DESCRIPTION OF PRESENT STATUS OF STEAM GENERATORS

ROCHESTER GAS AND ELECTRIC CORPORATION

R. E. GINNA NUCLEAR POWER PLANT UNIT NO. 1

DOCKET NO. 50-244

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A. SUMMARY

During the January 1974 shutdown, localized deterioration of a significant number of tubes were found in the "A" steam generator hot leg side. The deterioration was a corrosion type attack of the tube wall O. D. just above the tube sheet. Using both an analytical and an experimental program, the allowable limits for localized wall reduction of Inconel 600 tubing has been established by the Westinghouse Electric Corporation. Production tubing was tested with simulated defects similar to, or more severe than that observed in plant tubing, to define the relationship of strength to the configuration of the defect. Various factors were considered in the analysis including the properties of the tubing and the combined loadings occurring during accident conditions. It was concluded that a tube with a localized minimum wall thickness of 25% of the original wall (75% reduction) in the straight portions of the U tube was sufficient to withstand the worst combination of loading conditions for a main steam break or a LOCA. To provide additional margin a criteria has been established to plug all tubes with eddy current indications of 50% or greater wall penetration. The margin between the allowable wall penetration of 75% and 50% indicated penetration from the eddy current inspection provides margin for the extrapolated corrosion rate.

The Ginna plant will be shut down after approximately six months operation to confirm that the corrosion attack has been arrested. At that time a selected number of steam generator tubes will be reexamined by eddy current testing. However, if by that time there is conclusive evidence from

other facilities and tests that such an examination would be unnecessary, relief from this commitment will be requested.

B. STEAM GENERATOR INSPECTION

1. Eddy Current Inspection

The initial eddy current (EC) test program for both steam generators (S.G.) consisted of inspection of 1098 hot leg side tubes and 516 cold leg side tubes. The inspection pattern is shown graphically in Figures 1 and 2. This pattern was established to give a comprehensive inspection of those areas of the generator where from past experience defects might be expected and to avoid unnecessary deliberate radiation exposure to personnel. The results of the EC tests indicated that a significant number of tubes having localized deterioration exist in "A" S.G. hot leg. Based on the experience of other facilities and on the pattern of deteriorated tubes, a larger area of inspection was selected. It was expected that this expanded program would examine all the deteriorated tubes in the "A" S.G. hot leg. At the conclusion of the expanded program, the decision was made to examine all the tubes. No deteriorated tubes were found during this phase of the examination program. The results of the EC inspection are given on Table 1 and the location of the defects are illustrated on Figures 3 through 6. The scope of the EC examination in "A" S.G. cold leg and "B" S.G. hot leg and cold leg was not increased because:

a. The number of tubes showing defects was very few compared to the amount found in "A" S.G. hot leg.

b. The percent deterioration was very much less than observed in "A" S.G. hot leg. All deterioration was less than 20% except for 5 tubes with deterioration between 20% and 26%.

c. The EC inspection pattern gives a comprehensive inspection of those areas of the generator where defects might be expected.

d. Defects are randomly located - large numbers of adjacent tubes with defects did not appear.

e. "B" S.G. cold leg showed no tube deterioration.

In summary, a total of 5390 tubes were inspected with EC techniques in the two steam generators and 629 tubes were found to have deterioration of which 17 tubes have deteriorations of 50% or greater. The maximum deterioration found had an EC indication of a 64% penetration. All EC indications, except one, were located from 1/2 to 6 inches above the tube sheet. That one indication was at 8 inches above the tube sheet.

2. Tube Removal

Two tubes were removed from the "A" steam generator. The tubes were examined at the site by Rochester Gas and Electric Corporation and by the Westinghouse Electric Corporation in Pittsburgh.

The examination confirmed that local wall thinning on the O. D. surface had occurred at the locations where EC indications were present. The observed corrosion of the tube with the 64% indication is over a length of approximately 1-1/2 inches in an arc of approximately 180° around the circumference of the tube's O. D. surface. The reduction in the wall occurs gradually over this area with a maximum penetration at one small area and then tapers to full tube wall thickness. While the EC indication of this tube was 64% wall penetration, a physical examination of this tube shows a maximum tube wall penetration of approximately 44%.

C. CAUSE OF STEAM GENERATOR TUBE DETERIORATION AND CORRECTIVE ACTION

Detailed examination of the tube samples removed from the Ginna steam generator revealed a local wall thinning caused by local corrosion of the tube's O. D. surface. It is believed that the corrosion has taken place beneath the sludge surface where both a concentration mechanism and aggressive species are believed to be present. The exact nature of the aggressive species is not known; however, it is believed that this species resulted from prolonged operation with a molar ratio of Na to PO_4 of 2.2 or less. Until recently, the emphasis has been to maintain the molar ratio below 2.6 to prevent caustic induced cracking; being below the molar ratio of 2.3 was not prohibited. It is now believed that

when below a molar ratio of 2.2 an acid could be formed and corrosion result from this. After removal of the sludge from the tube sheet by water lancing, the plant will be operated with a molar ratio of Na to PO_4 between 2.3 and 2.6. It is our belief and that of our supplier, the Westinghouse Electric Corporation, that this will arrest the localized corrosion to the tubes.

D. MECHANICAL TEST PROGRAM

In order to determine a tube plugging criteria, the minimum wall thickness necessary to withstand the worst combination of loading conditions for a main steam line break or LOCA must be determined. This was done by Westinghouse Electric Corporation through a combination of an experimental and analytical programs.

