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June 29, 1988

U.S. Nuclear Regulatory Commission
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Gentlemen:

Docket 50-305
Operating License DPR-43
Kewaunee Nuclear Power Plant
Additional Information Regarding NRC Bulletin No. 88-02: Rapidly Propagating Fatigue Cracks in Steam Generator Tubes

References: 1) NRC Bulletin No. 88-02, "Rapidly Propagating Fatigue Cracks in Steam Generator Tubes", dated February 5, 1988.

2) Letter from Mr. D. C. Hintz (WPSC) to US NRC Document Control Desk, dated May 2, 1988.

The attachments to this letter provide the status of our actions relative to item C.2 of NRC Bulletin 88-02. Attachment 1 contains a review of Wisconsin Public Service Corporation's (WPSC's) actions relative to this issue. Attachment II is the Westinghouse Electric Corporation report detailing their evaluation of the susceptability of Kewaunee's steam generators to a tube fatigue failure.

The bulletin requires that a detailed description of our program and the results of the analyses be submitted early enough to permit NRC staff review and approval prior to restart from the next scheduled refueling outage. It is currently anticipated that Kewaunee Plant will restart for fuel cycle 15 in April of 1989.

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Per discussions with our NRC Project Manager, we anticipate submittal of the attached information at this time will allow for review and approval prior to our currently scheduled restart. Pending such NRC approval, we will maintain our currently in place enhanced primary-to-secondary leak rate monitoring program as an interim compensatory measure.

If you have any questions concerning this issue, please contact me or a member of my staff.

Sincerely,

E.R. Mathews

D. C. Hintz for
Vice President - Nuclear Power

Attach.

DR/jal

cc - Mr. Robert L. Nelson, US NRC
Mr. A. B. Davis - US NRC, Region III

Subscribed and Sworn to

Before Me This 29th Day
of June 1988

Lois A. Nuthals
Notary Public, State of Wisconsin

My Commission Expires:

May 3, 1992

Attachment I

Letter From D. C. Hintz To Document Control Desk

Dated

June 29, 1988

Additional Information Regarding NRC Bulletin No. 88-02:

Rapidly Propagating Fatigue Cracks in Steam Generator Tubes

Additional Information Regarding NRC Bulletin No. 88-02: Rapidly Propagating Fatigue Cracks in Steam Generator Tubes

Item C.2 of NRC Bulletin 88-02 requires a program be implemented to minimize the probability of a rapidly propagating steam generator tube fatigue failure such as occurred at North Anna Unit 1. The suggested program includes two parts. First, the analysis would include an assessment of stability ratios (including flow peaking effects) for the most limiting tube locations to assess the potential for rapidly propagating fatigue cracks. This assessment would be conducted such that the stability ratios are directly comparable to that for the tube which ruptured at North Anna. Second, the analysis would include an assessment of the depth of penetration of each anti-vibration bar (AVB). This assessment will establish which tubes are not effectively supported by AVB's and will also permit an assessment of flow peaking factors.

An assessment of AVB penetration depths and tube support conditions for Kewaunee's steam generators was performed by Westinghouse. The results of this assessment and a description of the methodology used were included in our submittal dated May 2, 1988 (reference 2). The resultant AVB position maps are also contained in Attachment II of this submittal.

Subsequent to our May 2, 1988 submittal, WPSC contracted Westinghouse to continue the analysis to determine Kewaunee's susceptibility to a tube fatigue failure. The additional analysis was performed to establish stability ratios for the Kewaunee tubes relative to the stability ratio for the ruptured North Anna tube. The effects of flow peaking due to identified AVB patterns were included in this analysis. Although our earlier submittal specifically identified five (5) tubes as requiring the additional analysis, the analysis was actually performed for all of the Row 8 through Row 12 tubes. The final conclusions of this submittal are thus based on a combination of the results of the stability ratio assessment and the previously reported tube support conditions. The Westinghouse report detailing the results of these analyses is included as Attachment II of this submittal.

