NUCLEAR SHUTDOWNS: TUBULAR WOES

Problems with steam generator tubes in nuclear reactors are forcing shutdowns and changes in operating procedures

BY IVARS PETERSON

Thousands of thin-walled tubes, each no wider than a thumb, stretch upward and fill the lower half of a typical steam generator in a pressurized water reactor. Inside a massive, eight-story cylinder, those water-filled tubes transfer heat from the reactor's core to an independent, secondary water supply circulating around the tubes and turn it to steam, which drives a turbine generator. Tube failures, like the recent incident at the Ginna power plant in Ontario, N.Y. (SN: 1/30/82, p. 68), are turning out to be an expensive and complicated problem for utilities to solve.

A Nuclear Regulatory Commission report, released in November 1981, concludes that tube deterioration results from "a combination of inadequate design and fabrication, non-optimum secondary system design and materials of construction, and poor operating practices, especially, in the secondary water chemistry control." The report also notes that additional inspection, repair and replacement efforts add significantly to worker radiation exposure.

In the primary cooling system, water under high pressure (to keep it from boiling) passes through the reactor vessel and picks up heat to reach a temperature as high as 310°C. The water also collects traces of fission products leaking from fuel rods and becomes slightly radioactive. In addition, oxygen atoms within water molecules may transmute into nitrogen-16, a highly radioactive isotope, but because of its short half-life, the nitrogen-16 decays to almost undetectable levels within a few minutes.

Although the water flows through a stainless steel system, some corrosion still occurs. The corrosion products, including iron, nickel and chromium compounds, circulate with the cooling water and can turn into materials containing radioactive isotopes such as cobalt-60, which has a long half-life. Because these radioactive products can deposit throughout the system and build up over the lifetime of a plant, routine maintenance and repair is increasingly difficult. Much effort has gone into developing demineralizer systems for keeping the water pure.

During the Ginna incident, about 7,200 liters (1,900 gallons) of this radioactive coolant water was released into a bay beneath the reactor.

When the reactor-heated water reaches the steam generator, it must transfer some of its heat to the secondary cooling system to produce steam. William Layman of the Nuclear Safety Analysis Center at the Electric Power Research Institute says that in designing the heat exchanger, the engineer must balance heat transfer, which requires thin-walled tubes and large surface areas, against strength, which suggests thick-walled tubes. Steam generator tubes are generally made of a nickel-based alloy called Inconel, about one millimeter thick.

Most tube problems involve corrosion or vibration damage. However, the term "corrosion" covers a spectrum of processes that may be sensitive to subtle changes in factors like temperature, type of alloy, salt content and pH. Egon Matijevic, a corrosion expert at Clarkson College in Potsdam, N.Y., says, "There are conditions where a small change in a parameter can have a big effect." A reactor built in the United States can have very different corrosion rates and problems compared to an identical reactor sold in Japan. Problems may vary even among units within a nuclear plant.

A significant part of the corrosion oc-

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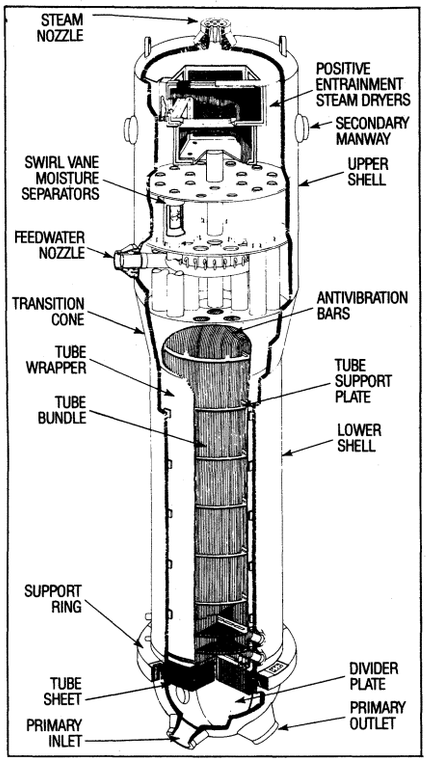


Steam generators are massive, 20-meter-tall structures, shown below during construction of a nuclear reactor. Inside, at left, thousands of thin-walled tubes fill the lower part of the generator. Corrosion problems can occur at the tube sheet or at support plates.

