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DESCRIPTION
LTR. RE. THEIR 12/10/76 REQUEST...TRANS THE FOLLOWING.......

PLANT NAME: TURKEY PT # 3 & 4

ENCLOSURE
ANSWERS TO QUETIONS #'S 2 AND 4, AND REVISED ANSWERS TO QUESTIONS 8 AND 9 PERTAINING TO THE STEAM GENERATORS TUBE INTEGRITY SUPPLEMENTAL INFORMATION.......

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December 30, 1976
L-76-434

RECEIVED 1-6-77 U.S. NUCLEAR REGULATORY COMMISSION Mail Section

Office of Nuclear Reactor Regulation
Attention: Mr. George Lear, Chief
Operating Reactors Branch #3
Division of Operating Reactors
U. S. Nuclear Regulatory Commission
Washington, D. C. 20555

Dear Mr. Lear:

Re: Turkey Point Units 3 and 4
Docket Nos. 50-250 and 50-251
Steam Generator Tube Integrity
Supplemental Information

On December 10, 1976, we received a request for information (12 questions) concerning steam generator tube integrity. The answers to Questions 1, 3 through 6, and 8 through 12 were submitted on December 22, 1976 (L-76-432). The answers to questions 2 and 7, and revised answers to questions 8 and 9, are attached.

Very truly yours,

E. L. Adomat

for Robert E. Uhrig
Vice President

REU/MAS/cpc

Attachments

cc: Mr. Norman C. Moseley, Region II
Robert Lowenstein, Esquire

165

QUESTION #2 Estimate the error band and specify the degree of confidence in the strain data provided in response to question 1, i.e. specify the tolerances in the manufacturing strain.

ANSWER #2 The tolerances in manufacturing strain based on 44 Series Steam Generator Engineering drawings are obtained as follows:

1. Axial strain:

Axial strain at the I. D. of the extradose is measured as

$$\varepsilon_a = \frac{r_t}{R}$$

where r_t is the tube radius to the I. D. and R is the bend radius at the middle surface. R has a dimensional tolerance of $\pm 1/32'' = \pm .03125''$. r_t has a maximum value of

$$r_t = \frac{\text{Max. Outside Tube Dia.}}{2} - \text{Min. Wall Thickness}$$

$$= \frac{.880}{2} - .045 = .395''$$

and a minimum value of

$$r_t = \frac{\text{Minimum Outside Tube Dia.}}{2} - \text{Max. Wall Thickness}$$

$$= \frac{.8675}{2} - .055 = .379''$$

Thus, the maximum axial strain for a row #1 tube, which will be most effected by these tolerances since it has the smallest radius is:

$$\varepsilon_{a\ \text{max.}} = \frac{.395}{2.1875 - .03125} = .183 \text{ in/in}$$

and the minimum axial strain is:

$$\varepsilon_{a\ min.} = \frac{.379}{2.1875 + .03123} = .171 \text{ in/in}$$

Therefore: $\varepsilon_a = .177 \pm .006$ in/in

2. Hoop strain:

The maximum ovality for a 44 Series Steam Generator tube is specified as 10%. This is equivalent to a strain of

$$\varepsilon_{h\ max.} = .007$$

The minimum strain is

$$\varepsilon_{h\ min.} = .000$$

3. Since the tube wall is always thinned at the extradose, the ratio of t_θ/t_{ave} taken from mill data (Figure 2-1) will be used in the strain tolerance calculations. From Figure 2-1 the tolerance on this quantity is less than $\pm$ .01. Therefore,

$$\varepsilon_{r\ max.} = \frac{.95(t_{ave}) - t_{ave}}{t_{ave}} = -.050 \text{ in/in}$$

$$\varepsilon_{r\ min.} = \frac{.97(t_{ave}) - t_{ave}}{t_{ave}} = -.030 \text{ in/in}$$

The range of equivalent strain due to manufacturing processes can now be evaluated:

