ENCLOSURE 1

STEAM GENERATOR
INTEGRITY CONSIDERATIONS
FOR
SAN ONOFRE UNIT 1
FOLLOWING
POSTULATED STEAM AND FEEDLINE BREAKS

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SECTION 1

INTRODUCTION

The introduction of auxiliary feedwater flow into a steam generator has the potential to produce a thermal shock to the generator vessel. The severity of this shock depends of course on the temperature of the water injected and the water level present in the steam generator. The system design of San Onofre Unit 1 is such that the steam generators could easily dry out in the case of steam break transients. In such a case, the auxiliary feedwater could be introduced into a hot, dry steam generator.

The purpose of this report is to evalute the impact of such a transient on the integrity of the steam generator shell. Since a number of steam generator tubes have recently been sleeved, a consideration of their integrity has also been included. The integrity of the steam generator tubesheet and internals is also considered.

SECTION 2

SECONDARY SYSTEM PERFORMANCE

The secondary systems for San Onfore Unit 1 contain no main steam isolation valves, and thus all generators operate in tandem. The postulation of a steam break or feedline break results in a rapid decrease in the water level of the steam generator. Both auxiliary feedwater pumps trip off on low secondary pressure, so there is no auxiliary feedwater until the operator takes action. The operating procedures require the plant operator to restart the motor driven pump, and this has been assumed to occur at five minutes from the safety injection signal/ reactor trip.

The operating procedures from San Onofre Unit 1 have recently been revised, and the system has been evaluated for a number of postulated transients where the new procedures are followed [1]. Transients studied include:

- Double ended steam break from full power
- Double ended steam break from zero power
- Intermediate full power steam break
- Small steam break. (0.02 ft^2 per loop)
- Doubled ended feedline break from full power.

Each of the above transients result in a degree of decrease in steam generator water level with the worst cases being produced by the large steam breaks. In these cases the total mass of water in the steam generator drops to zero as early as 200 seconds. The water levels for each of these transients are shown in Table 2-1.

Auxiliary feedwater flow is introduced at no later than five minutes from the safety injection signal, and the flow rate depends on the power level at which the break occurred. The steam break at full power results in higher flow, so it is most severe. The maximum auxiliary feedwater flow rate is limited to 150 gallons per minute per loop by Administrative Controls following manual reinitiation of flow.

Steam Break from full power - Auxiliary feedwater initiates at 5 minutes, providing about 100 gpm per loop. At 950 seconds the flow is throttled back to 25 gpm, and at 1250 seconds, the flow increases again to about 67 gpm. Administrative controls are implemented to limit the primary system cooldown to about 100F per hour.

Steam Break from zero power - Auxiliary feedwater flow begins at 5 minutes, and remains constant at about 25 gpm per loop.

TABLE 2-1

STEAM GENERATOR WATER LEVELS FOR VARIOUS TRANSIENTS

TRANSIENT	WATER LEVEL BEHAVIOR
Large Steam Break at zero power	All S/Gs dry out at 600 sec.
Large Steam Break- full power	All S/Gs dry out at 200 sec.
Intermedidate Steam Break (0.1 ft^2)	No dry out - mass does not decrease
Small Steam Break (0.02 ft^2)	No dry out, mass drops from 69000 lb. to 59000 lb. in 2000 seconds
Double ended Feedline Break	Affected S/G dries out @ 228 sec. Others retain some mass, dropping to about 700 lb. (Mostly steam)

SECTION 3
SECONDARY SHELL INTEGRITY

The geometry of the steam generators for San Onofre Unit 1 is shown in Figure 3-1. The units were manufactured at the Westinghouse plant in Lester, Pa., and began operation in 1967. The secondary shell of these units is composed of A-212 Grade B steel.

The primary impact of a postulated steam line break is to introduce auxiliary feedwater into the secondary side during a time when the water has been exhausted, resulting in a thermal shock. To evaluate the impact of this postulated transient, fracture analyses were carried out on a number of regions of the secondary side, as shown in Figure 3-1.