Based on the relatively low number of tubes found to be unsupported and thus potentially susceptible to fatigue failure, WPSC elected to pursue the assessment of stability ratios using a one dimensional calculation of the operating conditions in the Kewaunee steam generators. The one dimensional analysis was compared to a similar one dimensional calculation for another plant which had also been analyzed using the three dimensional approach. This comparison was used to develop a relative stability ratio adjustment factor to be applied to the comparison plant's three dimensional relative stability ratios.

Several factors contributed to the WPSC decision to use the one dimensional approach. First, as mentioned above, a relatively low number of tubes were found to be unsupported during the AVB analysis. Specifically, only three (3) Row 9 and above tubes in steam generator 1A and nineteen (19) Row 9 and above tubes in steam generator 1B were found to be unsupported to the tube centerline by at least one AVB. (The steam generator 1B total includes tube Row 10 Column 49 which marginally met the support criteria but which was conservatively included in the stability ratio analysis.)

Although a number of row 8 tubes were unsupported, Westinghouse stated that these tubes would only be susceptible to fatigue under flow peaking significantly worse than any yet identified. For this reason, it was felt that no Row 8 tube was susceptible to the fatigue failure mechanism.

Another factor in our decision to use the one dimensional calculation was the fact that the Kewaunee steam generators contain downcomer flow resistance plates. The existence of these plates has a beneficial effect on the steam generator circulation loop hydraulics and bundle flow rate in the stability ratio analysis.

The final factor in our decision was the strong similarity between Kewaunee and the comparison plant. The comparison plant also contains downcomer flow resistance plates in their steam generators and operates with steam generator conditions nearly identical to Kewaunee's. This leads to a small adjustment (0.6 percent) to the comparison plant's three dimensional relative stability ratios. This small adjustment results in a correspondingly small uncertainty level in the adjusted relative stability ratios.

The resultant relative stability ratios with flow peaking included are listed in Table 3 of the Westinghouse report. The values shown are calculated relative to the ruptured North Anna tube. The acceptance criteria established for application of these relative stability ratios is a 10 percent reduction relative to a North Anna Row 9 tube. Applying this criteria, any tube with a relative stability ratio of less than 0.9 is determined to be not susceptible to the fatigue failure mechanism. As shown in Table 3, the maximum relative stability ratio calculated for a Kewaunee tube was 0.84 for the Row 9 Column 60 tube in steam generator 1B. Based on these results, it was concluded that all of the tubes in the Kewaunee steam generators are acceptable and no modifications are required to prevent a rapidly propagating fatigue crack such as occurred at North Anna Unit 1.

The final two points requiring discussion are the Kewaunee steam generator operating conditions assumed in the above analsyis and comparison of these analyzed conditions to past operating history. The above relative stability ratio analysis was performed based on the current Cycle 14 operating parameters for steam generator 1B. Steam generator 1B was selected because its operating conditions were determined to be slightly more limiting than those of steam generator 1A. This results because steam generator 1B is operating at a slightly higher power level.

With regard to historical operation, WPSC considers the current operating conditions to be conservative. In all cases, the average steam generator steam pressures of previous fuel cycles were higher than the value used in the analysis (739 psia). In addition, no major steam generator modifications which could have an adverse impact on the analysis have been made. For this reason, we feel that past operating conditions are enveloped by the current values used in the analysis.

In summary, WPSC has performed the analyses required by NRC Bulletin 88-02, and has determined that no corrective actions are required to prevent a rapidly propagating fatigue crack such as that which occurred at North Anna Unit 1. The methods and results of the Westinghouse analysis upon which this conclusion is based are included in more depth in Attachment II.