To determine the affect of localized corrosion on the strength of tubes a comprehensive series of mechanical burst tests have been performed on straight sections of 7/8 inch diameter Inconel 600 tubing. The tubing was standard production grade Inconel material which was obtained from Westinghouse Specialty Metals Division. In this series of tests a flat was machined on the tube samples to simulate the affect of broad thinning of the tube. These flats (defects) were of varying lengths, i.e., approximately 1/2, 1, 1-1/2, 2, and 9 inches long, to permit a determination of burst strength as a function of defect length.

The tests on the 7/8 inch tubing (0.867 inch x 0.048 inch wall) were performed at room temperature and with approximately 12 or 25 mils of wall remaining. These remaining wall thicknesses correspond to approximately 25% and 55% of the original no-defect wall thickness. The results of this series of tests are presented in Figure 7 as burst pressure versus reciprocal flaw length. The slope of these curves is essentially the same as those obtained from a similar program where part through wall slots were machined in the tubing. The results of this series of tests on 7/8 inch tubing were as expected, and they tend to confirm the results of the previous tests.

It will be noted from this data, that the burst pressures at room temperature are in the range of 4200 to 3700 psi for tubing with 1 to 2 inch long flaws, and with approximately 25% of the original wall remaining. The burst pressure increases to about 6000 psi when the flaws are in the 1/2 inch long range. In comparison for normal tubing the burst pressure is approximately 11,000 psi.

The effect of service temperatures and minimum code allowable properties are also indicated on Figure 7 for 25% wall remaining. It will be noted that the strength of the tube to withstand internal pressure is very substantial even with as little as 25% of the tube wall remaining.

1. Transient Loadings - Main Steam Line Break

The normal operating internal pressure across the tube varies somewhat as a function of power level, in the range of 1200 to 1400 psi.

The large steam line break accident produces a potential condition where the steam side pressure can go to nearly atmospheric conditions when the entire contents of the steam generator are discharged. Coincidental with this condition on the steam side, the reactor pressure will also decrease due to the cooling of the reactor coolant. The pressure differential increases shortly after the break and decreases after the pressurizer empties. In the limit, with atmospheric pressure on the steam side, the reactor pressure would ultimately be limited by the code safety valves on the reactor coolant system to approximately 2500 psi, which is the design pressure of the reactor coolant system. A sequence of events to produce this condition would be extremely difficult to produce in the system. For purposes of this analysis, however, a 2500 psi differential will be assumed as a limiting maximum condition.

Referring to Figure 7, the curve indicated as minimum tube properties at service temperature with 25% wall, it will be noted that with a 2 inch long flaw the tubing will withstand 2500 psi internal pressure. Shorter defect lengths and nominal material properties would increase the allowable pressure loading on the tube.

For this limiting condition it is concluded that the minimum acceptable wall would be equivalent to 25% of the original tube wall based on a two inch long broad area defect, and considering that

the tubing has minimum mechanical properties. A review of material test reports for steam generator tubing has indicated that the tubing is consistently produced with nominal properties providing additional margin for this analysis.

2. Loss of Coolant Accident

WCAP 7832 "Evaluation of Steam Generator Tube, Tube Sheet, and Divider Plate Under Combined LOCA plus SEE Conditions" was recently submitted to the AEC. This analysis considered the possible pressure, hydraulic, and seismic loadings in the tubes and tube bundle during the combined loss of coolant accident and seismic occurrence. The analysis presented in this report was specifically for a 3/4 inch O.D. tube which is being used in later steam generators than the RG&E units and the conclusion was for this condition a uniform minimum wall of .026 inches was required.

The corresponding values for the 7/8 inch diameter tubing used in the RG&E steam generators has been determined to be .021 inches (40% tube wall). The limiting stress condition was determined to occur in the U-bends due to the bending moment imposed by the discharging fluid. It should be noted, however, that the corrosion observed in the RG&E unit is localized and occurs in the straight section at the top of the tube sheet.

Referring to the analysis in this report for various nodal points

in the tube bundle, it should be noted that the bending moments in the region of the tube sheet are so small as to be negligible. At the tube sheet the primary stresses in the tube are caused by the initial pressure differential between primary and secondary sides which is at its highest value at time $t = 0$. This would correspond to the normal differential pressure across the tubes at full load of approximately 1400 psi. Accordingly in this region where the corrosion has actually occurred the results provided in Figure 7 could similarly be applied and the 25% wall thickness is fully sufficient.

As a limiting condition, during a LOCA, the reactor pressure would be at containment pressure with the steam generator shell side pressure being at the steam conditions that existed prior to the accident. This would result in the pressure on the outside of the tubes being greater than the pressure on the inside of the tubes. Experimental work has been performed at room temperature on the collapse pressure of 7/8 inch O. D. 0.050 inch wall tubes with locally machined flats to simulate defects. Based on this work, a tube with a 2 inch long flat with 25% of the wall remaining at design temperature and minimum tube properties is capable of sustaining an external pressure of approximately 1600 psi for 1% ovality as compared to approximately 850 psi full load steam pressure. Therefore, a tube with 25% of the original tube wall,

based on a 2 inch long broad area defect, is capable of sustaining the limiting pressures occurring during a LOCA.

3. Conclusion

Based on the testing program performed and analysis presented in WCAP 7832 it is concluded that minimum wall thickness of 25% (75% penetration) will withstand all the loading conditions imposed on the tubing by the LOCA and steam line break conditions.

