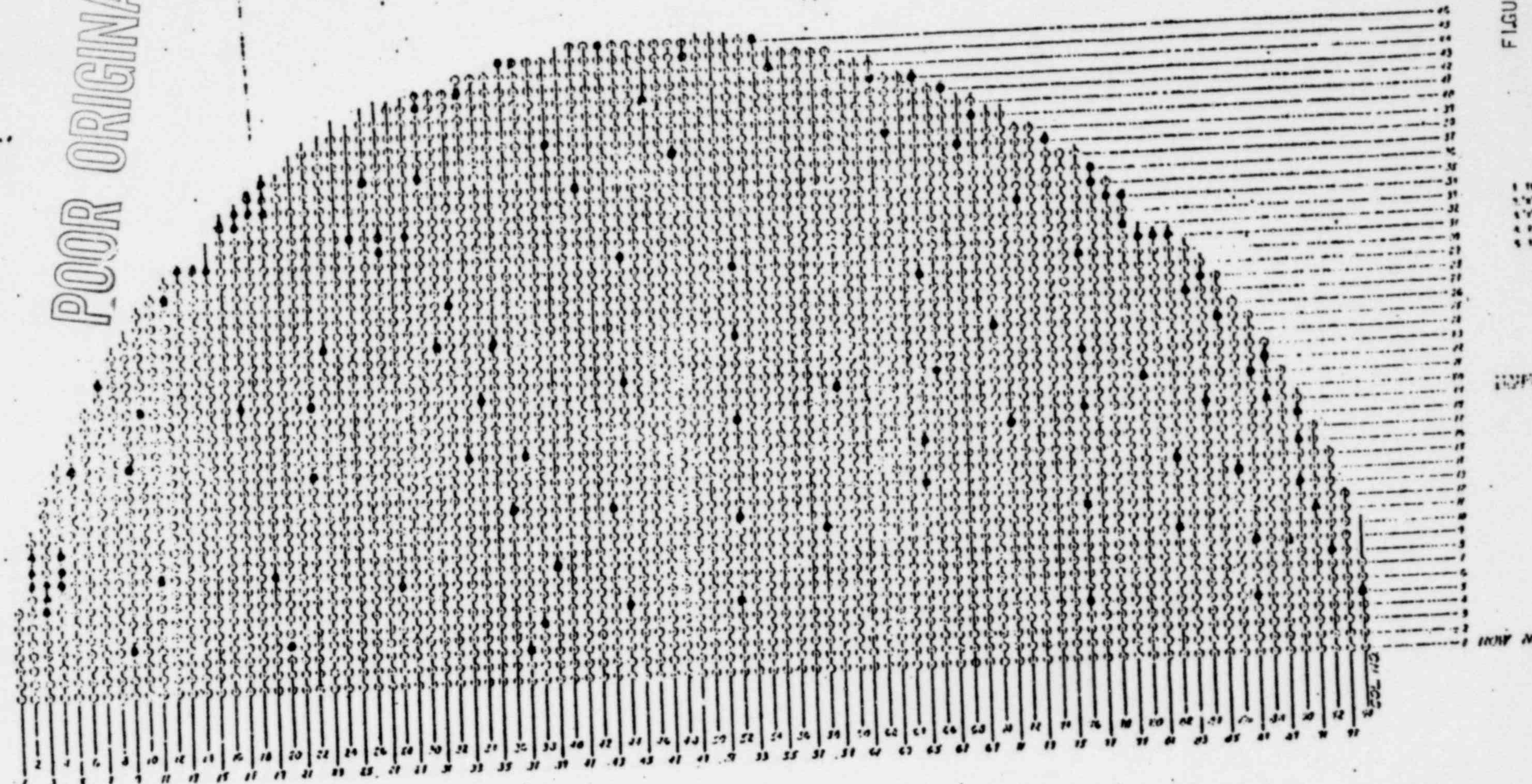
1B STEAM GENERATOR

Hot Leg 100 KHz ABS
.540
89 tubes

FIGURE 8

1536 227

POOR ORIGINAL



1B STEAM GENERATOR

Hot Leg 7.5 KHZ

.700

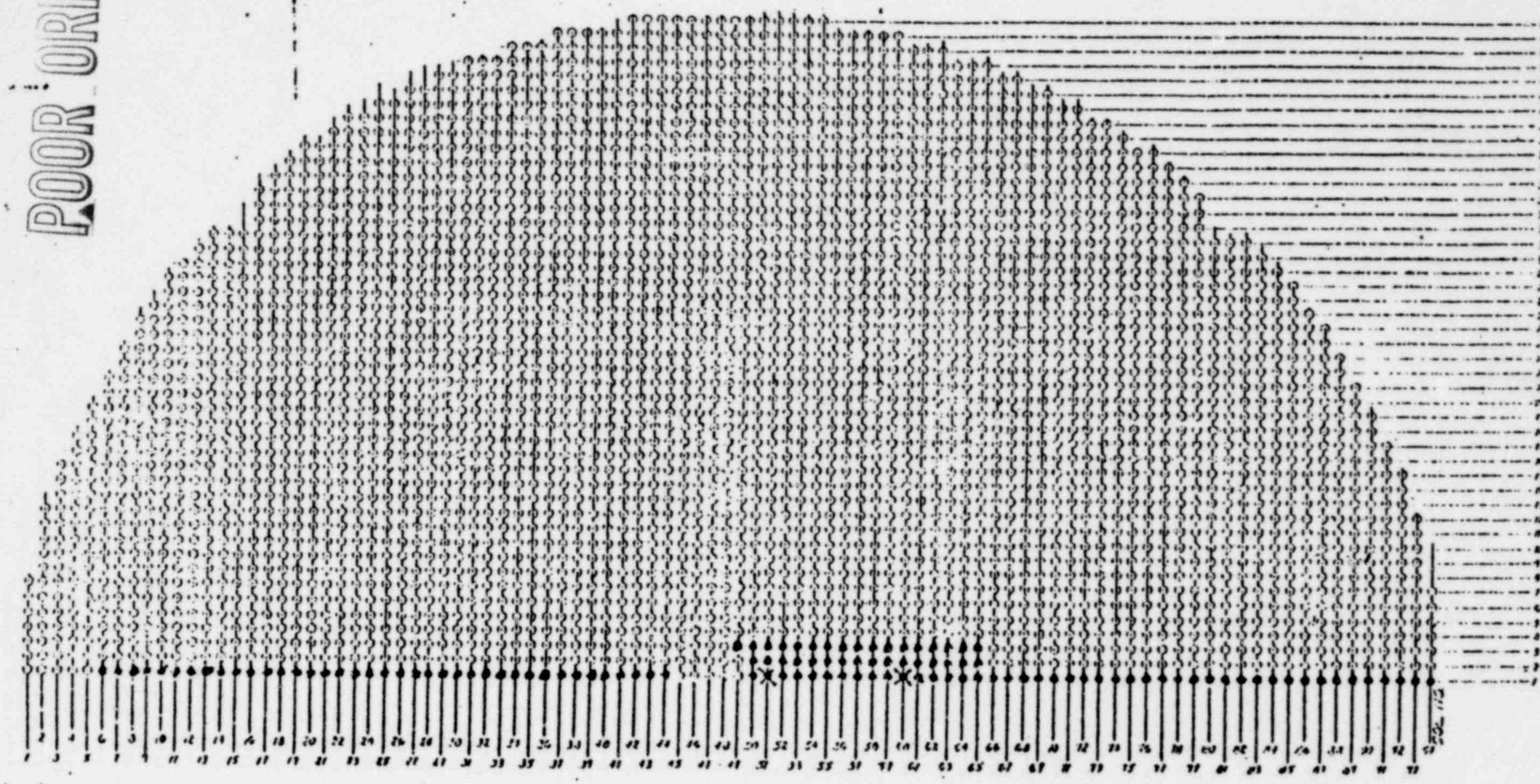
119 tubes

FIGURE 9

1536-228

FIGURE 10

1536 229



1C STEAM GENERATOR

(TUBE SHEET VIEWED FROM INSIDE PRIMARY CHANNEL WITH DIVIDER PLATE)