Attachment II

Letter From D. C. Hintz To Document Control Desk

Dated

June 29 , 1988

Additional Information Regarding NRC Bulletin No. 88-02:

Rapidly Propagating Fatigue Cracks in Steam Generator Tubes

SUSCEPTIBILITY TO HIGH CYCLE FATIGUE OF STEAM GENERATOR TUBES KEWAUNEE NUCLEAR POWER PLANT

The Kewaunee Nuclear Power Plant steam generators have been evaluated for the susceptibility of unsupported U-bend tubes with denting at the top tube support plate to a fatigue rupture of the type experienced at Row 9 Column 51 (R9C51) of Steam Generator C, North Anna 1.

1.0 BACKGROUND

The initiation of the circumferential crack in the tube at the top of the top tube support plate at North Anna 1 has been attributed to limited displacement, fluid elastic instability. The unstable condition prevailed in the R9C51 tube when the tube experienced denting at the support plate. A combination of conditions were present that led to the rupture. The tube is not supported by an anti-vibration bar (AVB), has a higher flow field due to local flow peaking as a result of non-uniform insertion depths of AVB's, has reduced damping because of denting at the top support plate, and has fatigue properties consistent with a lower bound fatigue curve for the tube material in an all volatile treatment (AVT) water chemistry environment.

2.0 EVALUATION CRITERIA

The criteria established to provide a fatigue usage less than 1.0 for a finite period of time (i.e., 40 years) is a 10% reduction in stability ratio that provides at least a 58% reduction in stress amplitude (to < 4.0 ksi) for a Row 9 tube in the North Anna 1 steam generators. This reduction is required to produce a fatigue usage of < 0.021 per year for a Row 9 tube in North Anna and therefore greater than a 40 year fatigue life objective. This same criteria is being applied as the principal criteria in the evaluation of Kewaunee tubing.

The determination of stability ratio is the evaluation of a ratio of velocities, the effective velocity divided by the critical velocity. A value greater than unity (1.0) indicates instability. The stress ratio is the expected stress amplitude in a Kewaunee tube divided by the stress amplitude for the North Anna 1, R9C51 tube.

Assuring a stress amplitude that corresponds to a stability ratio equivalent to 10% lower than R9C51 of North Anna 1 is required of Row 9 tubes in the Kewaunee steam generators as well as Row 10, Row 8, and smaller U-bend radius tubes. Displacements can be computed for these tubes using relative stability ratios to R9C51 of North Anna I and an appropriate power law relationship based on instability displacement versus flow velocity. Different U-bend radius tubes will have different stiffness and frequency and, therefore, different stress and fatigue usage per year than the Row 9 tube. These effects are accounted for in a stress ratio technique. The stress ratio is formulated so that a stress ratio of 1.0 or less produces acceptable stress amplitudes and fatigue usage for the tubing in a given steam generator, for the reference fuel cycle analyzed.

The Kewaunee steam generators have downcomer resistance plates and operate at a lower loading than other Series 51 steam generators, which have already been analyzed for susceptibility to tube fatigue. In addition, almost all of the AVBs penetrate to at least Row 9. For these reasons, the stresses in the Kewaunee tubes are lower than those in the Series 51 steam generators which have been analyzed, previously. As a result, in Kewaunee, only tubes with high stability ratios will be susceptible to tube fatigue of the type experienced at North Anna 1. It is shown that all Kewaunne relative stability ratios are less than 0.90 and stress ratios are not required to show acceptability.

The stability ratios for Kewaunee tubing must be evaluated relative to the ruptured tube at Row 9 Column 51, North Anna 1, Steam Generator C, for two reasons. The local effect on the flow field due to various AVB insertion depths is not within the capability of available analysis techniques and is determined by test as a ratio between two AVB configurations. In addition, an analysis and examination of the ruptured tube at North Anna 1 provided a range

of initiating stress amplitudes, but could only bound the possible stability ratios that correspond to these stress amplitudes. Therefore, to minimize the influence of uncertainties, the evaluation of Kewaunee tubing has been based on relative stability ratios and relative flow peaking factors.