Maximum Equivalent Strain:

$$\varepsilon_{equiv._{max.}} = \frac{\sqrt{2}}{3}\left[(\varepsilon_{a_{max.}} - \varepsilon_{h_{min.}})^2 + (\varepsilon_{a_{max.}} - \varepsilon_{r_{min.}})^2 + (\varepsilon_{h_{min.}} - \varepsilon_{r_{min.}})^2\right]^{1/2}$$

$$= .47\ [1.83^2 + .233^2 + .050^2]^{1/2}$$

$$= .141 \text{ in/in}$$

Minimum Equivalent Strain:

$$\varepsilon_{equiv._{min.}} = \frac{\sqrt{2}}{3}\left[(\varepsilon_{a_{min.}} - \varepsilon_{h_{max.}})^2 + (\varepsilon_{a_{min.}} - \varepsilon_{r_{max.}})^2 + (\varepsilon_{h_{max.}} - \varepsilon_{r_{max.}})^2\right]^{1/2}$$

$$= .47\ [.164^2 + .201^2 + .037^2]$$

$$= .123 \text{ in/in}$$

Thus, the tolerance in equivalent strain for tubes in Row 1 due to tube forming processes is given by:

$$\varepsilon_{equiv.} = 0.132 \pm 0.009 \text{ in/in}$$

Similar calculations for tubes in Rows 2, 3, and 4 yield the following results:

	ε_a		ε_h		ε_r		$\varepsilon_{equiv.}$		Tolerance
	max.	min.	max.	min.	max.	min.	max.	min.	±
Row 2	0.116	0.110	0.007	0.000	-0.04	-0.02	0.093	0.079	0.007
Row 3	0.085	0.081	0.007	0.000	-0.03	-0.01	0.069	0.056	0.006
Row 4	0.068	0.064	0.007	0.000	-0.03	-0.01	0.058	0.045	0.006

As shown, the equivalent strains calculated for the different rows decrease (as the row number increases) due to the increasing bend radii, although the tolerances on tube dimensions remain the same.

The significance of the calculated equivalent strains given above and in the response to Question 1 toward initiation of intergranular penetration is discussed in the answer to Question 9.

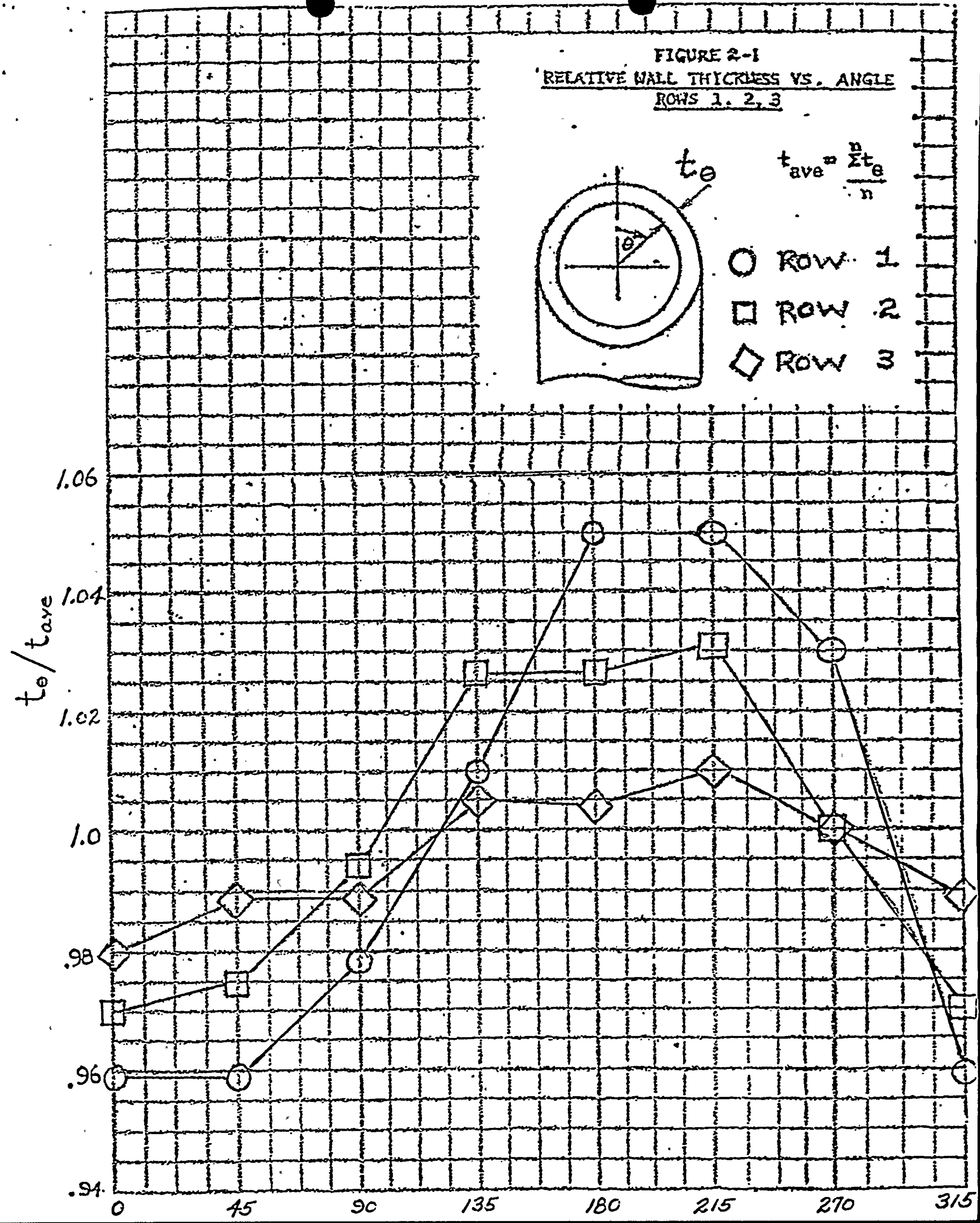
FIGURE 2-1
RELATIVE WALL THICKNESS VS. ANGLE
ROWS 1, 2, 3
t_θ
$t_{ave} = \frac{\sum^{n} t_\theta}{n}$
θ
○ ROW 1
□ ROW 2
◇ ROW 3
t_θ / t_{ave}
1.06
1.04
1.02
1.0
.98
.96
.94
0
45
90
135
180
215
270
315