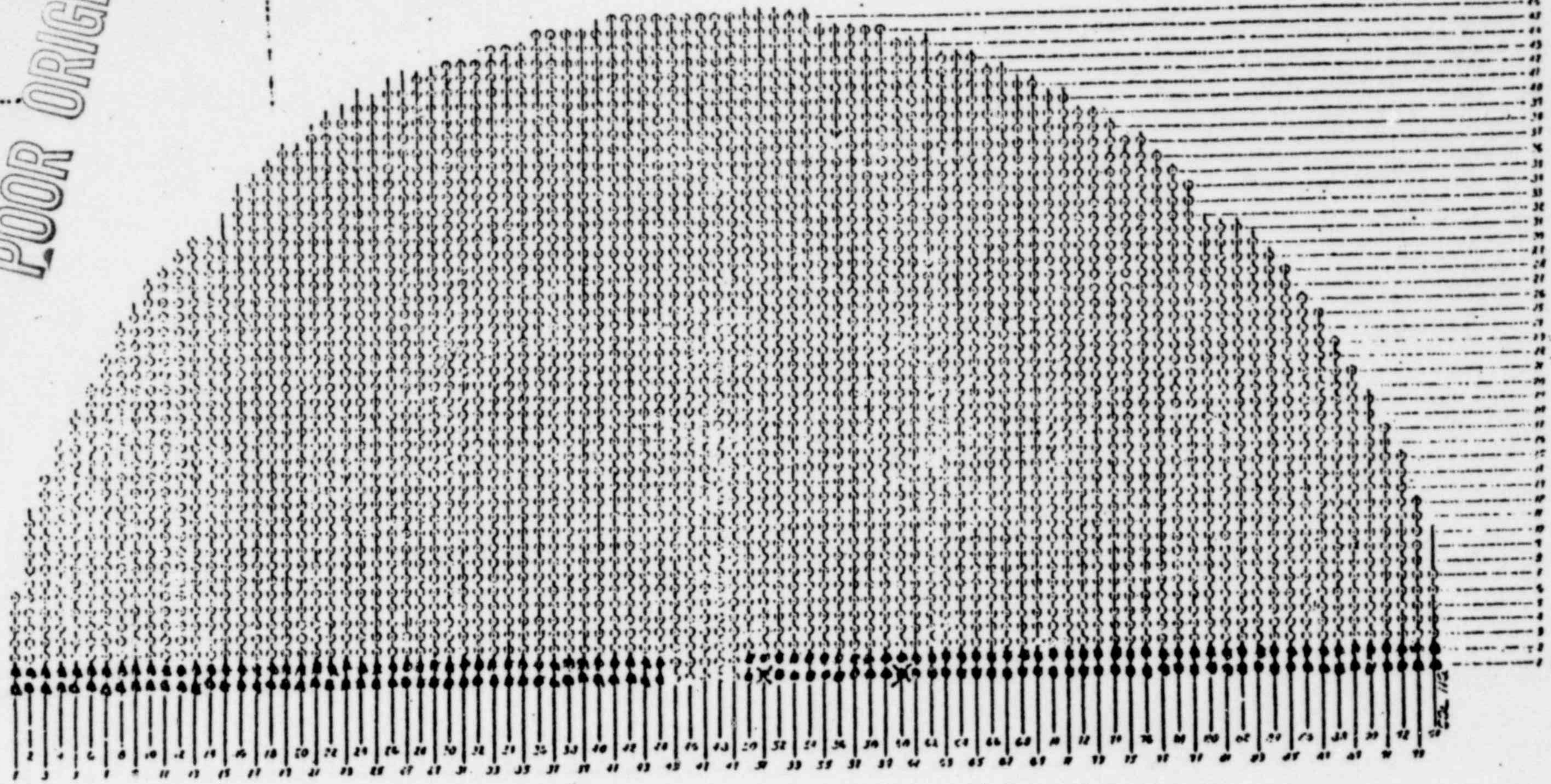
100 KHZ Absolute

.610 .540 117 tubes

X Leakers

FIGURE 11

1536 230



1C STEAM GENERATOR

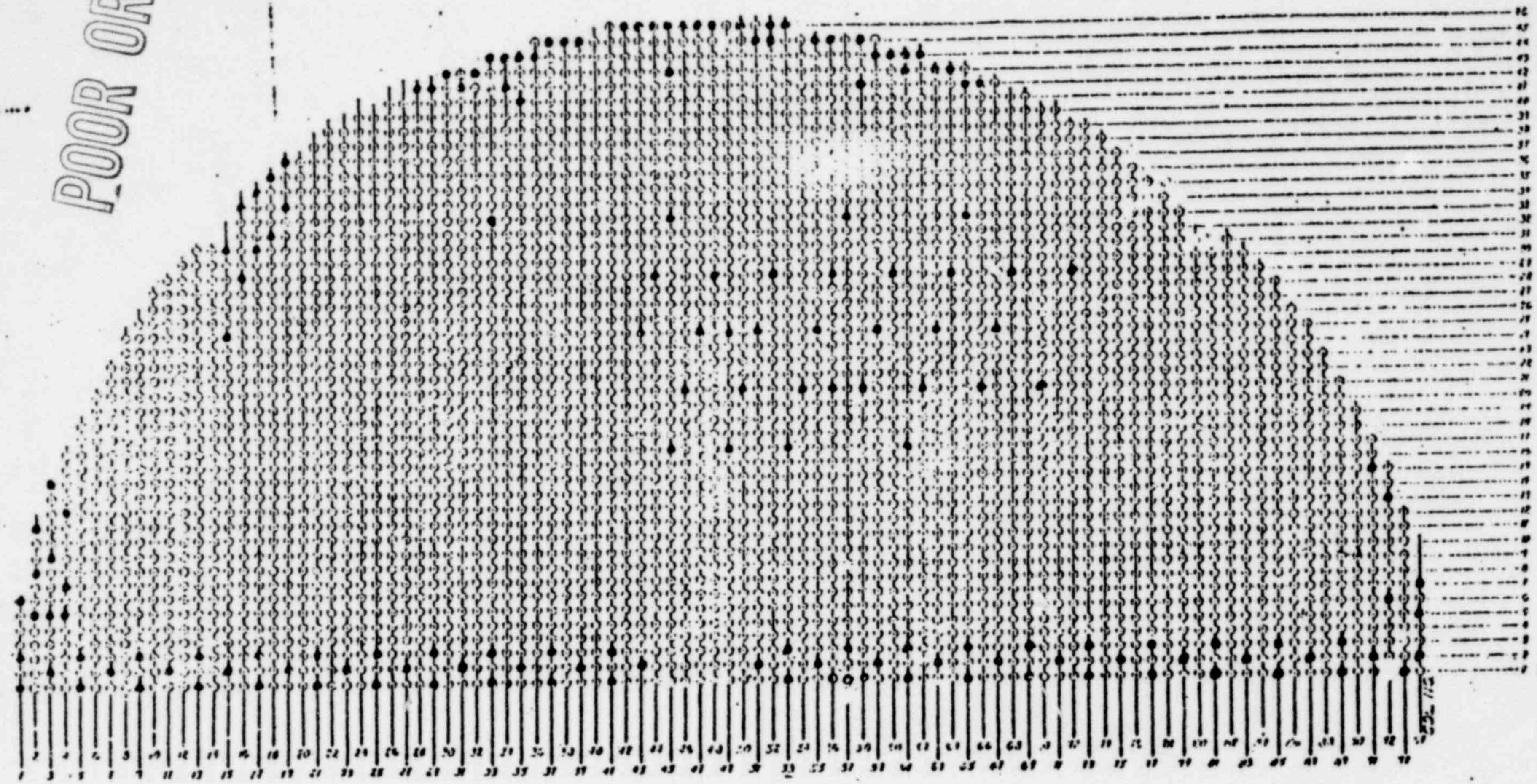
Hot Leg 100 KHz DIFF.