E. EDDY CURRENT TESTS

The tubing tester uses eddy currents as the probing media to measure variations in effective conductivity and/or permeability of the tubes being tested. The response from the eddy current tester is fed through the memory oscilloscope to the tape recorder and then to the strip chart recorder. The action of the paper chart recorder thus provides continuing assurance that the data received is actually being recorded by the tape recorder. The tubes were examined for anomalies at frequencies of 400 KHz and 100 KHz. In addition, selected tubes were probed at 25 KHz to detect the level of sludge on the secondary side of the tube sheet.

The EC equipment is calibrated using a sample of steam generator tubing into which very small diameter holes have been drilled at various wall penetrations. Calibrating the EC equipment in this manner will result in overestimating the amount of wall penetration due to O. D. surface deterioration of the type found at Ginna. The overestimation

is approximately a factor of 1.4 apparent/actual over the range of 10 to 65% indicated penetrations. This tendency to overestimate the amount of the penetration of the tube in the inspections performed in the field has been shown using laboratory standards and tubes removed from several plants. Examination of the tubes removed from Ginna shows a maximum tube wall penetration of approximately 44%, compared to the field EC measurement of about 64%. This confirms the conservatism of the EC measurement and no penalty or credit is assumed in the tube plugging criteria for EC indications.

F. RATE OF DETERIORATION

An eddy current test of the Ginna steam generators was done in May 1972. The initial results of this test indicated no detectable tube defects. (Subsequent review revealed one possible indication of a defect. However, the EC inspection in 1974 showed no defect present at the location of the 1972 EC indication.) In January 1974 when the eddy current tests were repeated, defects were discovered; the maximum being 64% deterioration as determined by eddy current. Assuming a constant deterioration over the 16-1/2 months of operation results in a 3.88%/month deterioration. If the steam generators are reinspected after six months operation, a 23.3% deterioration allowance must be included in the tube plugging criteria. It should be noted that a 23.3% deterioration allowance is conservative because it is based on the worst case tube and overestimation

of the deterioration by EC test results rather than physical examination of the tube. It is expected that corrosion will be arrested. However, this conservative type of evaluation provides assurance that the integrity of the steam generator primary system boundary is maintained.

G. CRITERIA FOR PLUGGING

Section D stated that the maximum allowable deterioration of the tube walls above the tube sheet is 75%. Therefore, tubes with 75% deterioration must be plugged. Also, a deterioration rate must be considered to insure that a tube with a small amount of deterioration will not exceed the allowable value before the next steam generator reexamination. Section F states that this deterioration allowance should be 23.3% assuming a reexamination after 6 months of operation. For additional margin this value will be approximated as 25%.

In summary:

75% maximum tube deterioration
-25% deterioration allowance
50% tube deterioration

Therefore, tubes indicating a 50% or greater wall deterioration have been plugged and certain steam generator tubes will be reexamined by eddy current testing after 6 months of operation.

H. ADDITIONAL SURVEILLANCE

A re-inspection of selected steam generator tubes will be done using eddy current techniques after 6 months of operation. The purpose of the re-inspection will be to confirm that tube wall deterioration has been arrested.

It is the belief of the Westinghouse Electric Corporation and the Rochester Gas and Electric Corporation that by instituting more restrictive secondary water chemistry controls that the tube wall deterioration can be curtailed or reduced to a negligible rate.

TABLE 1

1974 EDDY CURRENT TEST RESULT

"A" Steam Generator

HOT LEG All tubes were tested (3260)

329	tubes	showed	defects		< 20%	deterioration
63	"	"	"	≥ 20% but	< 25%	"
50	"	"	"	≥ 25% "	< 30%	"
36	"	"	"	≥ 30% "	< 35%	"
14	"	"	"	≥ 35% "	< 40%	"
24	"	"	"	≥ 40% "	< 45%	"
12	"	"	"	≥ 45% "	< 50%	"
12	"	"	"	≥ 50% "	< 55%	"
4	"	"	"	≥ 55% "	< 60%	"
1	"	"	"	≥ 60% "	< 65%	"
0	"	"	"	≥ 65%		

2715 tubes showed no defects

COLD LEG 516 tubes were tested

57 tubes showed distorted signals or defects of << 20%
1 tube showed a defect of < 20%

458 tubes showed no defects

"B" Steam Generator

HOT LEG 1098 tubes were tested

21 tubes showed defects < 20% deterioration
5 tubes showed defects ≥ 20% but ≤ 26%