3.1 Analysis Methodology

The analysis methods used were identical to those suggested for thermal shock analysis in Section XI of the ASME Boiler and Pressure Vessel Code, and employ linear elastic fracture mechanics (LEFM). The stress intensity factor for a postulated series of flaw depths is calculated, and compared with the material fracture toughness. This comparison is carried out at a number of times during the thermal transient of interest, and the smallest value of calculated critical flaw size is reported.

The stress intensity factor for all cases was calculated by the solutions published by McGowan and Raymund [2]. The fracture toughness of the material was taken from the reference K_{Ic} curve of the ASME Code, Section XI. The values of RT_{NDT} used for the analysis are the most conservative values for the material of interest, since specific values were not determined for the actual vessels. The value of RT_{NDT} was assumed to be 60F for all regions, even though it is highly likely that the true value will be lower.

Detailed analyses are reported here for four different regions of the secondary shell. These analyses were performed for other steam generator models, but are believed to conservatively applicable to the San Onfore steam generators.

3.2 Tubesheet Stub Barrel Region

Results for the stub barrel region were taken from an analysis completed for a much more severe transient on a Model F steam generator [3]. The transient analyzed was a steamline break which resulted in 32F auxiliary feedwater injection into a dry steam generator, at a flow rate of 1500 gpm, about 10 times the maximum possible flow for San Onofre. The auxiliary feedwater temperature at San Onofre ranges from 40-100F, so the temperature assumed is also very conservative.

The results of this analysis are presented in Figure 3-2, and show that the critical flaw depth for the governing time step is approximately 1.6 inches. The wall thickness for the Model F is 3.13 inches in this region, so the critical flaw depth is over half the wall thickness. The corresponding wall thickness for the San Onofre steam generator is 3.38 inches, so the results are clearly conservative.

3.3 Lower Shell/Cone Junction

The fracture analysis results for this region were taken from the same reference as those for the stub barrel [3] using the same conservative transient. In the Model F steam generator the wall thickness in this region is about sixteen percent less than that of San Onofre (2.84" vs 3.38) so the thermal stresses calculated will be slightly lower than those for the same transient on the San Onofre geometry. The transient imposed is so much more severe than the worst case possible for San Onofre that the net result is a very conservative analysis.

A specific critical flaw size was not reported in reference 3 for this transient, but it was shown that the critical flaw size was greater than 25 percent of the vessel wall. The calculated stress intensity factor for a quarter thickness flaw oriented axially was 100 ksi$\sqrt{in}$, while the fracture toughness in the region was at the upper shelf, or 200 ksi$\sqrt{in}$. Therefore the critical flaw depth is greater than quarter thickness, or greater than 0.71 inches.

3.4 Feedwater Nozzle

The fracture evaluation for the feedwater nozzle was again taken from an analysis conducted on a Model F steam generator with the same low temperature and high flow rates discussed above. The Model F feedwater nozzle geometry is shown in Figure 3-3, and the thickness in the nozzle knuckle region is 6.33 inches. The feedwater nozzle in the San Onofre steam generators is slightly thicker overall than that for the Model F, as may be appreciated by comparing the shell thickness at the nozzle to shell weld (3.76 inches vs. 3.9 inches for San Onofre)

The actual critical flaw depth for the feedwater nozzle was not reported in reference 3, but it was shown to be greater than 25 percent of the ligament, or 1.6 inches. The stress intensity factor for a quarter thickness flaw at the governing time step was 151 ksi$\sqrt{in}$, as compared to the fracture toughness of 200 ksi$\sqrt{in}$.

3.5 Uppper Shell/Cone Junction

Results for this region were obtained from a detailed stress analysis recently carried out for a Model 44 steam generator [4]. The flow path for auxiliary feedwater in the San Onofre steam generators is such that the feedwater can come into contact with the upper shell/cone weld after spilling onto the splash plate from the feedring. Such a scenario is very unlikely for Model F generators, because the splash plate is located somewhat below the weld. On the other hand the location of the splash plate for the Model 44 is very nearly the same as for San Onofre, so the analysis of the upper shell cone weld should be directly applicable.