.610 .540 probe 178 tubes

X Leakers

1536 231

FIGURE 12



1C STEAM GENERATOR

CoLD Leg 400 KHZ

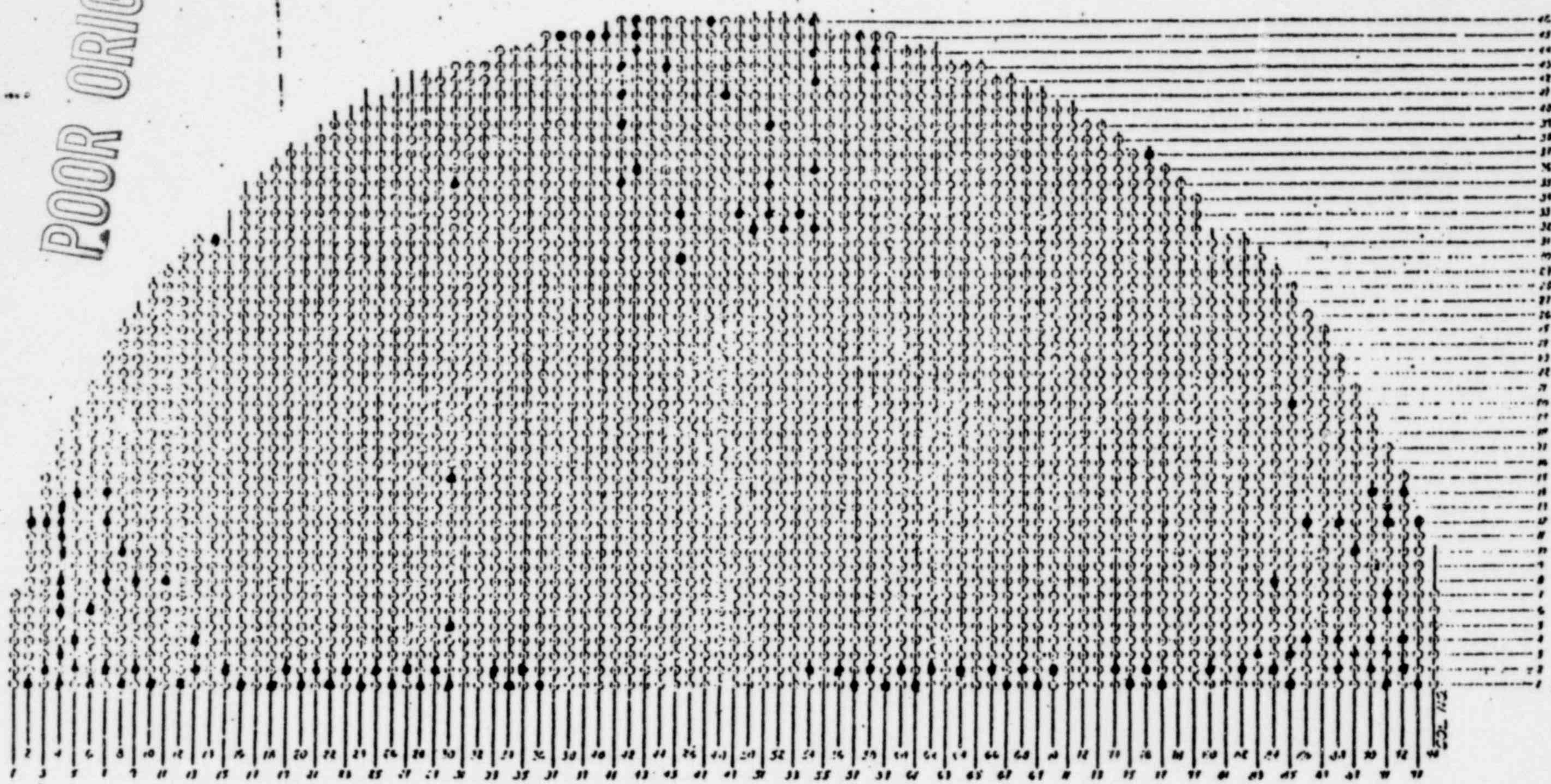
.700

163 tubes

163 1

FIGURE 13

1536 232



1A STEAM GENERATOR

7.5 KHz
Support Plate Corrosion Indications
.700 132 tubes

132 +

POOR ORIGINAL

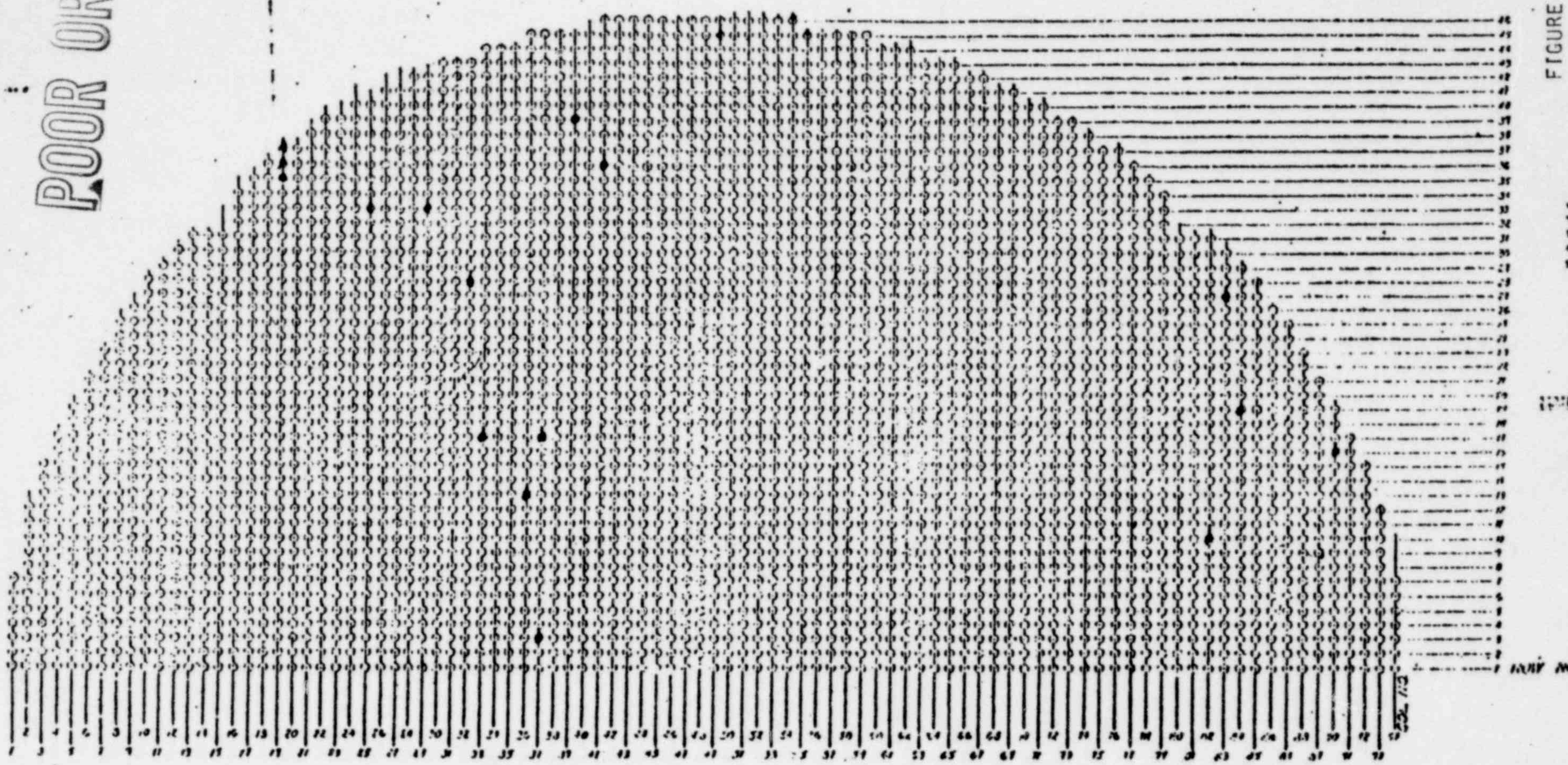


FIGURE 14

1" B" STEAM GENERATOR

HOT LEG 7.5 KHZ.