1072 tubes showed no defects

COLD LEG 516 tubes were tested

no tube defects were found

Figure 1

Inspection Pattern S. G. Hot Leg

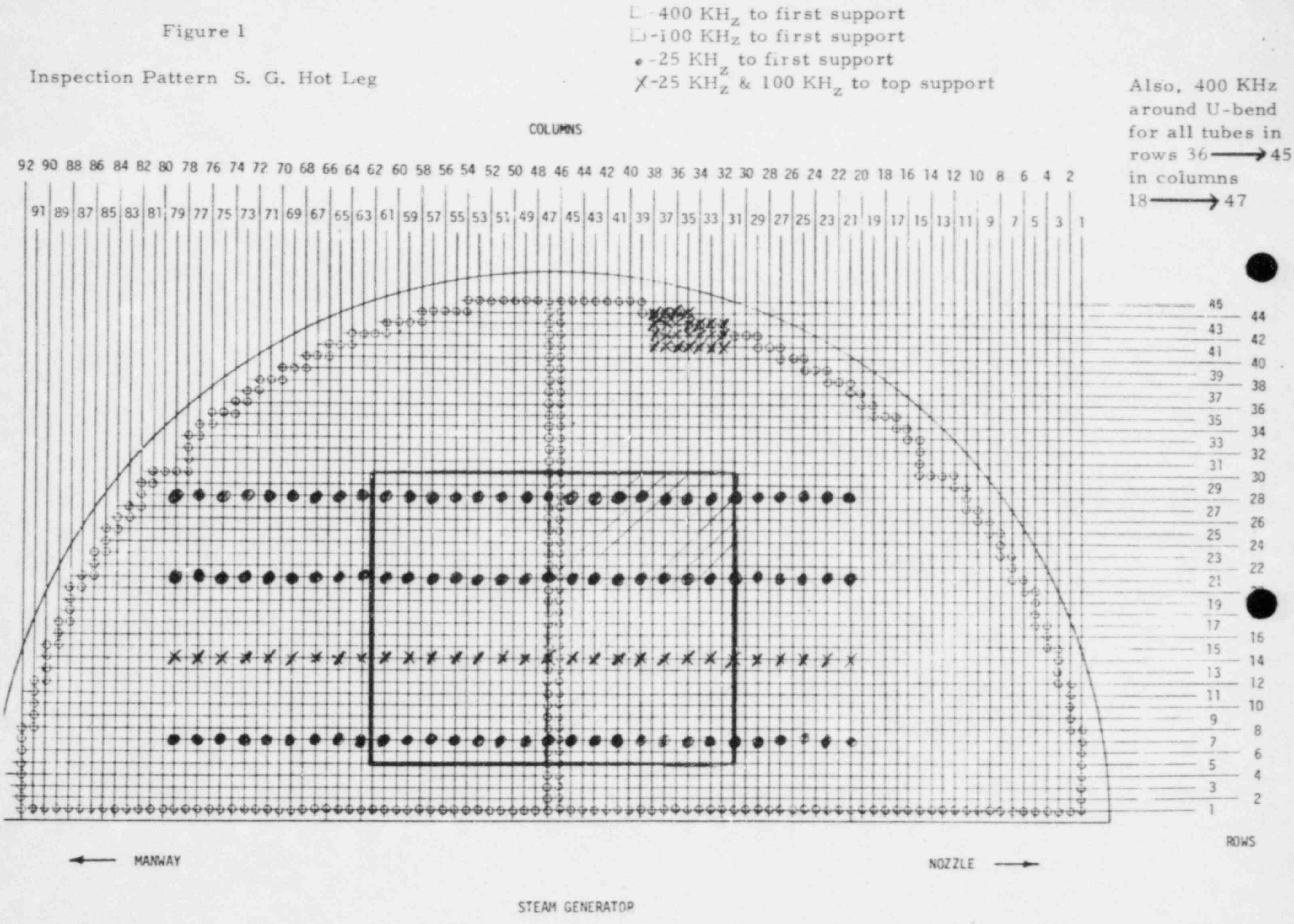


Figure 2