The steam line break transient analyzed in this case involves cold feedwater introduced into a hot dry steam generator, but the temperatures and flow rates are different. The auxiliary feedwater temperature is 70F, and the flow rate is 350 gallons per minute. The temperature is probably a reasonably realistic value for the feedwater at San Onofre, keeping in mind that even if the original temperature was lower, the water would be heated up somewhat by the time it contacted the shell. The flow rate used is over twice the maximum flow rate possible for San Onofre, and therefore the transient is quite conservative. The wall thickness for the Model 44 in this region is 3.5 inches, compared to 3.89 inches for San Onofre.

A fracture analysis was carried out specifically for this report using the stresses reported in reference [4]. Results showed that there is no critical flaw depth for this region; that is no flaw would propagate in this region regardless of depth during a large steam break.

3.6 Results and Conclusions

The analytical results shown in this section clearly show that the structural integrity of the secondary shell of the San Onofre steam generators will not be threatened by the occurrence of a large steam break. Although the steam generators are likely to dry out in the case of such an event, the auxiliary feedwater flow will not cause a thermal shock of great severity because the flow rate is too low. Furthermore, the consequences are judged to be even less severe than those reported here, because the transients on which the analyses are based on much more severe than those which could occur at San Onofre.

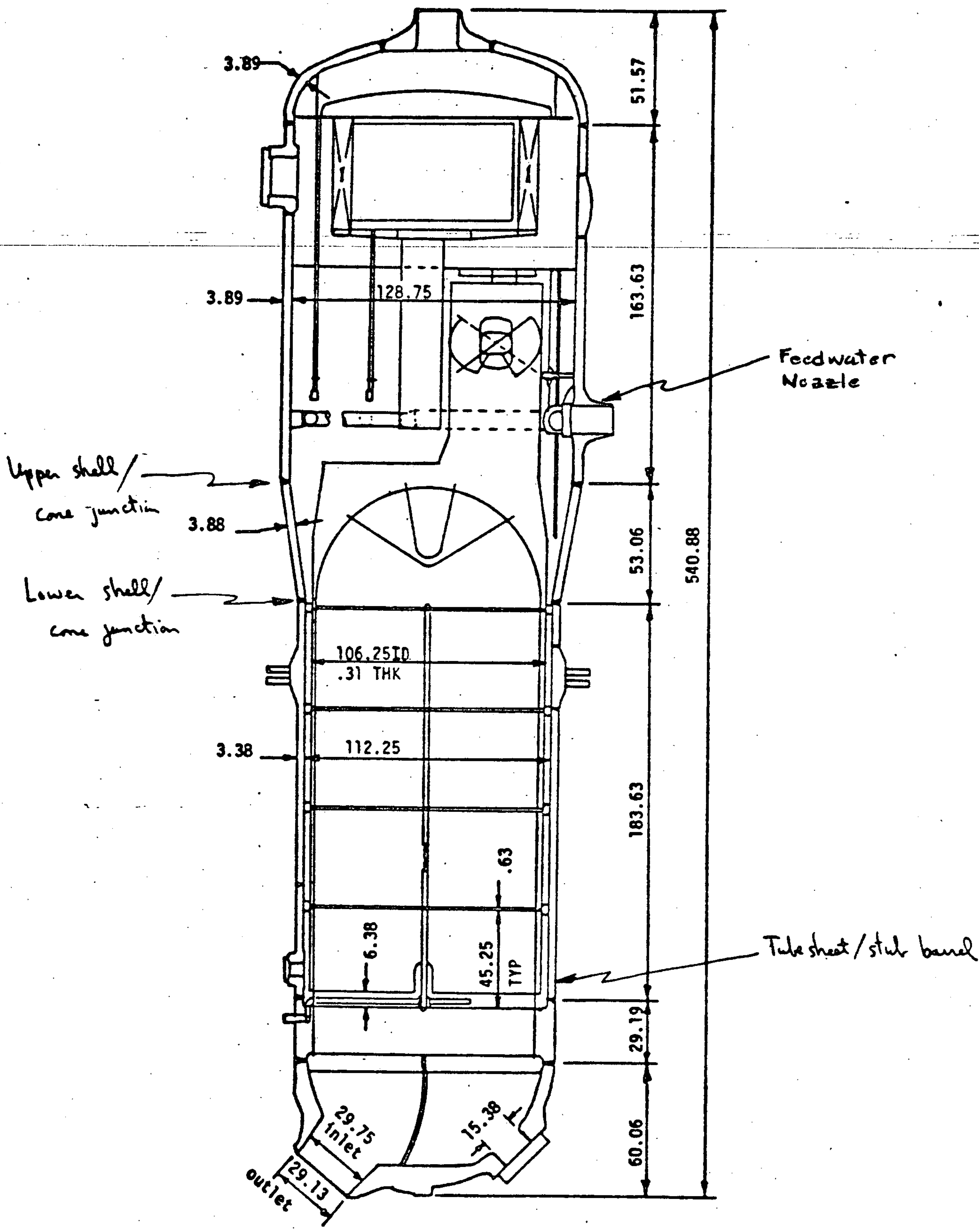


Figure 3-1 Geometry of San Onofre Unit 1 Model 27 Steam Generator; with Locations analyzed for Large Steam Break

