Steam Generator Tube Operational Experience

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Early, commercial nuclear power plant steam generator tubes were formed from Alloy 600, a corrosion-resistant high-nickel alloy. Early supplies of the Alloy 600 tubes were provided in a mill-anneal condition. Most of the steam generator tubes which have required plugging over the years have been mill-annealed Alloy 600 tubes. Information on the operational experience with Alloy 600 tubes can be found in the following NRC Information Notices:

- IN 98-27, "Steam Generator Tube End Cracking"
- IN 97-88, "Experiences During Recent Steam Generator Inspections"
- IN 97-49, "B&W Once-Through Steam Generator Tube Inspection Findings"
- IN 97-26, "Degradation in Small-Radius U-Bend Regions of Steam Generator Tubes"
- IN 96-38, "Results of Steam Generator Tube Examinations"
- IN 94-62, "Operational Experience on Steam Generator Tube Leaks and Tube Ruptures"
- IN 90-49, "Stress Corrosion Cracking in PWR Steam Generator Tubes"

Subsequently, steam generator tube manufacturers determined that by thermally treating the Alloy 600 material for later tubes, the corrosion resistance of the tubes was improved. Industry experience with thermally treated Alloy 600 steam generator tubes suggests that these tubes are more resistant to in-service cracking than mill-annealed Alloy 600 tubes. A few indications of degradation in thermally treated Alloy 600 tubes have been reported, however, and one is discussed in IN 97-26, listed above.

Now, most steam generator tubes for new steam generators are being fabricated from thermally treated Alloy 690, an alloy with a higher amount of chromium and reduced amount of nickel. Alloy 690 is considered to be very resistant to the types of degradation experienced by the Alloy 600 tubes. At this time, the NRC staff is not aware of any primary or secondary side cracking in Alloy 690 tubing.

Some tubes have also been plugged due to fretting and denting, degradation mechanisms due to the design of the support plates and antivibration bars and the presence of loose parts, rather than the tubing material.

In the 20 years preceding the failure at Indian Point 2 on February 15, 2000, there had been seven steam generator tube ruptures in commercial nuclear power plants, all in tubes fabricated from mill-annealed Alloy 600. The last tube rupture occurred in 1993 at Palo Verde, Unit 2. It is considered a tube rupture rather than merely tube leakage when tube leakage of reactor coolant exceeds the makeup capacity. See Table 1 for information about the seven tube ruptures.

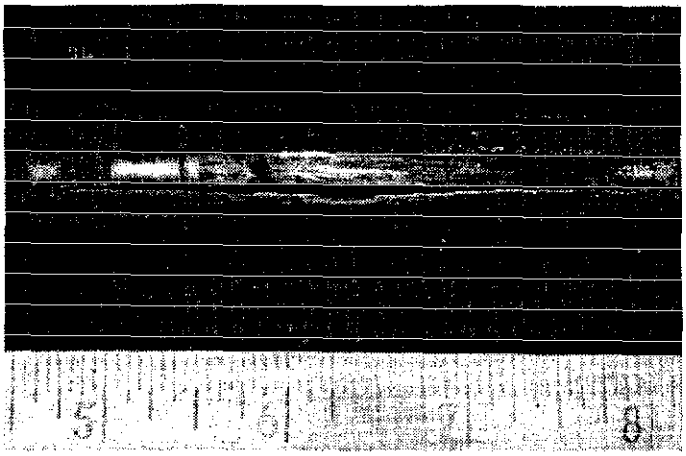

Figure 1. Example steam generator tube rupture at McGuire, Unit 1

There are other cases where defects have grown through the thickness of the tube wall, and caused the tube to leak. In these cases, either the plant was shut down due to the tube leakage, or the through-wall defect was detected as a result of the tube inspection during a plant outage.

Table 1. Steam Generator Tube Ruptures (from NUREG/CR-6365)

Date	Plant, SG Model	Maximum Leak Rate GPM	Degradation Mechanism	Rupture Size	Rupture Location	Stressors and Contributing Factors
2/26/75	Point Beach-1, W-44	125	Wastage	2 adjacent ruptured bulges each about 20 mm long and wide	Slightly above the tubesheet, outer row on the hot leg side	Large sludge pile, ineffective cleaning
9/15/76	Surry-2, W-51	330	Primary water stress corrosion cracking	114.3 mm long axial crack	Top of U-bend in Row 1, Column 7	High stresses and ovalization caused by inward movement of the legs due to support plate deformation
10/2/79	Prairie Island-1, W-51	336	Loose parts wear	38 mm long axial fishmouth opening	Tube bundle outer surface, 76 mm above the tubesheet on the hot leg side, Row 4, Column 1	sludge lancing equipment left in the steam generator
1/25/82	Ginna, W-44	760	Loose parts wear, fretting	100 mm long axial fishmouth opening	127 mm above the tubesheet on the hot leg side, Row 42, Column 55 (third row in from the bundle periphery)	Loose parts (baffle plate debris) left in the steam generator, wear of peripheral tubes, fretting of inner tubes
7/15/87	North Anna-1, W-51	637	High-cycle fatigue	360 circumferential break	Top of the 7th upper tube support plate on the cold leg side, Row 9, Column 51	High-cycle vibration, denting, lack of anti-vibration bar support
3/7/89	McGuire-1, W-D2	500	Outer diameter stress corrosion cracking	95 mm long axial crack in a 645 mm long groove, 9.5 mm wide at the maximum point	711 mm above the tubesheet at the lower tube support plate on the cold leg side, Row 18, Column 25	Long shallow groove, possibly a contaminant
3/14/93	Palo Verde-2, CE-80	240	Outer diameter stress corrosion cracking	65 mm long axial fishmouth opening in a 250 mm long axial crack	Freespan region between the 08H and 09H tube support structures on the hot	Tube-to-tube crevice formation, bridging deposits, caustic secondary water

					leg sid, Row 117, Column 144	chemistry, susceptible material

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