Inspection Pattern S. G. Cold Leg

▯ - 100 KHz to first support

● - 25 KHz to first support

X - 25KHz & 100 KHz to top support

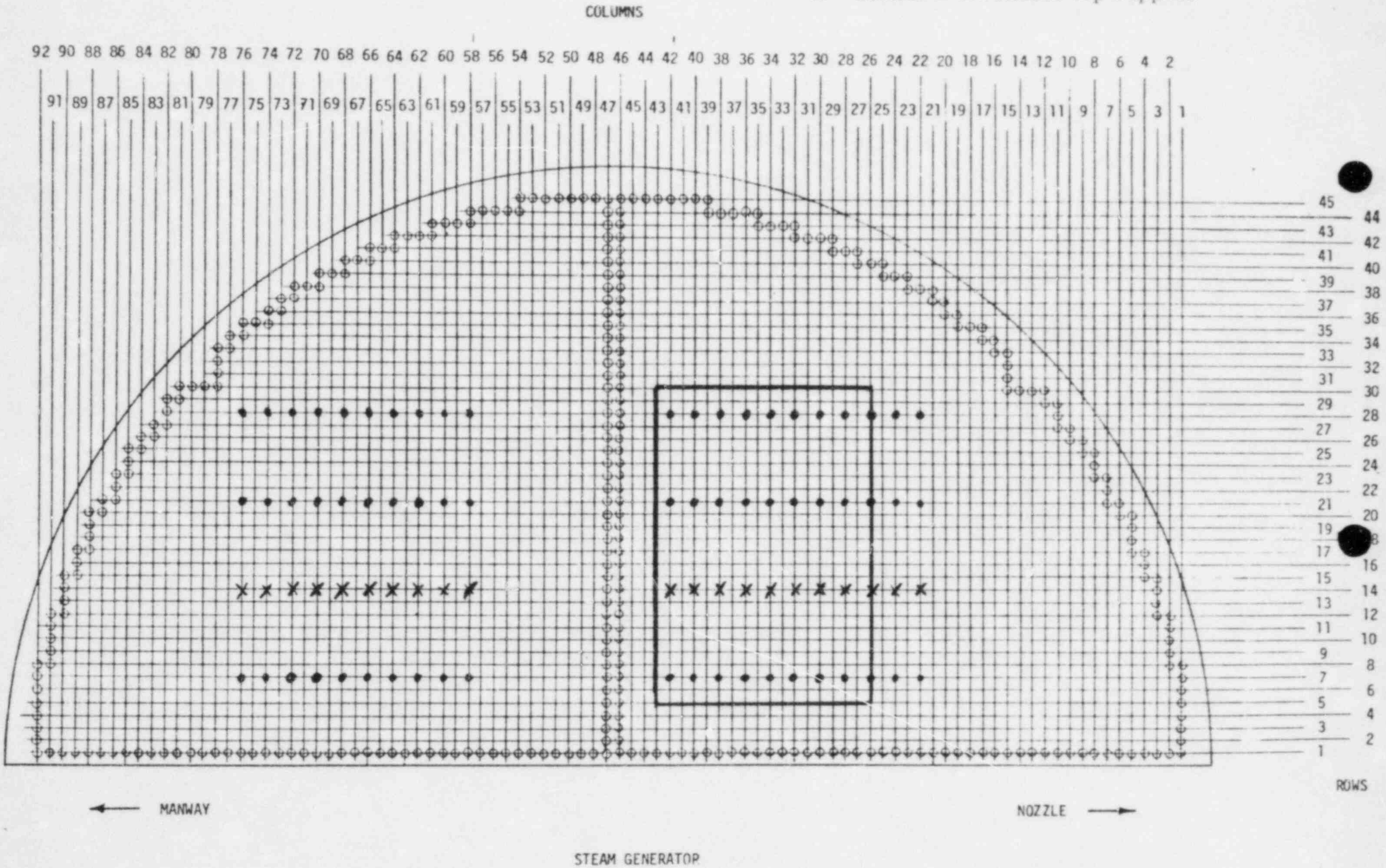


Figure 3

"A" S. G. Hot Leg