Support / Plate Corrosion Indications

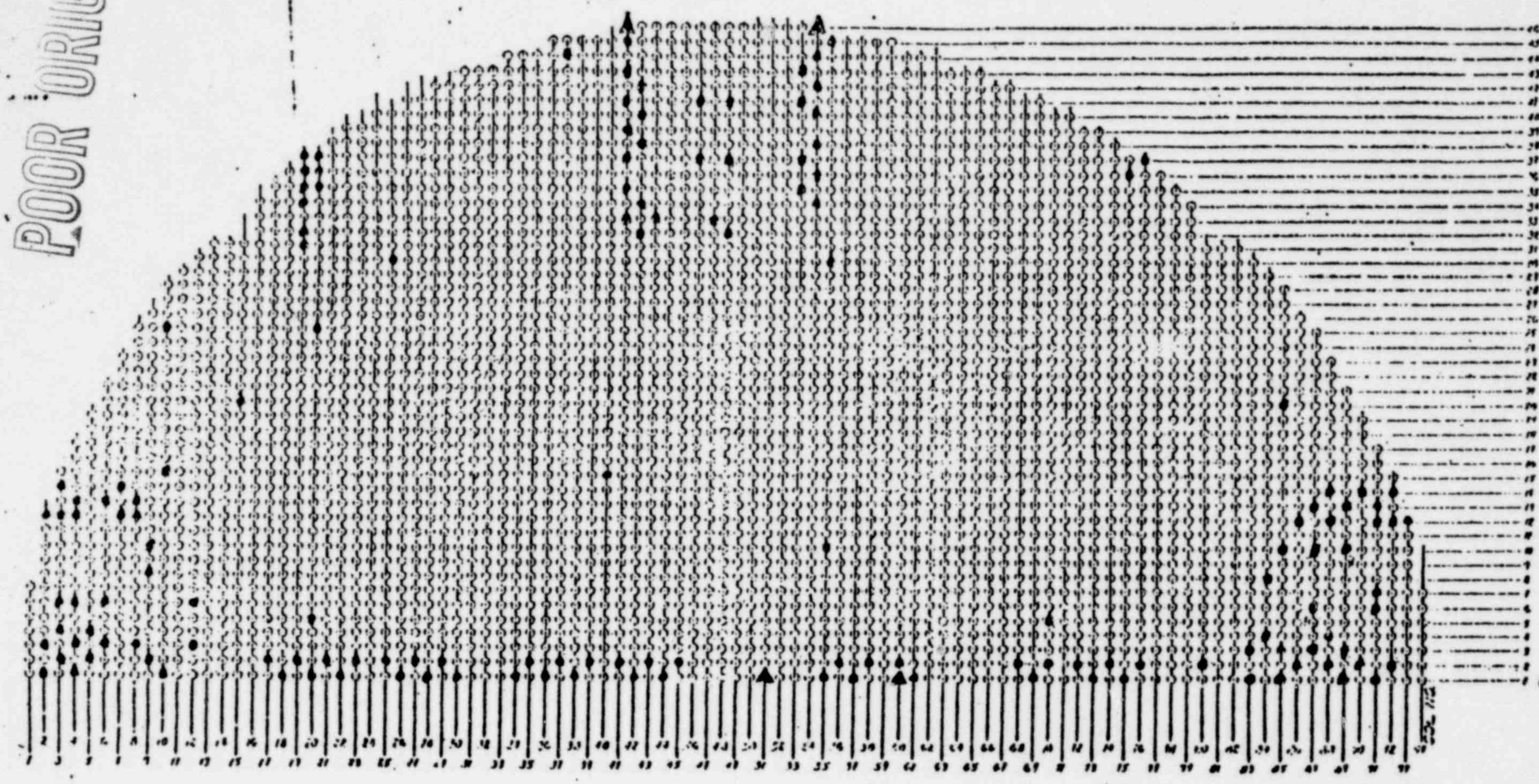
19 tubes

1536 233

POOR ORIGINAL

FIGURE 15

1536 234



1C STEAM GENERATOR

7.5 KHZ   155 tubes

Support Plate Corrosion Indications

155

Appendices

Appendix A - Powdex Resin Discharged into Steam Generators, February 27, 1979 Event

Appendix B - Powdex Resin in Steam Generators - Chemistry Summary

Appendix C - Steam Generator Chemistry Summary

Appendix D - Boric Acid Conditioning Program for Steam Generators

Appendix A

Powdex Resin Discharged Into Steam Generators

On February 27, 1979, while placing a Powdex vessel in the Condensate Polishing System back into service, the filter tubes were ruptured allowing the Powdex resin to be carried to the steam generators. The exact quantity of resin discharged to the steam generators is not known, but is estimated to be 200 to 300 pounds.

The operational events leading to the discharge hinge on the timing of fill and pressurize operations on a single Powdex vessel during return to service following installation of a new resin charge. Normally, after the filter elements are coated with resin, the vessel is slowly filled and pressurized to establish flow through the filter elements. The operating pressure differential across the filter elements is established as the discharge-side pressure follows the inlet-side pressure up to operating pressure. Thus, when the main condensate inlet line is opened, admitting condensate at operating pressure ($\sim$ 400 psig), a controlled ΔP across the filter elements has already been established.

During this event, however, the condensate inlet line opened before the vessel had been completely filled and an operating ΔP and had been established across the filter elements. This surge of higher pressure condensate created an abnormally high ΔP across the filter elements, rupturing the element seals. This permitted condensate to carry the resin off the filter elements and out through the vessel discharge valve.

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APPENDIX B

Powdex Resin in Steam Generators Chemistry Summary

The skeletal structure of an ion exchange bead is formed by the polymerization of styrene with divinyl benzene. In the synthesis of cation-exchange resin, the ionic groups, exchange sites, are introduced by reacting the stynrenated divinyl benzene bead with sulfuric acid. The reaction, sulfonation, takes place at the para position in the styrene component. In the hydrogen or acid form the cation exchange site is sulfonic acid, HSO_3 with the hydrogen ion as the active exchange ion.

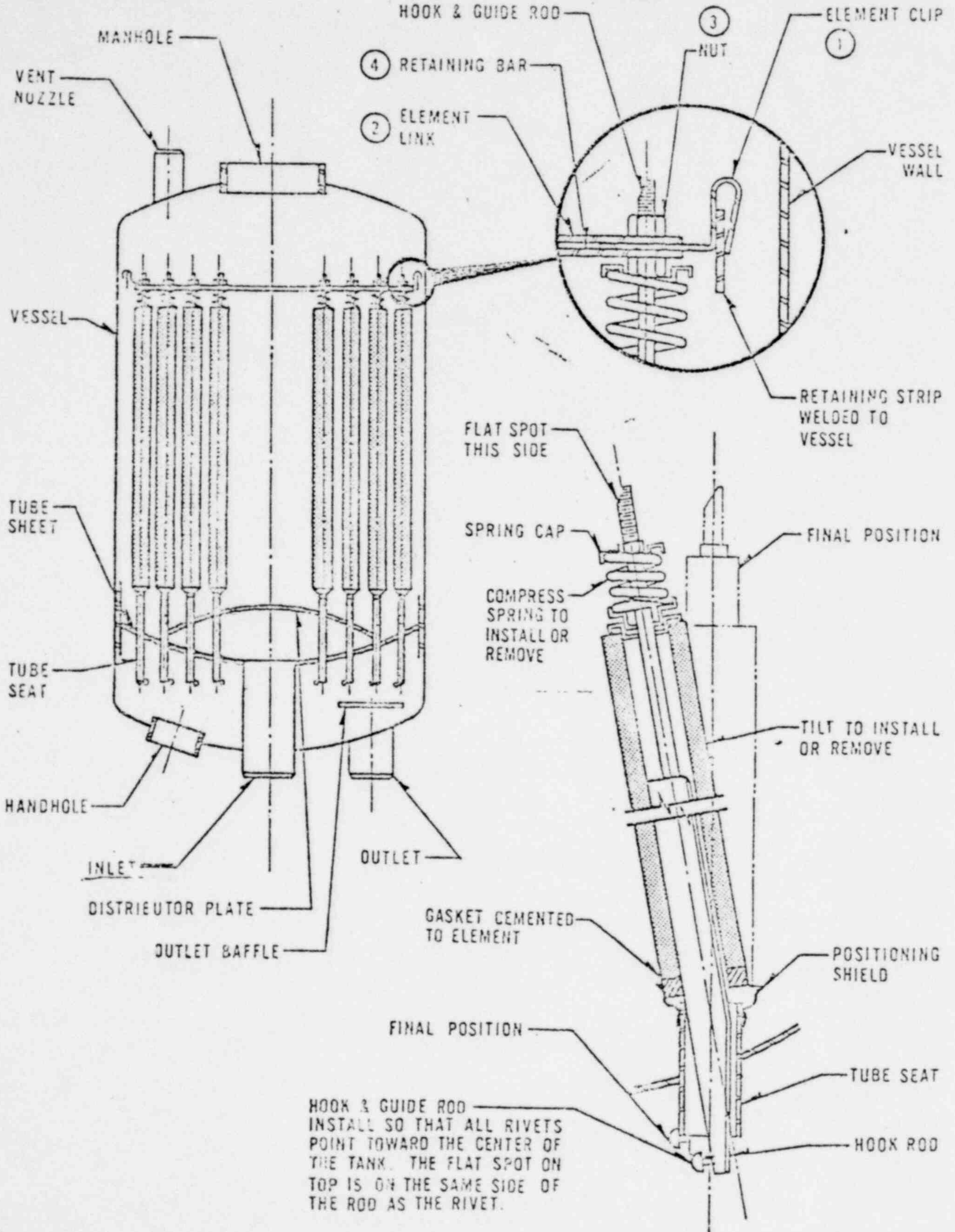
Ion exchange resin has limited thermal stability. Cation resin is the least stable in the hydrogen form. Almost total loss of the sulfonic acid occurs at 180°F (356°F) leading to the formation of sulfurous acid. Sulfuric acid is the product of sulfurous acid plus water.[1]