The criteria for establishing that a tube has support from an AVB and therefore eliminate it from further considerations is that at least one sided support is present to the tube centerline. Test results show that one sided AV8 support is sufficient to limit the vibration amplitude for fluidelastic excitation. AV8 support at the tube centerline is established by analysis of eddy current (EC) measurements and is a key factor in the assessment of fatigue failure susceptibility since the AVB positions determine the local flow peaking factors. The local flow peaking factor is a direct factor on the apparent stability ratio and a small percentage change causes a significant change in stress amplitude. The relative flow peaking factors for Kewaunee tubing without direct AVB support have been determined by instability tests. These factors have been applied to relative stability ratios determined by a one dimensional (1-D) adjustment of a three dimensional (3-D) tube bundle flow analysis to Kewaunee conditions and the combined relative stability ratio used in the evaluation.

3.0 DENTING AND WEAR EVALUATION

Existing eddy current data for the tubes in the Kewaunee steam generators, which could be affected by the North Anna phenomenon, were reviewed to evaluate tube denting at the top support plate and to determine the location of the AVBs.

The eddy current data from the 1986 examination, for Rows 8 through 12, was reviewed. The review showed that two tubes in Steam Generator A and seven tubes in Steam Generator B were dented with tube deformation. The results of the denting evaluation are given in Table 1. It is judged that support plate corrosion is present at the top support plate for all of the remaining tubes in these rows. In the analysis, all the tubes were assumed to be dented and were treated as clamped with maximum mean stress (due to denting deformation).

The eddy current test data also indicates that no tubes have wall thinning at the AVB locations. It is unlikely that these tubes with AVB support have been unstable.

4.0 AVB INSERTION DEPTHS

The eddy current data was reviewed to identify the location of the intersections of the AVBs with the tubes and to provide angular data on AVB locations for use in calculations to determine the deepest penetration of the AVBs. For the AVBs in the Kewaunee steam generators, one leg of each AVB assembly can be identified on both the hot and cold leg side of the U-bend. If the bottom of an AVB assembly is near a tube, only one AVB signal may be seen (which represents the curved lower end of the AVB). If a single AVB signal is found near the apex of the U-bend, tube support cannot be assured without supporting projection calculations based on AVB intersections of higher row number tubes in the same column. However, if both legs of an AVB assembly are identified on the tube, AVB support (at the tube centerline) is maintained. A typical eddy current record, indicating the presence of an AVB, is shown in Figure 1.

For this evaluation, limited AVB projections were made for tubes below Row B. Some penetrations to Row 7 were found.

Maps of the AVB insertion depths are shown in Figures 2 and 3. All unsupported tubes are listed in Table 2.

5.0 FLOW PEAKING FACTORS

Tests were performed to determine the flow peaking factors for Kewaunee configurations relative to the North Anna R9C51 peaking factor. The tests modeled the AVB design common to Kewaunee and North Anna. The tests focused on representative patterns of the variations of the AVB depth of insertion. It was found that the worst case flow peaking results, for Kewaunee, were 7 percent lower than the peaking factor determined for R9C51. Some AVB penetrations below Row 7 are present in the Kewaunee steam generators. The evaluation considered the possible influence of these AVB configurations on the

Row 8 flow peaking. Row 8 tubes would have to experience flow peaking 16% worse than North Anna R9C51 for the tubes to become susceptible to fatigue. The worst case found in any testing, to date, is 9% worse than North Anna R9C51. This worst case configuration does not occur in the Kewaunee steam generators. For this reason, it is judged that no Row B tube is suceptible to fatigue.

6.0 TUBE VIBRATION EVALUATION

One-dimensional analyses have been used to develop a relative stability ratio adjustment between Kewaunee and another Model 51 unit for which three-dimensional vibration analyses have been performed. Both Kewaunee and the other unit include downcomer resistance plates which have a strong influence on the circulation loop hydraulics and the bundle flow rate. This common feature, together with the fact that the thermal/hydraulic operating conditions (steam flow, steam pressure and circulation ratio) for these two units are nearly identical, means that the bundle flow fields are essentially the same for both units. As a result, the calculated one-dimensional adjustment for Kewaunee from the existing three-dimensional relative stability ratios is very small (0.6% higher).

