LETTERS TO THE EDITOR

COMMENTS ON "FAILURE PROBABILITY OF AXIALLY CRACKED STEAM GENERATOR TUBES: A PROBABILISTIC FRACTURE MECHANICS MODEL"

In Ref. 1, Mavko and Cizelj proposed a strategy for operating pressurized water reactor plants with certain sizes of cracks in the steam generator tubes. The purpose of this letter is to indicate that the proposed method of screening tubes for removal from service may not be sufficiently conservative.

Using a fracture mechanics model, Mavko and Cizelj calculated tube failure probability as a function of the critical crack length following a loss-of-feedwater accident. These results, together with measured crack length distributions, were then used to determine the maximum size of through-wall cracks that may remain in service.

The underlying assumption in this approach is that an actual tube rupture is required to fail a steam generator. It is shown below, however, that if the number of cracks is sufficiently large, significant primary-to-secondary leakage may result from cracks that are smaller than the critical size. Since the leakage rate and the location of the feed line or steamline break will determine how quickly the operator is able to isolate the faulted steam generator, a tube rupture alone is not a sufficient safety criterion for plugging tubes.

Fracture and fluid mechanics considerations[2] indicate that the flow through cracks increases when the pressure differential across the crack is increased. For the 10-mm-long crack discussed by Mavko and Cizelj in connection with plugging limits, an increase from normal operating pressures to design pressures causes the leakage per crack to increase from 0.13 to 0.40 gal/min. Since the flow through 1500 such cracks roughly equals a flow from one ruptured tube, it is apparent that significant flow can be attained through cracks that are smaller than the critical size without actually rupturing a single tube. Thus, a transient may initiate multiple leakages from small through- and partially through-wall cracks.

If one could reliably predict the total leakage increase following a transient, leakage limits during normal operation could reduce the possibility of a sudden increase in leakage during an accident. In the absence of data on flow through cracks under prototypical conditions, however, predictions of flow through thousands of cracks with varying morphology may not be a realistic basis for a "leak before break" strategy.

Even though the frequency of events that can cause a significant primary-to-secondary leak is low (e.g., 10^{-4}/reactor-yr), the frequency of a core melt with containment bypass may be close to the event frequency if the primary- and second-side pressures cannot be equalized promptly. This risk may not justify continuous operation with tubes containing through-wall cracks, even if such cracks are much smaller than the critical size.

[This comment contains information that does not necessarily represent an agreed-upon U.S. Nuclear Regulatory Commission (NRC) staff position. The NRC has neither approved nor disapproved its technical content.]

J. Hopenfeld

U.S. Nuclear Regulatory Commission
Washington, D.C. 20555

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RESPONSE TO "COMMENTS ON 'FAILURE PROBABILITY OF AXIALLY CRACKED STEAM GENERATOR TUBES: A PROBABILISTIC FRACTURE MECHANICS MODEL'"

In Ref. 1, a methodology to estimate the failure probability of axially cracked steam generator tubes was proposed to cope with degradation processes that are increasingly affecting steam generator tubes in the transition zone. The method makes the assumption, among others, that the length and number of cracks in the steam generator tubing has been reliably determined.

The underlying assumption for this methodology is failure prediction based on indications collected during an inspection of all steam generator tubes whereby complete insight into the status of all the steam generator tubes is gained. This approach to gathering information on tube degradation differs from most currently used guidelines for steam generator inspection.

We believe that the proposed methodology for predicting steam generator tube failure probability could become a building block in developing an all-encompassing steam generator maintenance strategy in the future.

In Ref. 2, Hopenfeld expressed his concern about reactor coolant leakage through cracks in steam generator tubes, which was not discussed in Ref. 1. His arguments are correctly based on the fact that more and longer cracks will cause more primary-to-secondary leakage, which could uncontrollably exceed the technical specification limits in coincidence with a hypothetical accident condition. We fully agree with his statement, and there are activities under way to address this important question.

Regarding the strategies, let us briefly analyze the following hypothetical situation and consider a steam generator with tubes made of nickel-chromium alloy 600, severely affected by axial stress corrosion cracking in the tube expansion transition zone. Two inspection and plugging approaches are generally available:

1. The traditional sampling inspection[3] by bobbin coil followed by plugging of tubes with tube wall thickness loss in excess of ~50% is very likely to fail in the detection of such cracks.[4] Furthermore, the decision on plugging is made on estimated tube wall thickness rather than the crack length. Taking into account the prevailing nearly through- or through-wall depth of cracks considered,[5-9] the probability of selective elimination of longer cracks is very low. Our recent experience with inspection results confirmed that there is a very low correlation between the motorized rotating pancake coil crack length and the bobbin coil detection probability. The population of cracks in the tubing may lose some members during the traditional plugging process, chosen practically in a random manner with regard to the crack length. In other words, the probability density of the crack lengths will be virtually unchanged by the plugging process, and the extent of cracked tubes left in operation may be slightly reduced.

2. On the other hand, the 100% MRPC inspection followed by a crack-length-based plugging approach will selectively remove the longest cracks detected. The probability density of the crack lengths is therefore truncated an *appropriate* crack length. Thus, the extent of the population should be decreased in the most dangerous region. Furthermore, decreasing the appropriate crack length clearly reduces the tube bundle failure probability (defined as at least one tube rupture).

According to Hopenfeld, shorter cracks will produce lower leakage, which implies that truncating the probability density of crack lengths at a certain crack length should have beneficial consequences. Regarding the prediction of total leakage increase following a transient, an essentially similar approach can be applied to develop a probabilistic assessment of leakage rates. This could enable prediction of leakage limits during normal operation and full definition of acceptable steam generator operational risk.

B. Mavko and L. Cizelj

Josef Stefan Institute
Ljubljana, Slovenia

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