Ion exchange resin typically contains 1-2 percent chloride present as a containment. This chloride is also available for release to the steam generator bulk water upon thermal decomposition of the resin.

Under sponsorship of the Electric Power Research Institute (EPRI) Combusion Engineering (CE) has been evaluating the effects on steam generator materials of construction produced by introducing ion exchange resin into a test apparatus, isothermal capsules, containing oxides of copper and iron and operated at temperatures equivalent to steam generator operating conditions.[2] Findings to date reveal that the oxide formed on the carbon steel is similar in structure to oxides formed in dent producing acid chloride media in that the oxide possesses distinct laminations. CE has deduced that this oxide is non-protective in nature.

[1] Hall, Klaschka and et al, Thermal Stability of Ion Exchange Resins, Ion Exchange In the Process Industries Symposium, Society of Chemical Industry, London, July, 1969.

[2] Baldwin M.H. et al of CE, Alternate Steam Generator Materials and Designs, EPRI Contract RP-623-4, June, 1979.



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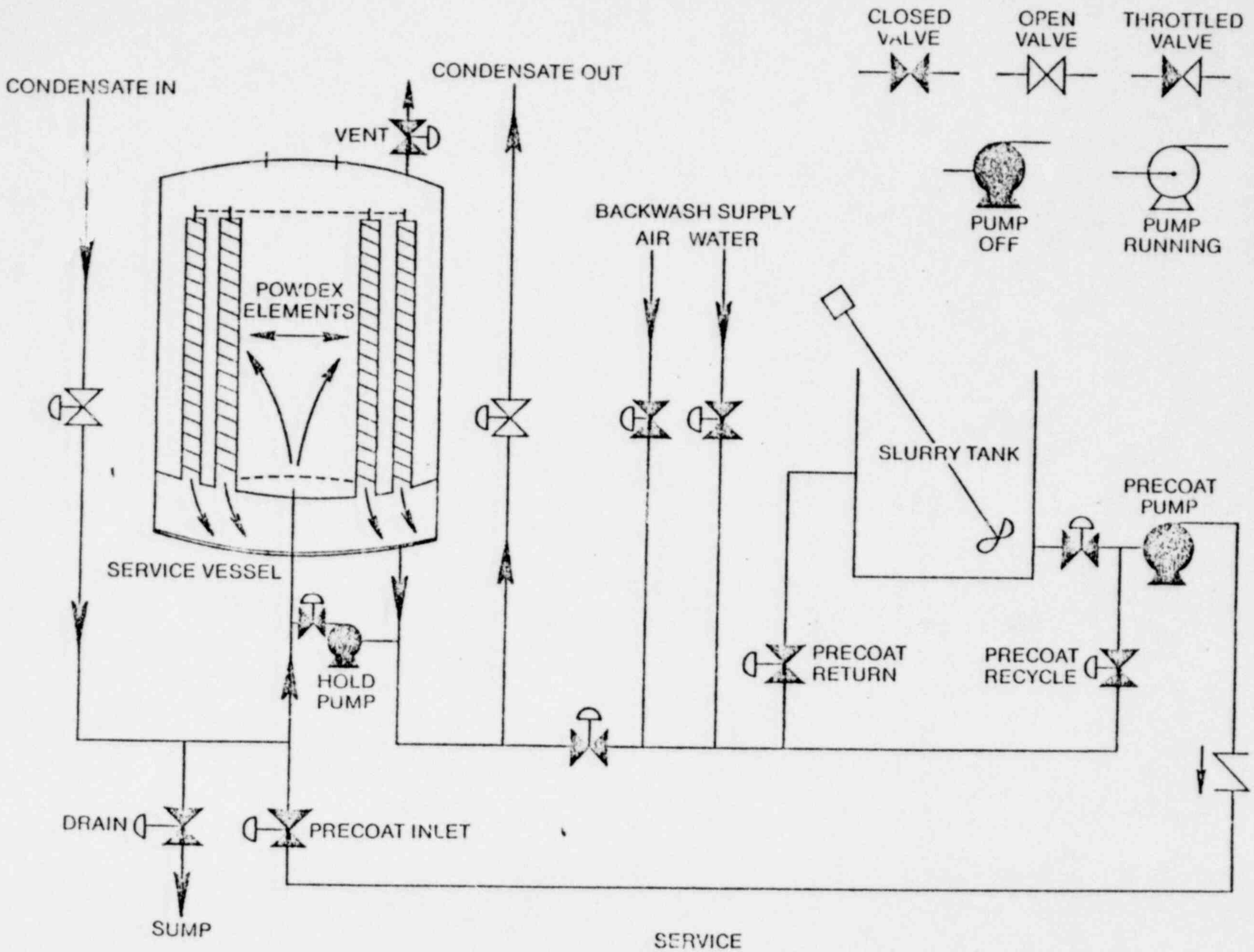
POWDEX® INTERNAL ASSEMBLY



ONE VESSEL OF MULTIPLE VESSEL POWDEX SYSTEM

1536 239

APPENDIX C

Steam Generator Chemistry Summary

A review of plant chemistry data logs was performed to investigate the cause of the steam generator corrosion. The discharge of Powdex resin into the steam generator on February 27, 1979, caused chemistry parameter excursions as shown in the table below:

Steam Generator Chemistry Parameters
Before and After Resin Discharge Event

	Baseline	Immediate Effect
pH @ 25°C	8.8-9.0	6.02
Cation Conductivity,	< 0.4 umhos	25 umhos
Chloride	< 0.05 ppm	< 0.05 ppm (unchanged)
Sodium	< 0.04 ppm	0.1 ppm
Silica	< 0.1 ppm	0.33 ppm
Ammonia	< 0.2 ppm	0.59 ppm

The long term effects of the resin discharge on steam generator chemistry were as follows:

1. Cation conductivity returned to less than 2 umhos on March 7, 1979. This is the first time since the discharge on February 27, 1979, that this parameter was within recommended limits.

2. Load reductions and shutdowns have caused cation conductivity excursions to as high as 40 umhos (5-2-79).

3. Steam generator chemistry approached baseline values toward the end of May, 1979.

The major findings of a Westinghouse review of plant chemistry data logs are as follows:

1. Reported anions, cations, and cation conductivities are not in balance.

2. Sodium concentration consistently exceeds that required for chloride stoichiometry.

3. Cation excursions <u>not</u> due to chlorides.

4. A large anion inventory exists in the steam generators and evidence indicates that this is due to sulphates.

5. Numerous events of silica passing through the Powdex system due to resin saturation have occurred. Silica in condensate results from condenser in-leakage.

Procedure for Boric Acid Conditioning of Steam Generators and Boric Acid Effect on Chemistry Parameters and Operating Guidelines

1.0 PURPOSE

To condition the North Anna Unit 1 steam generators with boric acid during startup and subsequent plant operation.

2.0 OBJECTIVES

To inhibit the corrosion process responsible for the steam generator tube denting. Measurements of the hydrogen produced in situ will be the criteria for determining the effectiveness of the steam generator boric acid conditioning.