QUESTION #7 As originally designed the support plates did not restrain the tubes during the heat-up and cool-down axial thermal expansion of the tubes. With corrosion particle buildup in the annulus between each tube and the support plate, restraint to thermal expansion is provided. Quantify the effect of such restraint upon the tubes and the support plate.

ANSWER #7 The effect of tube fixity at the support plate due to corrosion buildup has been evaluated. The evaluation included an ASME Section III analysis of Design, Normal, Upset, and Test Conditions.

In addition, a more recent evaluation has considered the effect on fatigue life of a tube fixed at the tube support plate closest to the tube sheet and fixed at the secondary face of the tubesheet. The tube was analyzed for a potential fatigue failure at the tubesheet when subjected to cyclic thermal and mechanical loads. The results of this investigation have shown that the steam generator tubing at the tubesheet junction is not susceptible to fatigue failure under any anticipated transient condition, including cold feedwater addition to a hot, dry steam generator, even when considering a worst location tube locked into the support plate closest to the tubesheet. The usage factor obtained from this analysis is less than 0.1.

With regard to the effect of the tube-plate fixity on the plate, the maximum transverse plate deformations are approximated by:

$$\delta_{t\ topplate} = [\alpha_{tubes}\ \Delta T_{tubes} - \alpha_{wrapper}\ \Delta T_{wrapper}] \text{ X } [\text{Length}_{(tubesheet-topplate)}]$$

$$= [7.85\ (546.1 - 70) - 7.05\ (518.0-70)]\ 10^{-6} \times 302.63''$$

$$= .18''$$

We judge that the plates can accommodate such deformations with minor yielding.

QUESTION #8 How many tubes have been examined at the U-bend apex, describe the methods of examination, the degree of confidence and the results.

ANSWER #8 Laboratory Examinations

A total of 71 U-bends have been removed from Surry 1, Surry 2, and Turkey Point 4 and have been examined by various non-destructive and destructive techniques. The apex of each bend was first examined by double wall radiography and selected bends were examined by eddy current techniques using a .540 inch diameter probe. If cracks were detected by both methods, only limited additional examinations were performed. If no cracks were detected, or there was a discrepancy between the two techniques, the bends were destructively examined by first sectioning transversely through the apex and metallographically examining the cross section. This was followed by cutting rings from the adjacent apex area, longitudinally slitting them, and bending them such as to place the ID surface in tension, as shown in Figures 1 and 2. This method of testing has the advantage of being able to examine a larger area than can be done metallographically, and has demonstrated the capability of detecting short, tight cracks that might be otherwise missed. After reverse bending, the ID surfaces were examined under a stereo microscope and if any fissures were detected, metallography was performed to determine the depth of penetration.