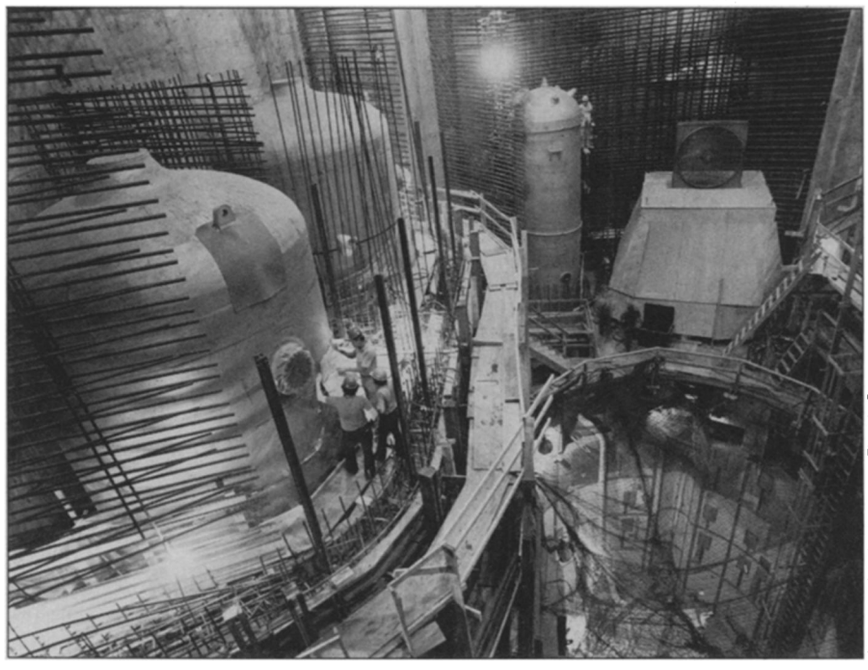
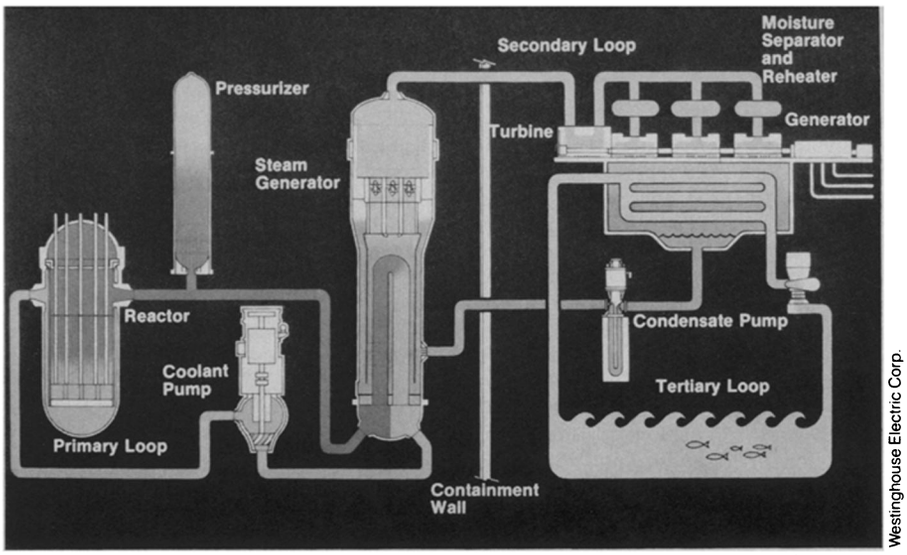


Photo and Art: Westinghouse Electric Corp.

SHUTDOWN *(Cont. from p. 105)*

In a pressurized water reactor, the primary loop carries hot, high-pressure water from the reactor to the steam generator, where water in the secondary loop is turned to steam to drive a turbine.