3.0 GENERAL CONSIDERATIONS OF STEAM GENERATOR BORIC ACID CONDITIONING

3.1 No radioactive material will be injected to the secondary side during any phase of this test.

3.2 Sampling will be conducted by using secondary system sampling points and local sampling points for liquid samples.

3.3 The operation and safety of the plant should not be affected by sampling activities described in 3.2 and 5.0.

3.4 Chemical additions to the steam generators will be made using the existing steam generator wet layup chemical addition system.

3.5 The blowdown concentrations of boron during the test will be comparable to those that have been experienced during periods of primary-to-secondary leakage.

4.0 PROCEDURE

4.1 Test Conditions

4.1.1 Steam generators should be drained and then refilled from the condensate storage tank (CST). Add sufficient boric acid to maintain a concentration of 50 ppm boron.

4.1.2 Maintain a low power (25%) boric acid soak (50 ppm as boron) for a period of at least 4 days, followed by continuous addition of boric acid (5 - 10 ppm as boron) to the steam generators during power escalation and 100% power.

4.1.3 Hydrogen monitoring should continue during the low power soak.

4.1.4 Establish a new corrosion hydrogen baseline after returning to 100% power to determine the effectiveness of the low power boric acid soak.

4.1.5 All chemistry and operating parameters must be closely monitored during each conditioning phase. The secondary side chemistry is to be within the specified guidelines.

4.1.6 All chemical additions should be continuous and at a constant rate.

4.1.7 During the low power soak treatment, blowdown should be secured except when sampling or when blowdown is needed to control chemistry.

4.1.8 The chemical and volume control tank should be maintained at a nearly constant pressure (±3 psi).

4.2 Test Preparations

4.2.1 Scavenging of Oxygen from Condensate Storage Tank (CST)

4.2.1.1 Add 35% hydrazine to the CST, promote mixing when possible, until a concentration of 2 ppm hydrazine is obtained in CST.

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4.2.1.2 Allow at least 24 hours for oxygen scavenging.

4.2.2 Preparation for the Injection of Boric Acid

4.2.2.1 Prepare a boric acid solution in the chemical addition tank using approximately 80 pounds of boric acid to approximately 200 gallons of condensate makeup.

4.2.2.2 Analyze final tank solution for boron and record result (approximately 8000 ppm); record volume of additive contained in tank.

4.2.2.3 Adjust steam generator blowdown to a nominal yet sufficient rate (not less than 5 gpm for a minimum of 1 hour) prior to sampling. Flush sample line, at a rate of not less than 500 ml/minute, prior to sampling according to schedule below (ASTM Procedure D3370, 1975).

Pipe Size (inside diameter), in.	Purging Period Per Foot of Line, sec.
1/8	5
1/4	10
3/8	15
1/2	25
3/4	40
1	60

4.2.2.4 Align the chemical addition system (auxiliary feed) to inject the boric acid solution to the steam generators.

4.2.3 Preparation for Boron Accountability Program

4.2.3.1 Boron analyses should be performed on condensate, feedwater, blowdown, main steam and heater drain samples, verifying boron concentration levels in the secondary plant prior to low power boric acid conditioning.

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4.2.3.2 Certify the sample points included in the boron accountability program (Section 4.2.3.1 and 5.0). If necessary, additional sample points may be included as directed by the lead engineer.

4.2.4 Assemble hydrogen measurement apparatus (Kent-C idge Mark IV Hydrogen Analyzer) as described in Section 7.1.

4.3 Test Sequence

4.3.1 Phase I - Draining and Filling of Steam Generators

4.3.1.1 Drain steam generators per operating procedures.

4.3.1.2 Fill steam generators, drawing feedwater from condensate storage tank through auxiliary feed system.

4.3.1.3 Upon initiating the steam generator fill, the oxygen concentration in the auxiliary feed inlet should be determined. If greater than 500 ppb oxygen is detected, additional hydrazine should be added to condensate storage tank.

4.3.1.4 Add hydrazine into the auxiliary feed pump suction continuously to provide a minimum residual in the initial fill of 2 ppm.

4.3.1.5 Boric acid addition should be started upon initiation of the steam generator fill. A 50 ppm boron solution will require an addition rate of about 185 gph of a 4% boric acid solution assuming the use of the motor driven auxiliary feed pump. A fill time of about 45 minutes per generator would be required based on the capacity of the motor driven auxiliary feed pump.

4.3.2 Phase II - Heatup (Prior to Hot Standby)

4.3.2.1 Heatup to 180°F for reactor coolant system chemistry hold of 8 hours; confirm boron concentration and adjust it using layup chemistry addition system.

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4.3.2.2 Heat up to approximately 400°F, hold to draw a pressurizer bubble.

4.3.2.3 Steam generator blowdown should continue at the maximum permissible rate during any transient period, as determined by plant conditions.

4.3.2.4 Frequent analyses should be performed to identify the occurrence of any chemical return phenomena. If chemical return is detected, heatup should be suspended until cleanup is effected.

4.3.2.5 Makeup water to the steam generators during this period should be identical to that used in the initial fill, i.e., 50 ppm boron and 2 ppm hydrazine in steam generator.

4.3.2.6 Adjust boron addition rate as required to maintain approximately 50 ppm in the steam generator blowdown.

4.3.2.7 As heatup progresses, hydrazine thermal decomposition will result in the production of ammonia. The 2 ppm excess hydrazine is expected to produce as much as 1.1 ppm ammonia. This will be reduced to some extent by blowdown.

4.3.3 <u>Phase III - Heatup (Hot Standby)</u>

4.3.3.1 Continue heatup until hot standby (547°F) condition is reached.

4.3.3.2 Continue hydrazine addition to condensate storage tank per Section 4.2.1.

4.3.3.3 Maintain 100 ppm hydrazine residual in steam generator blowdown. To achieve this level an auxiliary feed hydrazine concentration of about 1.25 ppm will be required. This is expected to result in an ammonia content in the steam of about 0.7 ppm. The corresponding steam generator ammonia concentration will be about 0.4 ppm, or somewhat higher than the recommended range for normal operation.

4.3.3.4 Maintain a boron concentration of 50 ppm in steam generator blowdown. This can be accomplished by addition either to the auxiliary feedwater pump suction or through the layup chemistry addition system.
Note: Some difficulty in accurate control is anticipated. While feedwater additions to all four generators can be expected to be equal over the long term, large variations are possible at any given moment.

4.3.3.5 Perform zero power physics testing as required.

4.3.3.6 During this period, steam dump will normally be to atmosphere and this is recommended to avoid potential ammonia attack of the condenser. The steam will contain about 0.7 ppm ammonia, 5 ppm boron and less than 50 ppb hydrazine. Thus, assuming a typical 4-day hold at hot standby, a total discharge of about 7.5 pounds of ammonia and about 50 pounds of boron (300 pounds of boric acid) is anticipated.

4.3.3.7 If necessary, blowdown at maximum rate until chlorides are less than detectable.

4.3.4 <u>Phase IV - Power Escalation</u>

4.3.4.1 Initiation of power operation in the unit can proceed at any point according to normal procedures.

4.3.4.2 Draw condenser vacuum and initiate steam dump to condenser per normal procedure. The expected ammonia content of the steam (0.7 ppm) exceeds the recommended level for normal operation; it does not exceed levels which have been commonly experienced in the past.

4.3.4.3 Establish 10 - 20 ppb minimum hydrazine residual in feedwater using normal addition system to ensure oxygen control.
Note: If pH requirements are not met (>8.0 in feedwater), the addition of ammonium hydroxide may be necessary.

4.3.4.4 Boron concentrations should be maintained at 50 ppm by using the layup chemistry addition system. Major boric acid additions can be made to the condensate pump suction if the boron concentration drops below 30 ppm. Approximately 175 gallons of 4% boric acid solution (10 pounds boron) will be required to effect a 20 ppm increase in concentration.

4.3.4.5 With the moisture separator reheater out of service, escalate power to approximately 30% and, if not previously done, put in automatic feedwater control system.

4.3.5 Phase V - Low Power (25%) Hold

4.3.5.1 Reduce power to 25% and leave in automatic feedwater control system.

4.3.5.2 Commence monitoring corrosion hydrogen.

4.3.5.3 Boron distribution and accountability in the secondary plant (sample points are given in Sections 4.2.3 and 5.0) should be determined.