The relative stability ratio calculation for Kewaunee was based on the following parameters for steam generator B which are for a recent typical operating point as supplied by Wisconsin Public Service:

Steam Flow	3.53×10^6 lbm/hr
Steam Pressure	739 psia
Circulation Ratio	3.12

These conditions for the B generator were determined to be slightly more limiting with respect to the relative stability ratio than those of the A generator. Specifically, generator B is operating at slightly higher power (≈100.3% vs 98.1%) and steam flow than the A generator, and has a slightly lower steam pressure (739 vs 753 psia).

The product of the relative stability ratios and flow peaking factors of Kewaunee (Row B through Row 12) tubing versus R9C51 of North Anna 1 are given in Table 3. Table 3 includes only those unsupported tubes which are potentailly susceptible to fatigue because of row number or flow peaking.

The results show that, based on the nominal one dimensional adjusted analysis, all Kewaunee tubes meet the relative stability ratio criteria with a maximum value of 0.84 versus the 0.90 criteria. Based on application of the one dimensional adjustment ratio and comparisons with direct three dimensional ratios for other analysis results, it is estimated that the uncertainty in the 0.6% adjustment is less than one fourth of one percent.

It is known that the full power operating conditions for Kewaunee have not varied significantly since the plant became operational in 1974. Nor have there been any mechanical modifications to the generators which could have had a significant influence on the U-bend thermal/hydraulics. As a result, it is expected that the analysis described herein, based on current operating conditions, is also representative of prior operation. For this reason, prior operating history was not evaluated.

7.0 OVERALL CONCLUSION

Based on judgement that current operating conditions are conservative, it can be concluded that no modification, preventive tube plugging, or other measure is necessary in Kewaunee to preclude a fatigue rupture similar to the North Anna 1 event.

Table 1

Dented Tubes in Rows 8 through 12
Kewaunee Nuclear Power Plant

Steam Generator	Row	Denting(1)	Corrosion(2)
A	8	None	All
	9	None	All
	10	None	All
	11	Column 13	All
	12	Column 4	All
B	8	Column 4	All
	9	None	All
	10	None	All
	11	Column 93	All
	12	Columns 2, 3, 4, 91, 92, 93	All

(1) Denting with tube deformation.

(2) NRCB 88-02 definition of denting.

Table 2

Kewaunee : Unsupported Tube Summary

	Row	Columns
S/G-A		
	8	2, 3, 4, 15, 25, 28, 34, 35, 38, 39, 42-50, 54, 60, 76, 90-93
	9	***93***
	10	***93***
	11	***93***
	12	none
S/G-B		
	8	2, 3, 34, 35, 38-58, 60-63, 68
	9	***35***, 42-54, 60-63
	10	***49*** *
	11	none
	12	none

Numbers in ***Italic*** indicate tubes potentially susceptible to fluid induced vibration, based on support conditions only.

* Support of this tube is at the limit of the criteria for acceptable support based on the projection technique.

Table 3. Kewaunee (WPS) Stability Ratios for Potentially Susceptible Tubes

SG	Row	Column	Stability Ratio**
A	8	15	0.55
		76 (19)*	0.55
		25	0.58
		28	0.57
		34	0.55
		35	0.55
		60 (35)	0.58
		38	0.56
		39	0.56
		54 (41)	0.59
	11	93 (2)	0.58
B	8	68 (27)	0.58
		34	0.55
		35	0.55
	9	83 (32)	0.58
		35	0.80
		60 (35)	0.84
		54 (41)	0.59
		42	0.59
	10	49 (46)	0.79

* Number in parenthesis is geometrically symmetrical location. It is given to facilitate identification of appropriate data point on Figure 4.