Westinghouse Electric Corp.

curs on the secondary coolant side of the steam generator tubes, affecting the tubes from the outside. Denting appears when plates supporting the tubes begin to rust. Because rust occupies a greater volume than the carbon steel it replaces, the tubes are squeezed inward. Tubes are also vulnerable to pitting, in which small holes appear on the tubes' surfaces, and to erosion caused by the movement of fluids. Contaminants in the secondary system water, like copper oxides and phosphates, also appear to promote corrosion.

Carlo Caso of Westinghouse Electric Corp., one of three companies designing pressurized water reactors, says, "The steam generators require a very carefully controlled chemistry. At the beginning, there was probably less attention given than necessary, and in those cases we observed corrosive attack at a rate faster than was expected."

Among improvements made since the problems were discovered are using stainless steel instead of carbon steel for tube supports and heat treating the Inconel alloy to give it a greater resistance to corrosion by changing the microscopic grain structure. Contamination in the secondary system is reduced by eliminating copper alloys in the secondary cycle, reducing leakage of air into the system and flushing with hydrazine to remove soluble impurities. Lowering operating temperatures also cuts down the rate of corrosion, but power production then must be cut back, too. Only units with substantial corrosion problems go this far.

Periodic tube inspections are essential to ensure tubes remain strong enough and do not leak excessively. The usual inspection technique is to insert a test coil, excited by an alternating current, along the full length of a tube. The resulting magnetic field induces eddy currents in the tube wall. The operator monitors disturbances in the eddy currents caused by flaws, but dents and tube support plates can distort the signals, making it difficult to detect flaws in those areas. Stress corrosion, small pits and fatigue cracks are also hard to pick up.

In two nuclear power plants in the last year, corrosion problems were severe enough to require replacement of the steam generators. More than 30 of the 48 pressurized water reactors in the United States have reported tube problems since 1975, while five plants have suffered tube rupture and extensive leakage into the secondary system forcing a plant shutdown. However, the reasons for the failures varied considerably, including stress corrosion cracking and damage due to a loose spring from some sludge removal equipment used earlier.

At the Ginna nuclear reactor, the problem was an axial crack in one tube, about 8 centimeters above the tube sheet. Layman says it isn't obvious that a corrosion-type failure occurred. "It's not one of the classical things that have been talked about in the past in other steam generators, where there is an obvious corrosion mechanism inducing it," he says.

Layman says nuclear plants are designed to handle leaks, but the problem at Ginna was complicated by a power operated relief valve that stuck open and lowered the pressure in the primary system more than the operators wanted. They corrected for that by starting the high-pressure injection pump after closing a backup valve. This raised the pressure rapidly enough so that the pressure transmitted through the leak opened the safety valve on the secondary side of the steam generator. Thus, about 485 curies of radiation in the form of noble gas isotopes were released to the atmosphere from the contaminated steam.

Layman says, "Nobody ever expected the generators to go 40 years without ever having tubes break." Detecting problems and making prompt repairs reduce the chance of a break. This involves plugging weakened tubes to take them out of service, or sleeving them. The sleeving operation consists of inserting a tube of smaller diameter to strengthen a tube or, in one plant, to alter the natural frequency of a tube to eliminate or reduce flow-induced vibrations.

Matijevic, whose research group is investigating corrosion from the viewpoint of colloid and surface chemistry and developing model corrosion systems to study the problems under controlled conditions, says, "It's an arsenal of problems which will require the work of a lot of people. Now, with new techniques and model systems, I think we can make progress much faster."

Caso says, "I think research is not the only thing that is needed to extend the life of a steam generator, because there is no way to find a material that would be completely immune to corrosion. With proper education and proper attention to details, the present steam generator can operate very well."

The recent NRC report says, "Industry-sponsored research work has helped to identify the causes and mechanisms for several different types of tube degradation that have subsequently led to some design and operating improvements. It is anticipated that tube degradation will continue, perhaps at a slower rate because of better control of variables leading to the problems."

That leaves utilities with an expensive problem to monitor and repair. □