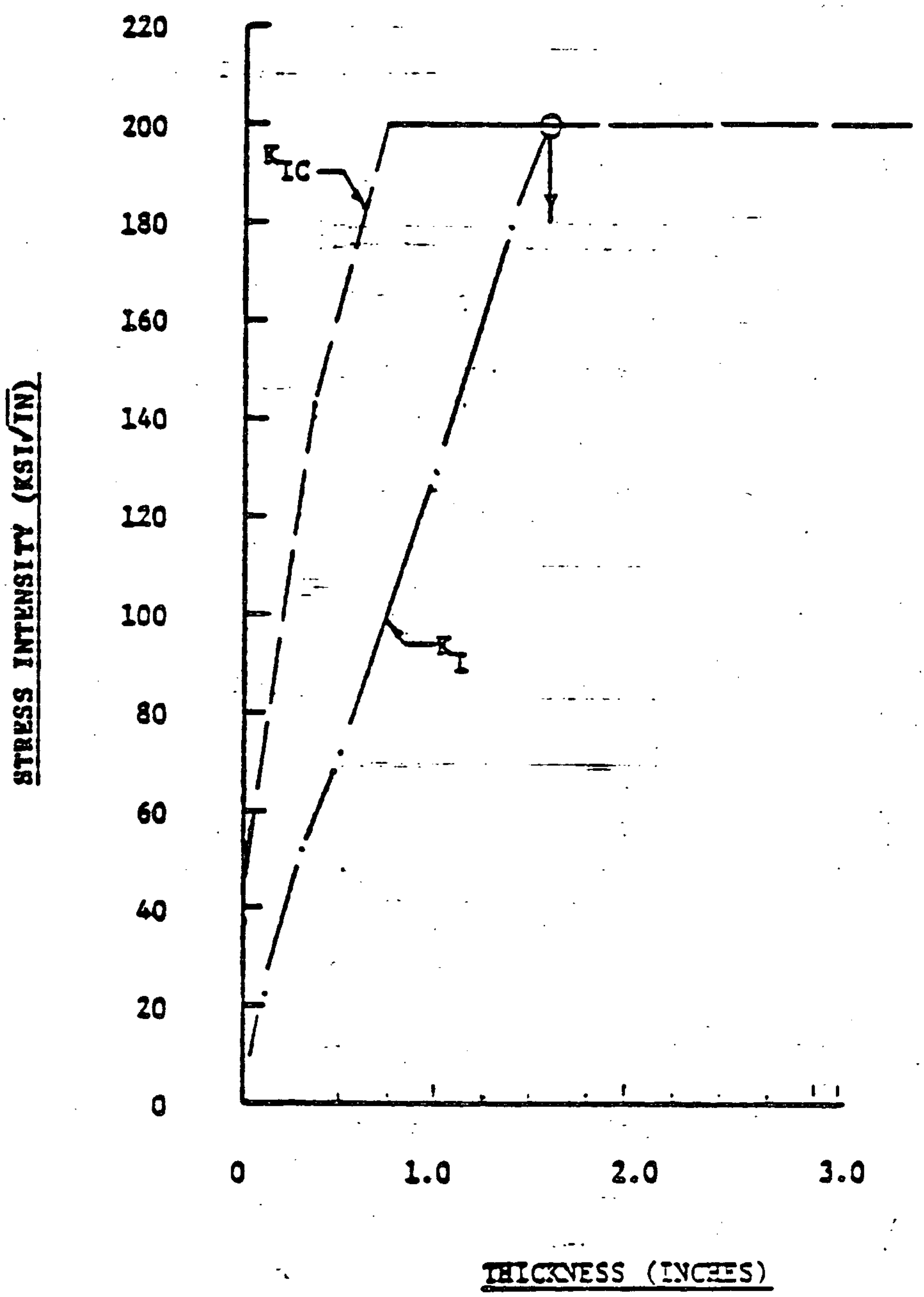