** Values given are the product of stability ratios and flow peaking factors relative to North Anna 1, R9C51.

Figure 1

Typical "AVB Present" Eddy Current Signal

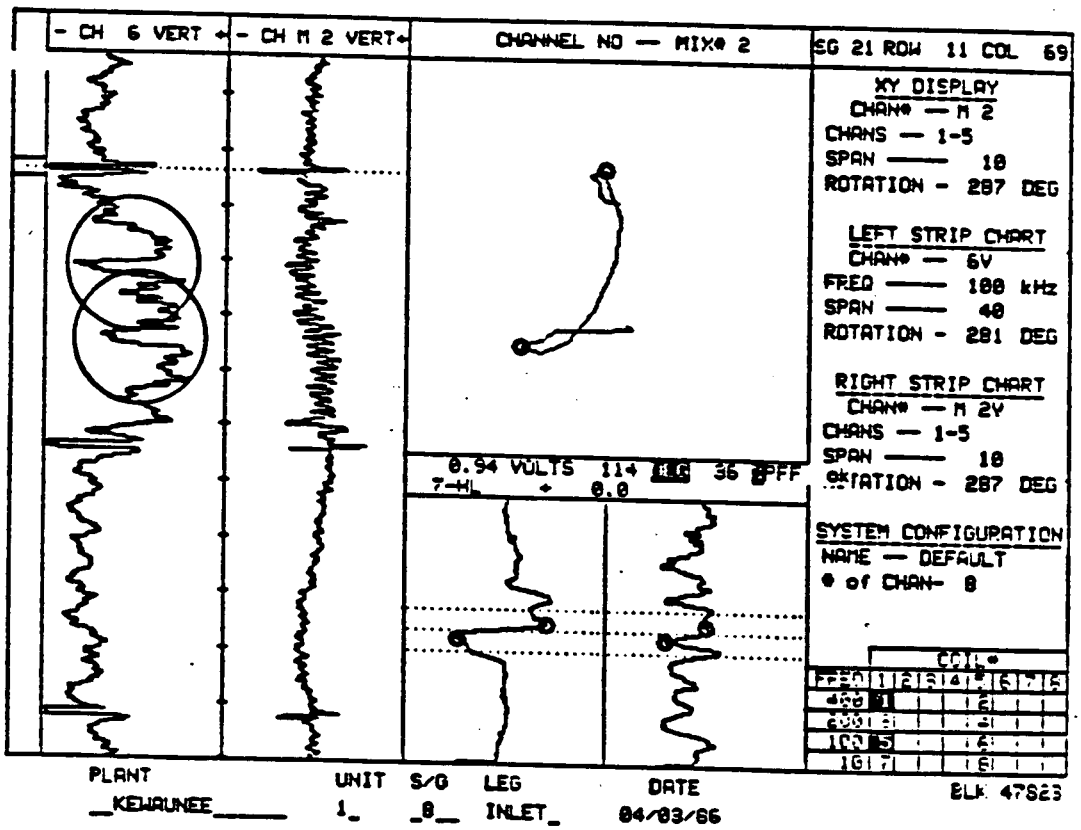
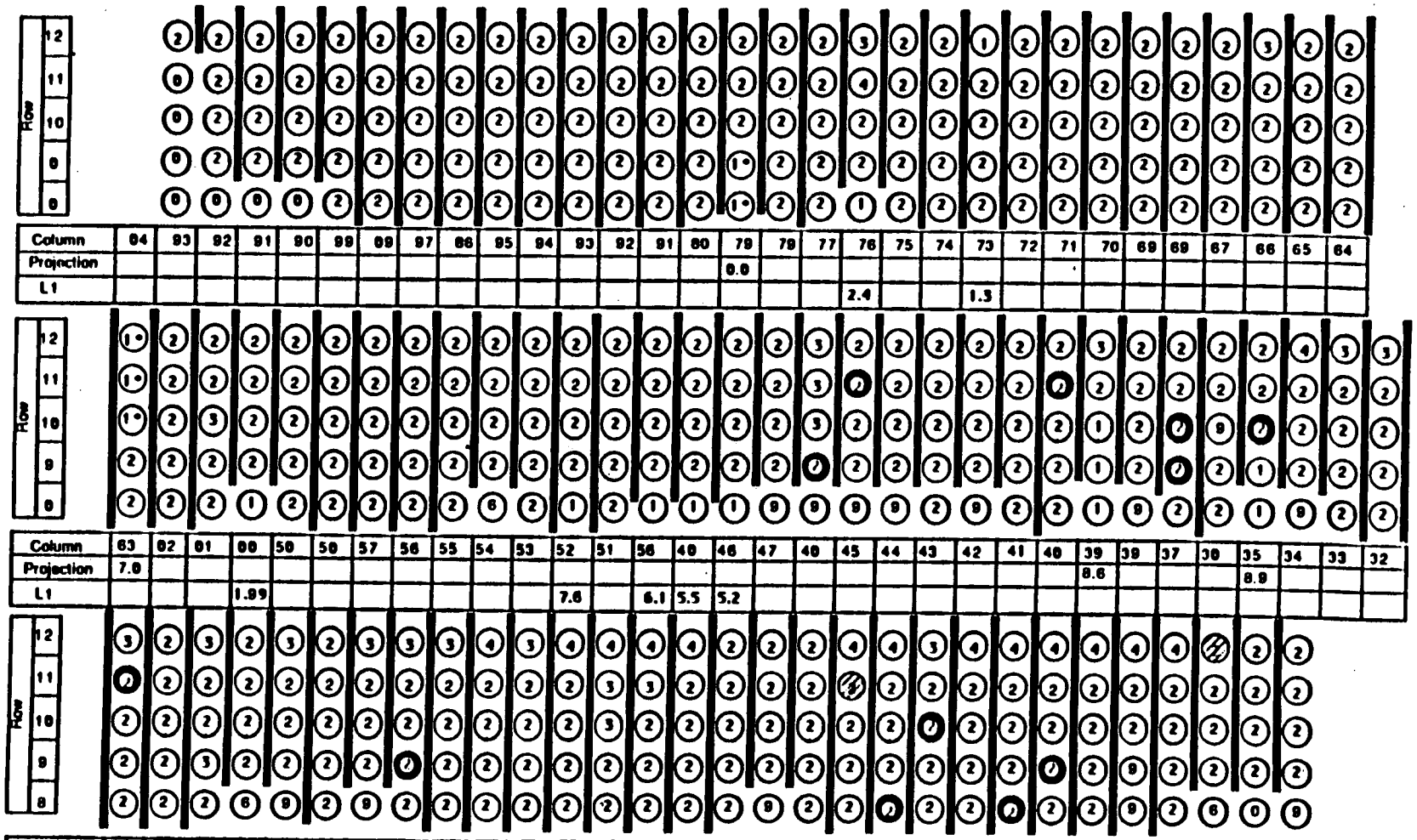