• - Deteriorations ≤≤20% to <50%

✗ - Deteriorations ≥ 50%

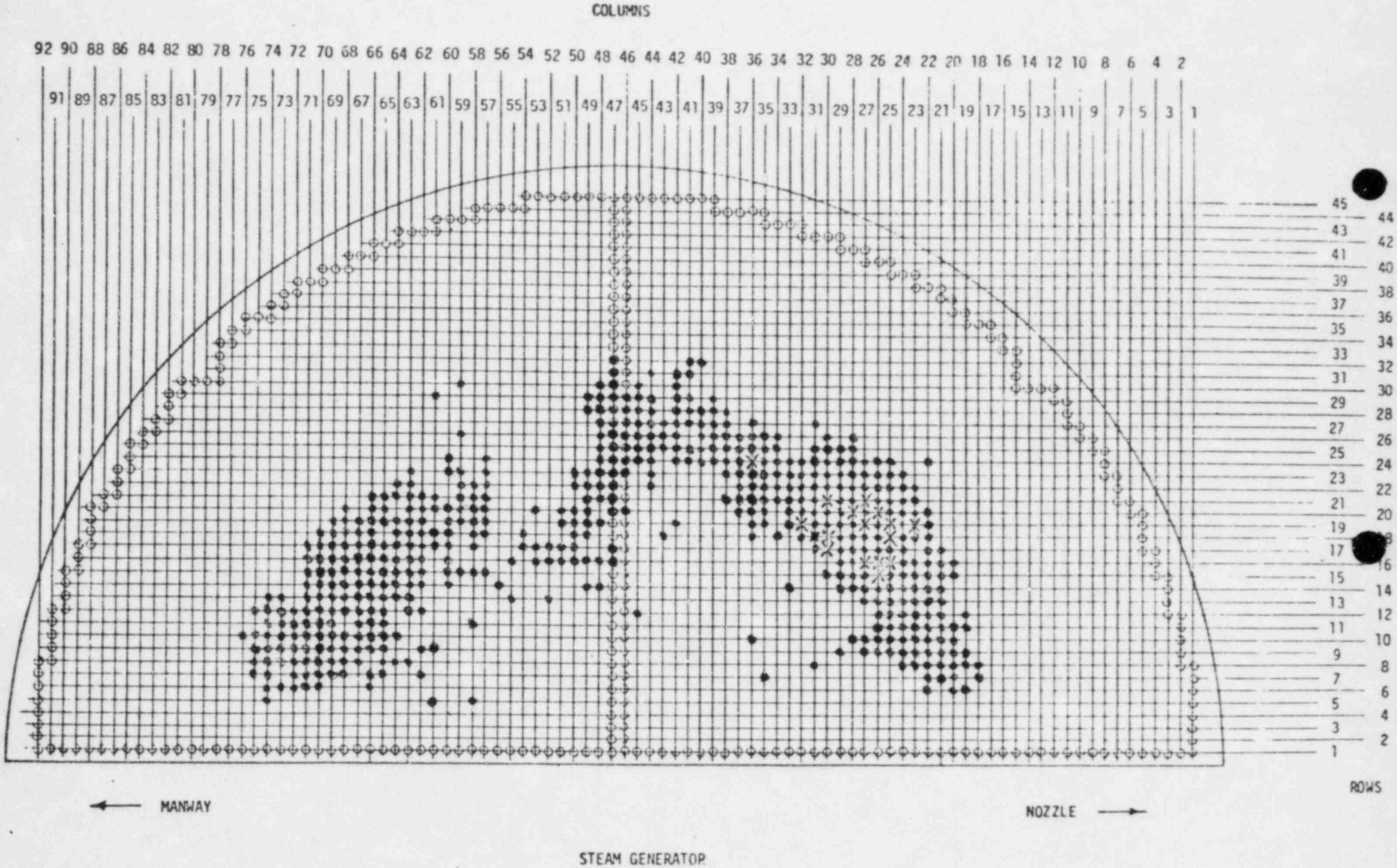


Figure 4
"A" S.G. Hot Leg

• - Deteriorations ≧ 20% to < 50%
X - Deteriorations ≧ 50%