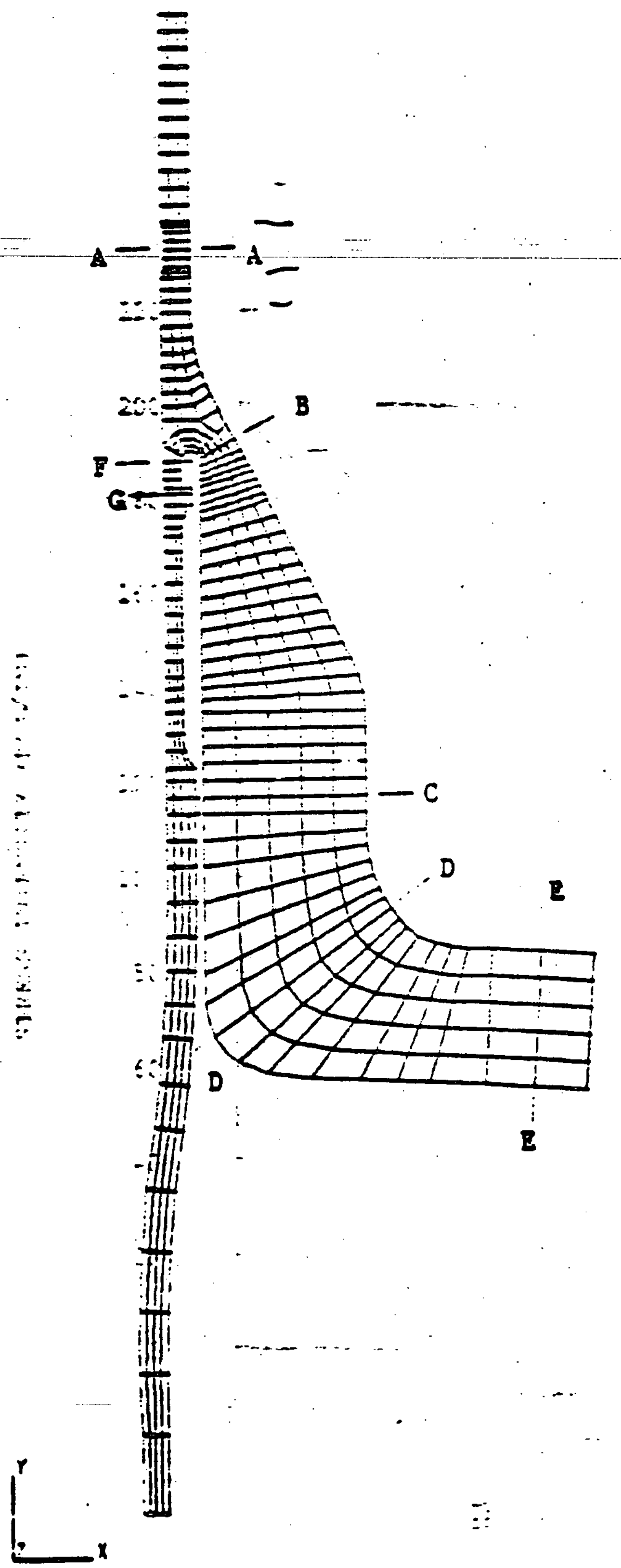