Figure 2
Kewaunee : S/G - A
AVB Positions



NOTES:
- Numbers in circles represent AVBs indications in corresponding tubes (1986 ECT data). (* means center of single indication is located consistent with projected position of AVB)
- L1 is length of single AVB indication
- Projections are based on centerline of the AVB relative to centerline of the tube.

-Plugged Tube

- HL Dent

- CL Dent

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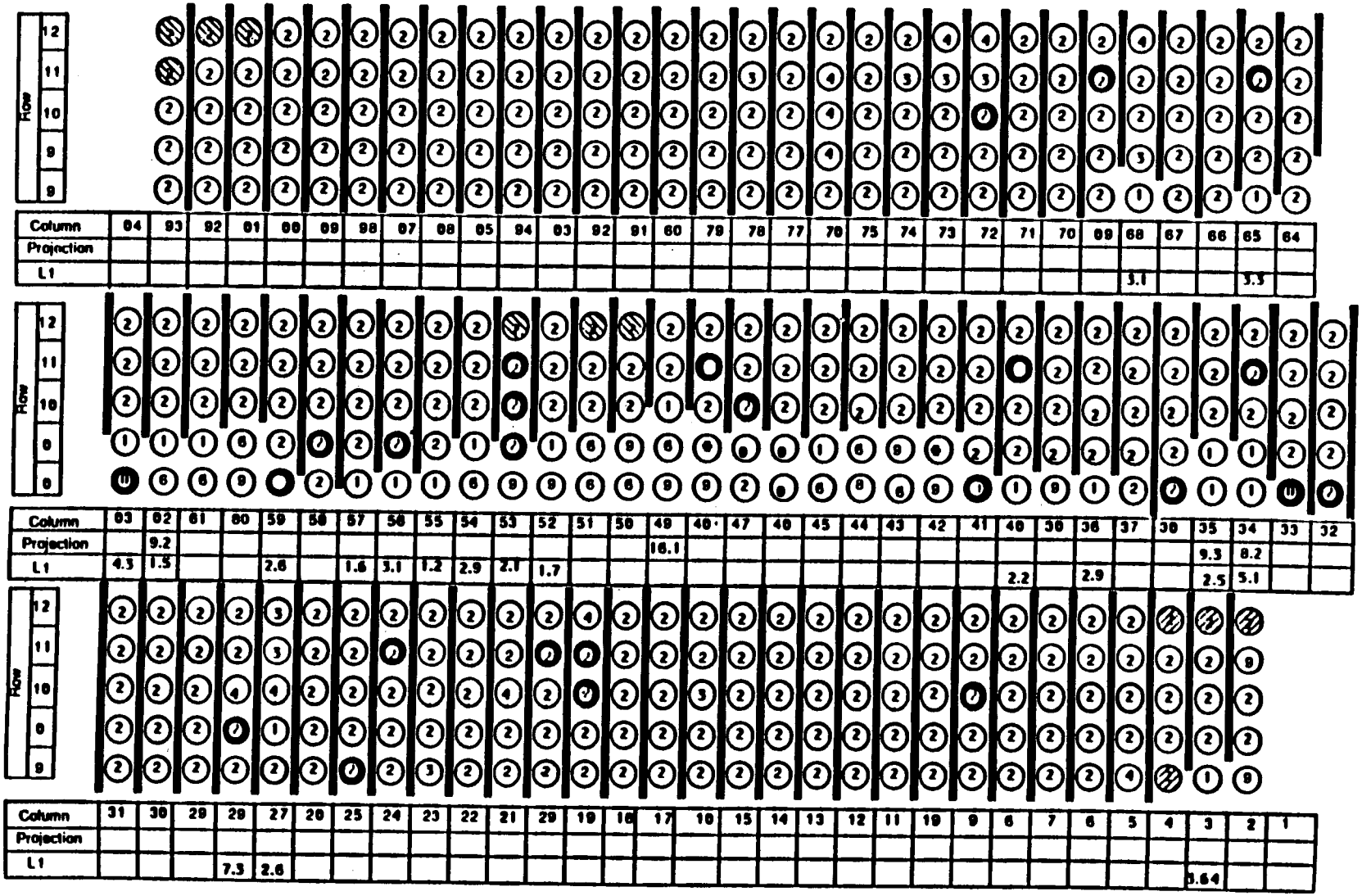
Figure 3
Kewaunee : S/G - B
AVB Positions



NOTES:
- Numbers in circles represent AVBs visible in corresponding tube (1988 ECT Data).
- L1 is length of signal for single AVB indications.
- Projections are based on centerline of the AVB relative to centerline of the tube.

O - Plugged

HL Dent

CL Dent

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