4.3.5.4 Maintain 10 - 20 ppb minimum hydrazihe residual in feedwater using normal addition system.

4.3.5.5 The steam generator blowdown boron concentration will be maintained within 45 ± 5 ppm by adjusting the feedwater inlet addition to the steam generator.

4.3.5.6 Maintain these conditions for a minimum of 96 hours, monitoring the chemical and operating parameters throughout.

4.3.5.7 Establish the steam generator boron demand (hideout) after 48 hours into the soak as outlined in the following steps:

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1. Determine boron concentration in the steam generator blowdown. Then, secure steam generator boron addition and blowdown.
2. After a minimum of 6 additional hours (54 hours cumulative), determine boron concentration in the steam generator blowdown. (Prior to sampling, blowdown should be flushed according to Section 4.2.2.3)
3. If $\frac{\text{boron @ t = 6}}{\text{boron @ t = 0}}$ is greater than 90%, demand is satisfied.

   Where, t = 6 is 6 hours after securing addition, and
   t = 0 is time of securing addition.
4. Resume addition required to maintain 45 - 50 ppm boron.
5. After 30 additional hours (84 cumulative hours into soak), repeat Steps 1 thru 3. If boron accountability is greater than 90%, resume addition for 6 more hours to complete treatment. However, if boron accountability is less than 90%, proceed to Step 6.
6. Resume boron addition until demand is satisfied (greater than 90% accountability), repeating Steps 1 thru 3 as determined by lead engineer.

4.3.5.8 Monitor the volume of additive in the chemical addition tank to determine the boric acid addition rate. Repeat Sections 4.2.2.1 and 4.2.2.2 as required to prevent tank from going dry.

4.3.6 Phase VI - Boric Acid Continuous Addition at 100% Power

4.3.6.1 At the conclusion of the low power soak, terminate boric acid addition.

4.3.6.2 Allow the steam generator blowdown boron concentration to decrease to 5 - 10 ppm, then increase power to 100%.

4.3.6.3 Resume boric acid addition, adjusting the boric acid feed rate as required to maintain the 5 - 10 ppm boron concentration.

4.3.6.4 Maintain these conditions monitoring chemical and operating parameters throughout.

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4.3.6.5 Monitor the volume of additive in the chemical addition tank to determine the boric acid addition rate. Replenish the tank as required and as defined in Sections 4.2.2.1 and 4.2.2.2.

4.3.6.6 Establish the corrosion hydrogen generation rate after confirming that all chemical parameters are stabilized.

5.0 SAMPLING

5.1 Sampling of secondary system water and condensed steam will be from the (1) condensate pump discharge, (2) main feedwater, (3) steam generator blowdown, and (4) main steam sample points.

5.2 Reactor coolant sampling will be performed at the normal reactor coolant sample point.

5.3 The main steam and feedwater sample points must be flushed prior to sampling as determined by lead engineer.

6.0 ANALYSES

6.1 Secondary Side Liquid Samples

6.1.1 All samples identified in Section 5.0 are to be analyzed for hydrazine and boron. Dissolved oxygen, pH, and ammonia will be measured in the condensate, feedwater, and blowdown samples.

6.1.2 Hydrogen analyses will be performed on the main steam and feedwater samples using Kent-Cambridge Mark IV Hydrogen Analyzers in accordance with the instrument instruction manual.

6.2 Reactor Coolant Samples

6.2.1 Reactor coolant samples will be analyzed for hydrogen content using the standard site analysis procedure and apparatus.

7.0 ANALYSIS SCHEDULE

7.1 Kent-Cambridge Dissolved Hydrogen Analyzer

7.1.1 Kent-Cambridge Analyzers will be connected to the main steam sample points.

7.1.2 One Kent-Cambridge Analyzer will be connected to the feedwater sample point.

7.1.3 Recorders will be connected to the Kent-Cambridge Analyzers to provide continuous monitoring of dissolved hydrogen.

7.1.4 Adjust total flow (approximately 550 cc/min bypassing sampling cup) to 800 cc/min ± 30 cc/min while maintaining active sample flow at 250 cc/min ± 15 cc/min.

7.1.5 Sample temperature is to be maintained at 85°F ± 15°F.

7.1.6 Electrical zero is to be checked for drift once each day.

7.1.7 Each instrument is to be calibrated according to operating instructions at least once each week.

7.2 On-Site Secondary Side Liquid Analyses

7.2.1 Hydrazine analyses are to be performed twice daily for all samples identified in Section 5.1.

7.2.2 Dissolved oxygen, ammonia, and pH analyses are to be performed daily on condensate, feedwater, and blowdown samples.

7.2.3 Boron analyses are to be performed at least 3 times per day on all samples outlined in Sections 4.2.3 and 5.0.

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7.3 Primary Side Hydrogen Analyses

7.3.1 Reactor coolant hydrogen analyses are to be performed in accordance with the site sampling schedule.

8.0 RECORDING OF DATA

8.1 All analytical data and results will be recorded in a permanent Westinghouse Engineering Workbook.

8.2 Plant data required during the test period include the following at least once each day; where unavailable, conditions will be estimated from heat balance drawings.

1. Unit power level.
2. Feedwater flowrate.
3. Main steam flowrate, temperature and pressure.
4. Steam generator blowdown rate.
5. Net amount of boric acid feed as established from feed tank makeup and the feed rates.
6. Routine secondary system chemistry data generated during testing.
7. Latest condenser leak rate measurement.
8. Reactor coolant flowrate, pressure and temperature (T_{ave}, T_H or T_C).
9. Volume control tank pressure.

9.0 DATA EVALUATION

The data will be evaluated to establish effects of boric acid on the steam generator net corrosion hydrogen generation rate and concentrations in other secondary system components.

10.0 REPORTING TEST RESULTS

A Westinghouse report will be issued to North Anna Unit 1.

11.0 MANPOWER AND FACILITIES REQUIREMENTS

11.1 Westinghouse engineering and chemistry technician personnel from the Chemistry Operations Group will participate in this program. The engineer will assume lead responsibility and will provide overall program direction. The Westinghouse chemistry technicians will perform the hydrogen and hydrazine analyses specified in Sections 5.0, 6.0 and 7.0. Additional analyses will be performed as required.

11.2 If needed, and as available, Westinghouse will provide the Kent-Cambridge Mark IV Hydrogen Analyzers. Westinghouse equipment will require access to electrical supply (110 V).

11.3 The customer will provide the technician manpower and laboratory facilities required for on-site analyses identified in Sections 7.2.2 and 7.2.3 (blowdown boron analyses only).

11.4 Westinghouse will perform any off-site analyses deemed necessary to fulfill the test objectives.

12.0 IMPLEMENTATION OF PROGRAM

The Westinghouse lead engineer will coordinate on-site testing activities with the cognizant customer representative(s) at the site and may modify the sampling and/or analyses as required to fulfill the test objectives.

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TABLE 1

Revised Secondary System Chemistry AVT Operating Guidelines

	Without Boric Acid	With Boric Acid
Condensate[1]		
Oxygen, ppb	<10	<10
Feedwater		
pH, @ 25°C	8.8 - 9.2	>8.0
Conductivity, μmhos	1.8 - 5.0	≤5
Oxygen, ppb	<5	<5
Hydrazine, ppb	$[O_2]$ + ≥10	$[O_2]$ + ≥10
Ammonia, ppm	≤0.5	≤0.5

Steam Generator AVT Chemistry Guidelines

	In the Absence of Locatable Condenser Leakage		In the Presence of Locatable Condenser Leakage	
Parameter	Without Boric Acid	With Boric Acid	Without Boric Acid[2]	With Boric Acid[2]
pH @ 25°C	>8.5	>7.0	>8.5	>7.0
Cation Conductivity μmhos/cm @ 25°C	<2.0	<2.0	2.0	2.0
Boron, ppm	N/A	5 - 10	N/A	5 - 10
Sodium, ppm	<0.04	<0.04	0.1	0.1
Chloride, ppm	<0.05	<0.05	0.15	0.15
Oxygen, ppb	<5	<5	<5	<5
Hydrazine, ppb	$[O_2]$ + ≥20	$[O_2]$ + ≥20	$[O_2]$ + ≥20	$[O_2]$ + ≥20
Ammonia, ppm	>0.06	>0.06	>0.06	>0.06
Silica, ppm	<0.05	<0.05	0.05	0.05
Blowdown, gpm	Continuous[3]	Continuous[3]	Continuous[4]	Continuous[4]

[1] Continuous overboard at air ejector drains.

