N73. REPAIRING AND REPLACING STEAM GENERATORS AT SOVIET 1000 MWE PWRS

BACKGROUND

Until a few years ago the steam generators used in Soviet PWRs had an excellent performance record, in contrast with the difficulties experienced with these components in the West. Unfortunately, in 1986-89 cracks were encountered in the steam generator cold headers at the 1000 MWe units, which has required an extensive program of analysis, modification, and replacement. Unlike most pressurized water reactors around the world, Soviet PWRs use horizontal steam generators. The 1000 MWe VVER-1000 model uses steam generators of the PGV-1000 type. In contrast with vertical type steam generators (with flat tubesheets), the ends of the heat exchanger tubes in the Soviet horizontal type steam generators are attached to the walls of two vertical cylindrical chambers, the inlet ("hot") header and the outlet ("cold") header. Primary coolant from the core enters through the inlet header, passes through the heat exchanger tubes, and leaves through the outlet header. The hot and cold headers are similar in structure, with normal operating temperatures of 320 °C and 290 °C, respectively. The material used for headers in PGV-1000 steam generators is pearlitic steel (10GN2MFA in the Soviet designation). The headers have an anti-corrosive austenitic cladding on the primary circuit side. During 1986-89, cracks were found in the ligaments between the holes in the perforated zones of the cold headers of PGV-1000 steam generators, where the heat exchanger tubes are attached (the thickness of the header wall is 170 mm in this region). The operating time to the onset of damage was 10,000 to 60,000 hours. Cracks of various depths were encountered in the cold headers, some extending into the cladding on the inner surface. Such cracking had been unknown in steam generator engineering up to this time. No similar damage was found in the hot headers.

ANALYSIS

Among the main findings of the various investigations were:

- Damage appeared to occur exclusively in steam generators where the heat exchanger tubes had been rolled explosively into the header, using "rigid" charges with a water layer.
- Header deformation resulted because the rolling procedure turned out to be mismatched with the axially asymmetrical structure of the perforated zone of the header.
- Deformation of headers and their seizure in the steam generator vessels during the tube-rolling process meant that headers were already loaded with high residual stresses (actually equal to yield strength) before arriving at site.
- In addition to the general plastic strain in the perforated zone, the practice of drilling deep holes into the header wall coupled with the explosive tube rolling technique led to the formation of a layer of embrittled cold-worked metal (strain up to 70%) in the ligaments near holes.
- The cold-worked layer proved to be very sensitive to cracking even at insignificant strains (up to 3%), especially in aqueous acidic conditions, with a tendency also to suffer pitting corrosion in aqueous conditions.

- The crevices arising from under rolling (with depths up to 20 mm) turned out to be the areas with the most severe corrosion, with initiation and propagation of cracks via the mechanism of stress corrosion cracking and subsequent propagation into the whole ligament.

- The operating temperature of the cold header was unsatisfactory for the header material because at 290 °C the 10GN2MFA steel undergoes strain aging. This does not occur at the temperature of the hot header (320 °C).

- In the under-rolling zones that were totally clogged up with corrosion products and deposits to the extent that the presence of water electrolyte was excluded (i.e., conditions were consistent wit those of the hot headers), corrosion damage and cracks were absent.

- Departure of water chemistry conditions from normal limits during operation, especially a fall in pH to acid values, accelerated the cracking process in the headers and led to a decrease in the time to initiation.

IMPROVING RELIABILITY

This information came to light only after several dozen of the PGV-1000 steam generators had already been manufactured.
To improve header reliability, it was clear that the following measures were needed:

- Lower stress levels to acceptable values.

- Develop tube rolling and header drilling procedures that do not impair metal properties in the perforated zone.

- Eliminate the possibility of slot corrosion in the crevices between the header and tube caused by under-rolling.

- Stipulate the required water chemistry conditions.

- Ensure periodic inspection to determine the integrity of the perforated zones in headers.

For more, see Titov, V.F., "Repairing and Replacing SGs at Soviet 1000MWe PWRs," Nuclear Engineering International, pp. 20-22, January 1991.