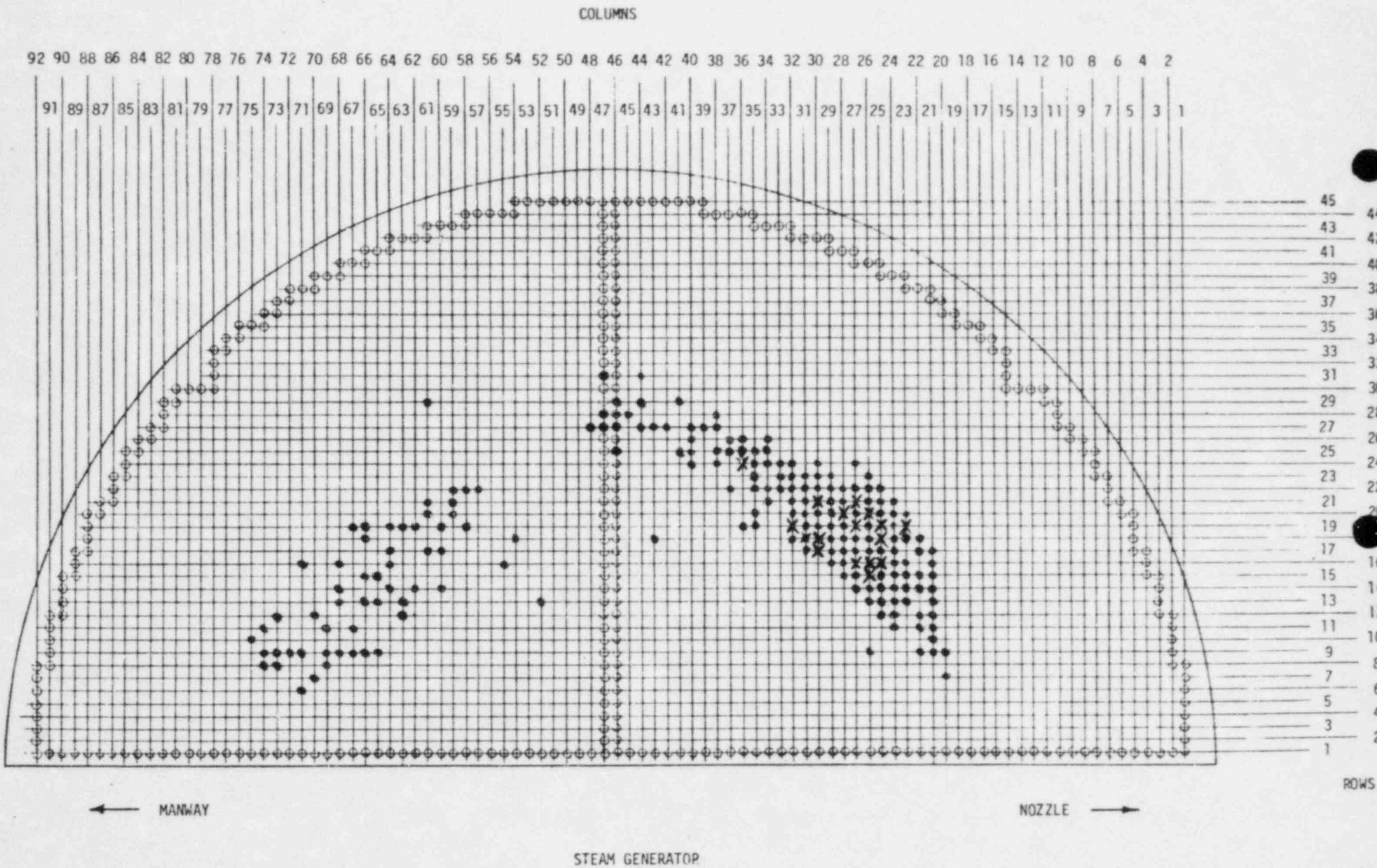


Figure 5

"A" S. G. Cold Leg

• - Deterioration ≥ 20%

X - Deterioration < 20%

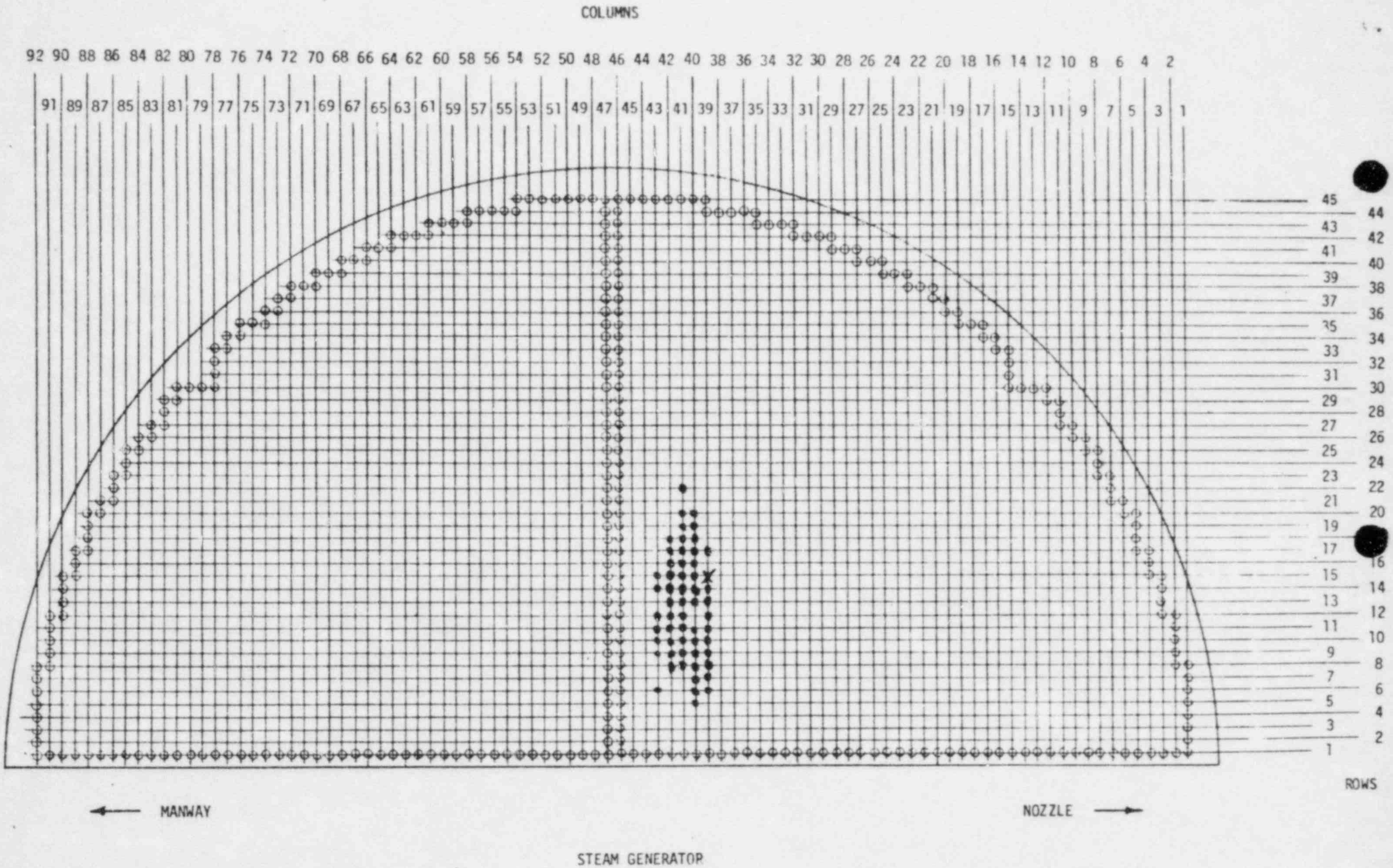
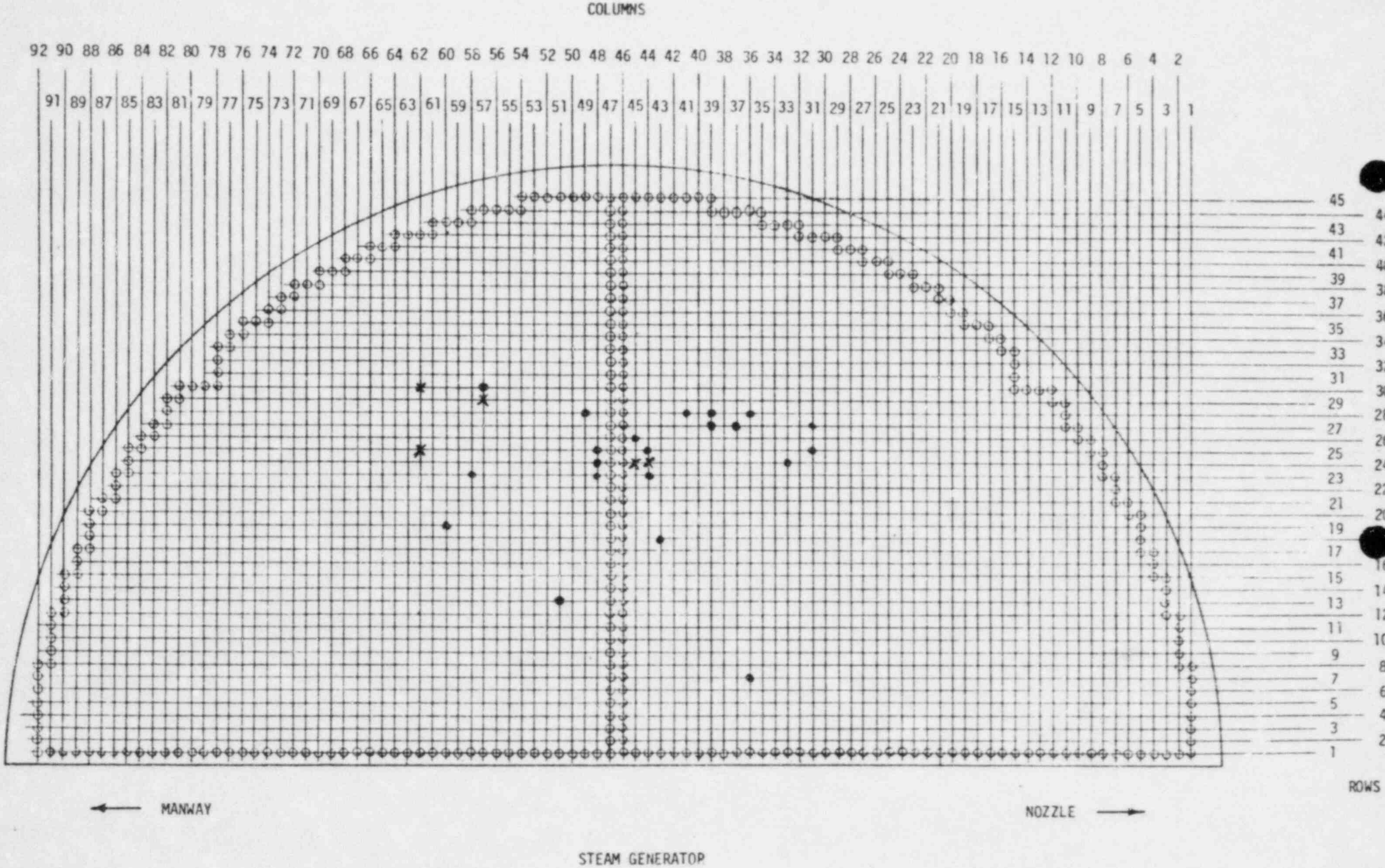