A total of 19 Row 1 U-bends were found to be cracked. All but four were initially detected by radiography; these four each contained one very short (1/16 inches long) tight crack which was detected by the reverse bend test. In several cases, cracks which were detected by radiography were not observed in the eddy current test as the signal was obscured by the background "noise." There were no cracks found in Row 2 or Row 3 U-bends.

Summarizing, the destructive reverse bend tests provide the greatest assurance of detecting even minute cracks. The radiographic examination detected all cracks except those which were very short and tight. The eddy current examination had somewhat less sensitivity but generally agreed with the radiographic findings. The results of these tests are summarized on attached Tables 1, 2, and 3.

TABLE 1

SURRY 1, S/G A (0.5 in. opening)

ROW	EXAM	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	X-R	OK	–	OK	CRK	CRK	CRK	CRK	CRK	CRK	CRK	CRK	CRK	CRK	–	OK
	EC ▲	–	–	ok	ok	CRK	CRK	OK	CRK	CRK	CRK	CRK	CRK	CRK	OK	–
	MET	–	–	ok	ok	–	–	CRK	ok	–	–	–	–	–	–	–
	BEND TEST	OK	ok	ok	CRK	–	–	CRK	CRK	–	–	–	–	–	OK	ok
* OVALITY	IN.	.074	.068	.075	.136	.212	.256	.361	.275	.139	.279	.248	.221	.142	.069	.056
OVALITY	%	8.4	7.7	8.6	15.5	24.2	29.3	41.3	31.4	15.9	31.9	28.3	25.3	16.2	7.9	6.4
2	X-R	OK	ok	ok	ok	ok	ok	ok	ok	ok	ok	ok	ok	ok	ok	ok
	EC ▲	ok	ok	ok	ok	ok	–	OK	ok	–	ok	ok	ok	–	ok	–
	MET	–	–	ok	ok	–	ok	ok	ok	ok	–	–	–	–	–	–
	BEND TEST	OK	ok	ok	ok	ok	ok	ok	ok	ok	ok	ok	ok	ok	ok	ok
* OVALITY	IN.	.070	.053	.065	.079	.110	–	.154	.162	–	.162	.141	.109	.066	.049	.060
OVALITY	%	8.0	6.0	7.4	9.0	12.6	–	17.6	18.5	–	18.3	16.1	12.5	7.5	5.6	6.9
3	X-R									ok						
	EC ▲															
	MET									ok						
	BEND TEST									ok						
* OVALITY	IN.									.050						
OVALITY	%									6.7						

COLUMN NO.

* Ovality = Diameter (max) − Diameter (min) ; CRK = Crack

12/27/76

▲ EC tests performed with standard U-bend probe at 70-100 KHZ which did not have improved centering devices.

TABLE 2

SURRY 2, S/G A (1.5 in. opening)

ROW	EXAM	1	2	3	4	5	6	7	8	9						
1	X-R	ok	ok	ok	ok	CRK	CRK	CRK	CRK	CRK						
	EC ▲	ok	ok	ok	–	CRK	–	–	CRK	CRK						
	MET	ok	ok	ok	CRK[1]	–	CRK	CRK	–	–						
	BEND TEST	ok	ok	ok	ok	–	–	–	–	–						
* OVALITY	IN.	.01	.009	.006	.021	.089	.120	–	.118	.127						
OVALITY	%	1.1	1.0	0.7	2.4	10.2	13.7	–	13.5	14.5						
2	X-R															
	EC ▲															
	MET															
3	X-R															
	EC ▲															
	MET															

COLUMN NO.

* Ovality = Diameter (max) - Diameter (min) ; CRK = Crack

12/27/76

▲ EC tests performed with standard U-bend probe at 70-100 KHZ which did not have improved centering devices.