Figure 3-2. Critical Flaw Depth for Stub Barrel Region @ 77.5 seconds after Large Steam Break



Section	Node	Thickness (in.)
A-A	321 through 330	.7546
B-B	736 through 751	1.24
C-C	2354 through 2369	4.75
D-D	2850 through 2865	6.327
E-E	3346 through 3361	(*)
F-F	783 through 792	.5
G-G	1031 through 1040	.5

*Note: Thickness is 3.94" for thermal analysis and 3.88" for pressure analysis.

Figure 3-3 Geometry of Model F Feedwater Nozzle

SECTION 4

INTEGRITY OF STEAM GENERATOR TUBES

The effect of the injection of cold auxiliary feedwater into the San Onofre steam generators is not of concern to the integrity of the steam generator tubes, whether they be sleeved tubes or original tubes.

The upper regions of the tubes will not feel any effect of the injection because they will be shielded by the wrapper, so the only directly affected region will be the base of the tubes, as the injection water collects on the tubesheet.

Both the original tubes and the sleeves are Inconel 600, a very ductile material which is not susceptible to fracture in the temperature range of interest. The failure mode in these tubes has been shown by extensive testing to be by ductile limit load. The most severe loading on the tubes will be imposed by internal pressure, and the large steam break does not result in the highest pressure difference across the tubes, so it is not the governing transient in this respect. The most severe pressure difference occurs during a postulated feedwater line break, and the critical flaw size for this case is determined in reference 5, and provided in Figure 4-1.

Thermal stresses do not affect the calculated limit load, no matter what their magnitude, so the large steam break will not seriously affect the integrity of the tubes.