Figure 6

"B" S. G. Hot Leg

• - Deterioration < 20%

X - Deterioration ≥ 20% to ≤ 26%



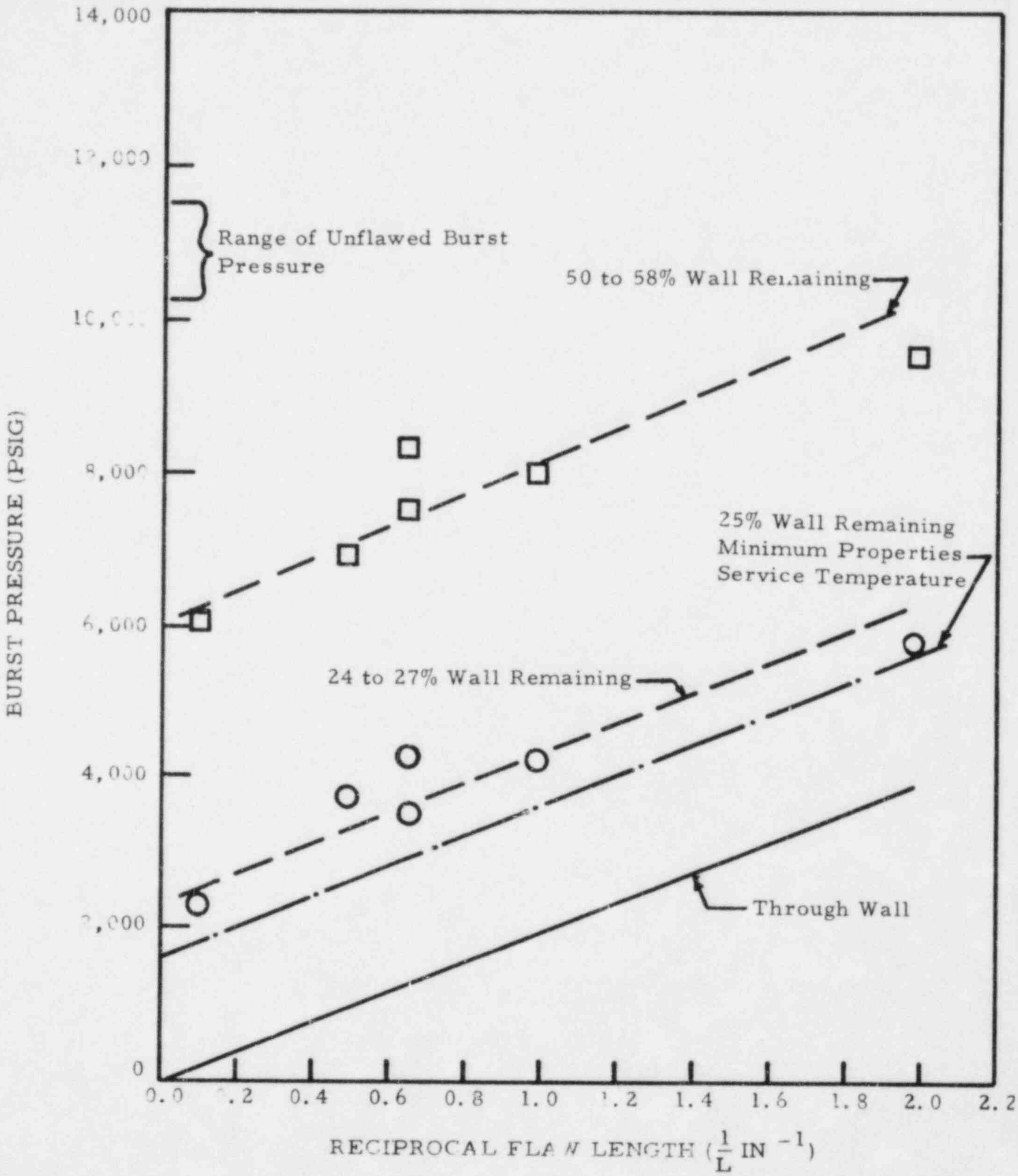


Figure 7 Room Temperature Burst Pressure 7/8" Tubes with Machined Flates