1-Crack was short, i.e. 1/16 inch and did not extend in length into adjacent

TABLE 3
TURKEY POINT 4B (1.88 in. opening)

		COLUMN NO.														
ROW	EXAM	92	91	90	89	88	87	86	85	84	83	82	81	80	79	78
1	X-R	ok	ok	ok	ok	ok	ok	ok	-	ok	ok	ok	ok	ok	ok	ok
	EC▲	ok	ok	-	-	-	ok	ok	ok	ok	ok	ok	-	-	-	-
	MET	ok	ok						ok	ok						
	BEND TEST	ok	ok	-	ok	ok	ok	CRK**	ok	ok	CRK**	CRK**	ok	ok	-	-
OVAL	IN.* TY	0	.034	-	.090	.140	.157	.159	.140	.125	.113	.111	.095	.087	-	-
OVAL	% TY	0	3.9	-	10.4	16	17.9	18.2	16	14.3	12.9	12.7	10.9	9.9	-	-
2	X-R	ok	ok	ok	ok	ok	ok	ok	ok	ok	ok	ok	ok	ok	ok	ok
	EC▲	ok	ok					ok	ok	ok	ok					
	MET	ok	ok						ok	ok						
	BEND TEST	ok	ok	-	ok	ok	ok	ok	ok	ok	ok	ok	ok	ok		
OVAL	IN.* TY	.085	.076	-	.079	.099	.096	.103	.091	.085	.097	.082	.090	.069		
OVAL	% TY	9.7	8.7		9.0	11.3	11.0	11.8	10.4	9.7	11.0	9.6	10.4	7.9		
3	X-R								ok							
	EC▲								ok							
	MET								ok							
	BEND TEST								ok							
OVAL	IN.* ITY								.044							
OVAL	% TY								5.0							

* Ovality = Diameter (max) - Diameter (min) ; CRK = Crack

12/27/76

▲ EC tests performed with standard U-bend probe at 70-100 KHZ which did not have improved centering devices.

QUESTION #9 What magnitude of service induced and/or total effective threshold strain is required to initiate intergranular cracking on either the extradose or intradose ID surface at the U-bend apex, and how is it affected by the change in the U-bend radius and thus the pre-strain or ovality in rows 1 to 4?

ANSWER #9 The fact that intergranular stress-assisted penetration has been observed in units which have flow slot "hourglassing" developing during operation indicates that there may not be a threshold stress or strain required alone for initiation of attack, but in addition a strain rate range which is another important variable. The strain and corresponding strain rate derived from Von Karman bending stresses at the apex of the U-bend, brought on by the flow slot hourglassing, decreases rapidly with increasing bend radius, for two reasons. First, the leg displacement due to flow slot hourglassing is asymtotic to zero at some point within the interior of the plate, and second, the larger U-bends are increasingly more flexible. Thus, the Von Karman effect, which is the product of the two, rapidly attenuates with increasing row number.

With regard to the magnitude of the total equivalent strains, these are given in the response to Question #1 for the extradose at the apex. The values at the intradose would be smaller because both axial and radial strains would be consideraly less. It is well to point out that all row #1 calculations are based on the tubes pulled at Turkey Point #4. The equivalent strain of .135 in/in represents a lower bound on critical equivalent strain at this time for the following reasons:

1. No row #1 tubes with I.D. indications have equivalent strains less than 0.135 in/in.

2. Among the tubes with no indications the ones experiencing the largest leg deformations have equivalent strains of .135 in/in or less.

In fact most tubes in the second category have had equivalent strains of .130 in/in $\pm$ .005 in/in.

Again, it should be emphasized that the presence of significant plastic deformation in the tight U-bends combined with pressure and residual stresses are not sufficient in themselves to cause failure. This is attested by both longer term operational experience in other units having equivalent U-bend configurations and stress conditions, as well as successful long term laboratory testing of U-bend samples exposed to reference primary coolant. The necessary additional factor required to initiate and propagate the defects is the dynamic strain on the U-bend as a result of the flow slot hourglassing.

Dynamic strain data on inconel 600 in primary coolant are not available although testing has been initiated by Westinghouse. However, the effects observed with austenitic stainless steels and high nickel alloys suggest that this dynamic straining effect is an important factor which is believed to be applicable to the U-bend failures.