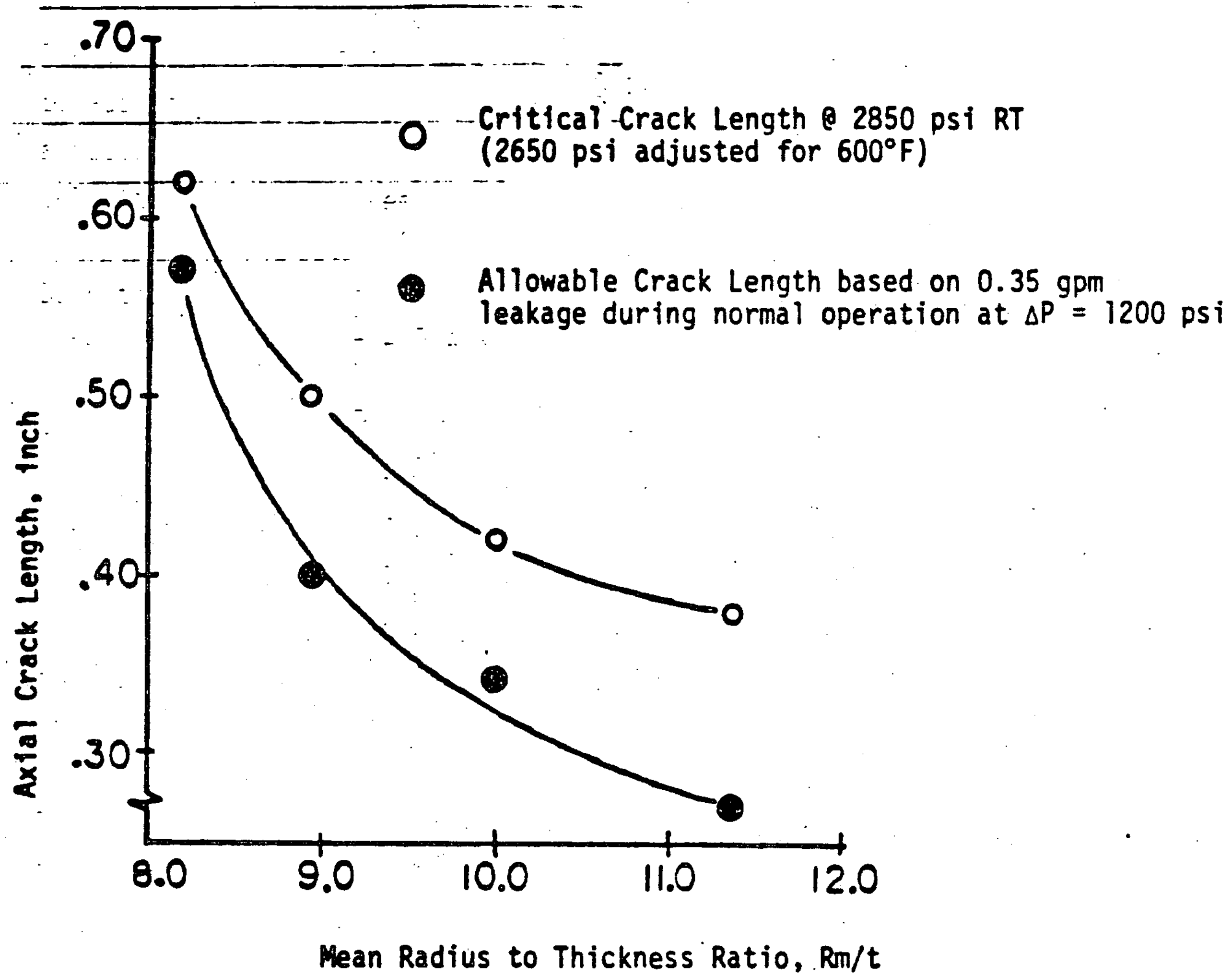


Figure 4-1. Critical Crack Sizes for Steam Generator Tubes (Ref. 5)

REFERENCES

1. Ellenberger, Sharon "SCE Steam and Feedline Backup Analysis for Emergency Procedures" Calculation note CN-TA-82-90, May 1982.

2. McGowan, J. J. and Raymund, M., "Stress Intensity Factor Solutions for Internal Longitudinal Semi-Elliptic Surface Flaws in a Cylinder Under Arbitrary Loading" in Fracture Mechanics, ASTM STP 677, 1979.

3. Adkins, G. L., et. al. "Supplementary Nonductile Fracture Analysis for the Model F Steam Generator". Westinghouse Tampa Report WTP-ENG-81-011, Feb. 1981. (Proprietary Class 2)

4. Gast, R. W. "Model 44 Steam Generator Shell and Transition Cone Analysis for Cold Feedwater Effects" Westinghouse Tampa Report WTP-ENG-82-034. May 1982 (Proprietary Class 2)

5. "Steam Generator Repair Report - San Onofre Unit 1" Westinghouse Electric Corp. Report SE-SP-40(80) Rev. 1, March 1981 (Westinghouse Proprietary Class 2)

SECTION 5

INTEGRITY OF STEAM GENERATOR TUBESHEET AND INTERNALS

The effects of the cold feedwater on the tubesheet itself have not been evaluated in this report because the tubesheet is not one of the most governing areas. The tubesheet is about 29" thick and is not as susceptible to cracking because the holes act as crack stoppers. In this region of the steam generator the most highly stressed cross section is the tubesheet/stub barrel weld region and it has been evaluated in detail.

No detailed analyses have been presented for portions of the steam generator internals which are not part of the pressure boundary. The majority of the internals do not encounter the cold auxiliary feedwater because they are shielded by the splash plate and wrapper. The wrapper itself as well as the splash plate are not severely affected by the cold auxiliary feedwater because they are very thin and cool quickly before thermal stresses can build up. These components are subject to very low stress due to other sources so their integrity is not in doubt.