[2] Continued operation with locatable contaminant ingress is not recommended.

[3] Operate at the minimum continuous blowdown rate required to maintain continuous monitoring capability, approximately 5 gpm/SG.

[4] Blowdown continuously at a rate required to maintain chemistry parameters.

TABLE 2

Steam Side Laboratory Analysis Frequency

Analysis[1]	Mon.	Tues.	Wed.	Thurs.	Fri.	Sat.	Sun.
Steam Generator Blowdown							
pH	X	X	X	X	X	X	X
Cation Cond.	X	X	X	X	X	X	X
Boron	X	X	X	X	X	X	X
Sodium	X	X	X	X	X	X	X
Chloride	X	X	X	X	X		
Suspended Solids			X				
Silica	X	X	X	X	X		
Ammonia	X	X	X	X	X	X	X
Hydrazine	X	X	X	X	X	X	X
Oxygen	X	X	X	X	X	X	X
Feedwater							
pH	X	X	X	X	X	X	X
Conductivity	X	X	X	X	X	X	X
Amine	X	X	X	X	X		
Ammonia	X	X	X	X	X		
Hydrazine	X	X	X	X	X	X	X
Fe/Cu	X		X		X		
Oxygen	X	X	X	X	X	X	X
Condensate and Main Steam							
pH	X	X	X	X	X	X	X
Cation Cond.	X	X	X	X	X	X	X
Sodium	X	X	X	X	X	X	X
Ammonia	X		X		X		

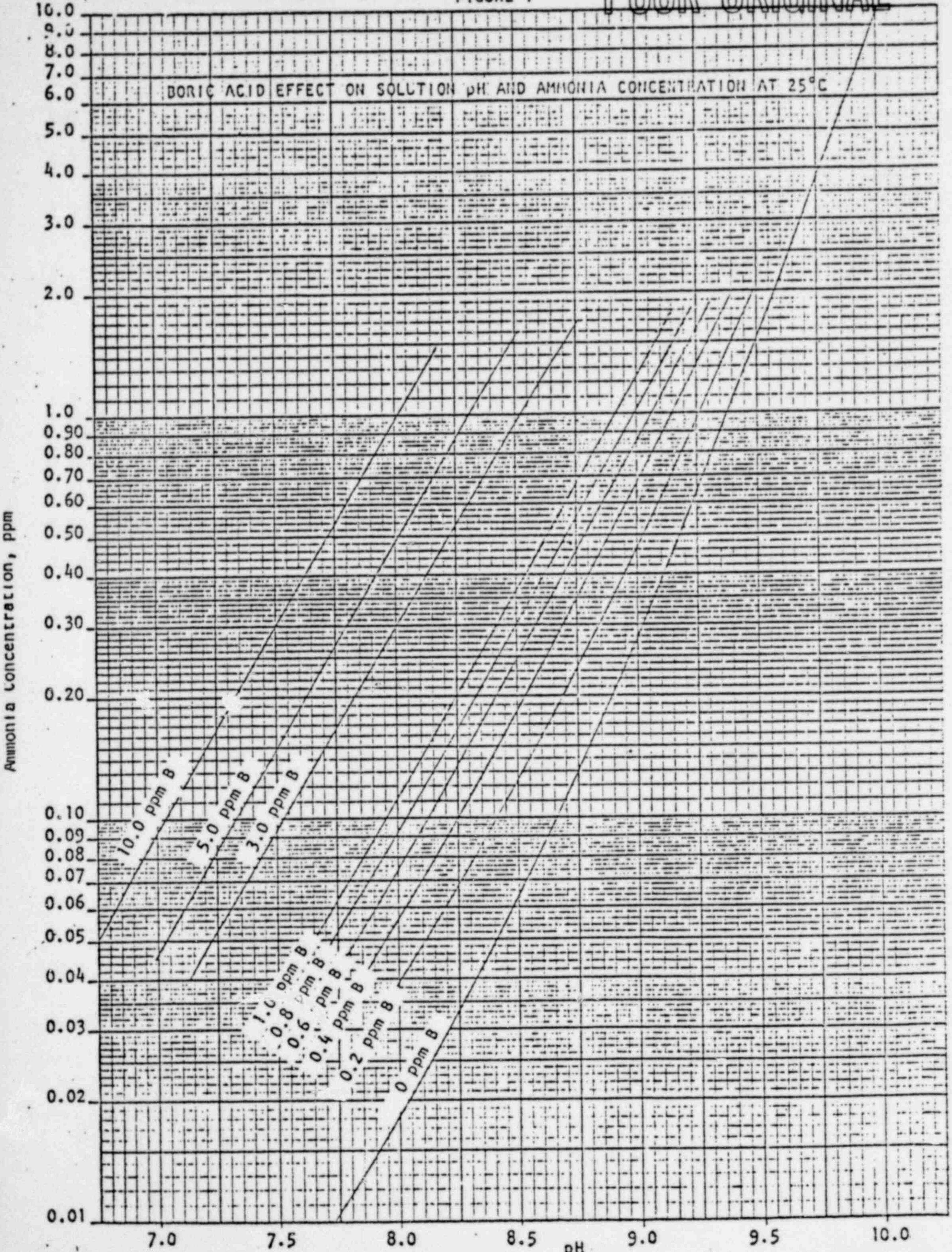
[1]Analytical methods are presented in WCAP-7333, "Chemical Analysis Procedures for Westinghouse Pressurized Water Reactors."

TABLE 3

BORIC ACID EFFECT ON SOLUTION pH AND AMMONIA CONCENTRATION AT 25°C

ppm B	ppm Ammonia 0	0.05	0.10	0.25	0.50	1.0
0	7.00	8.40	8.65	8.97	9.18	9.38
0.1	6.90	8.24	8.52	8.86	9.10	9.32
0.2	6.84	8.12	8.41	8.77	9.02	9.26
0.3	6.79	8.03	8.32	8.69	8.96	9.21
0.4	6.75	7.95	8.24	8.62	8.90	9.15
0.5	6.72	7.89	8.18	8.56	8.84	9.11
0.6	6.69	7.83	8.12	8.51	8.79	9.07
0.7	6.66	7.78	8.07	8.46	8.75	9.03
0.8	6.64	7.73	8.03	8.42	8.71	8.99
0.9	6.62	7.69	7.99	8.38	8.67	8.95
1.0	6.62	7.65	7.95	8.34	8.63	8.92
3.0	6.38	7.23	7.53	7.92	8.22	8.52
5.0	6.28	7.03	7.32	7.71	8.01	8.31
6.0	6.24	6.96	7.24	7.63	7.93	8.23
7.0	6.21	6.90	7.18	7.57	7.87	8.17
8.0	6.18	6.84	7.12	7.51	7.81	8.11
9.0	6.15	6.80	7.07	7.46	7.76	8.06
10.0	6.13	6.75	7.03	7.42	7.72	8.01
15.0	6.04	6.59	6.86	7.24	7.54	7.84
20.0	5.98	6.48	6.74	--	7.42	7.72
25.0	5.93	6.39	6.65	7.02	7.32	7.62
30.0	5.89	6.32	6.57	6.95	7.24	7.54
35.0	5.86	6.26	6.51	6.89	7.18	7.47
40.0	5.83	6.21	6.45	6.83	7.12	7.42
45.0	5.81	6.17	6.41	6.78	7.07	7.36
50.0	5.78	6.13	6.36	6.73	7.02	7.32
75.0	5.69	5.99	6.20	6.56	6.85	7.14
100.0	5.63	5.88	6.08	6.43	6.72	7.01

FIGURE 1


BORIC ACID EFFECT ON SOLUTION pH AND AMMONIA CONCENTRATION AT 25°C
Ammonia Concentration, ppm
10.0
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
10.0 ppm B
5.0 ppm B
3.0 ppm B
1.0 ppm B
0.8 ppm B
0.6 ppm B
0.4 ppm B
0.2 ppm B
0 ppm B
7.0
7.5
8.0
8.5
9.0
9.5
10.0
pH