Non-Propietary

Divider Plate Cracking in Steam Generators

Results of Phase II: Evaluation of the Impact of a Cracked Divider Plate on LOCA and Non-LOCA Analyses

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Technical Update, November 2008

EPRI Project Manager

H. Cothron

ELECTRIC POWER RESEARCH INSTITUTE
3420 Hillview Avenue, Palo Alto, California 94304-1338 • PO Box 10412, Palo Alto, California 94303-0813 • USA
800.313.3774 • 650.855.2121 • askepri@epri.com • www.epri.com

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Westinghouse Electric Company, LLC
Nuclear Service Division
P.O. Box 158
Madison, PA 15663

Principal Investigator
C. Cassino

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PRODUCT DESCRIPTION

Cracking in the steam generator divider plate to stub runner welds has been reported by Electricité de France (EdF) plants. EPRI Report 1014982 describes results of a Phase I conservative detailed analysis of a crack in the divider plate to stub runner weld of a domestic Westinghouse-designed steam generator. Results of the Phase I analysis show that a completely degraded divider plate to stub runner weld would impact tube sheet displacement. Therefore, Phase II work began in 2008 to better understand crack initiation and growth in a divider plate to stub runner weld and the impact on plant accident analyses, American Society of Mechanical Engineers (ASME) stress report fatigue limits, alternate repair criteria, and installed plugs and sleeves. This technical update provides a detailed analysis of the effect of a cracked divider plate on the behavior of a steam generator during normal and accident operating conditions.

Results and Findings

The conclusion of the analysis in this report is that a cracked divider plate is not a safety concern with respect to loss of coolant (LOCA) and non-LOCA transients in the affected steam generator or loop.

Challenges and Objectives

This report is intended for steam generator analysts and engineers in nuclear power. The report is primarily applicable to nuclear power plants that have Westinghouse-designed steam generators, without center stays or floating divider plates. The overall purpose of this report is to establish that divider plate cracking is not a safety significant issue for domestic plants. The specific goal of the analysis in this report is to determine the

- Bounding crack opening area (COA) that should be used in transient analyses for the case of a steam generator with a cracked divider plate
- Impact of steam generator divider plate cracking on LOCA analyses
- Impact of steam generator divider plate cracking on non-LOCA analyses

Applications, Values, and Use

The final report in 2009 will address:

- ASME Code stress report assumptions and an analysis of whether any structural criteria would be violated if the divider plate to stub runner weld is degraded
- Critical flaw sizes that must be detected if inspection of divider plate welds proves necessary
- The impact of a degraded divider plate on field repairs such as tube plugs

EPRI Perspective

The Westinghouse-designed steam generators are the only susceptible steam generators in the domestic fleet, and this is the only ongoing study on the impact of a degraded divider plate in the United States.

Approach

Investigators relied on finite-element analysis to define the input conditions for a variety of thermal-hydraulic models. They adjusted the models as necessary to accommodate a flow path in the steam generator through the divider plate during transient conditions.

Keywords

Divider Plate Cracking
LOCA
Stub Runner Weld
Westinghouse Steam Generators
Steam Generator Transients

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1 INTRODUCTION

There have been several documented cases of crack indications in the divider plate to stub runner weld in steam generators in operation outside of the United States [1]. The function of the divider plate in most Westinghouse steam generators is to provide a separation between the cold and hot legs of the channel head as the primary water enters the steam generator. The divider plate is not considered a primary pressure boundary in the context of this analysis. In most Model F, Model D and Model 51 steam generators the divider plate is also not considered a structural component of the lower steam generator complex.

In most Model F, Model D and Model 51 Westinghouse pressurized water reactor (PWR) steam generators the divider plate is initially welded to the channel head and then attached to the tubesheet via a weld to a strip of metal on the primary side of the tubesheet called the stub runner. The weld between the stub runner and the divider plate is subject to bending and tension during regular operation of the steam generator. The tension on the divider plate occurs as the tubesheet bows from the difference between the primary and secondary operating pressures. The bending on the divider plate occurs because there is typically a temperature and a pressure difference between the hot leg and cold leg side of the tubesheet and divider plate. The weld that connects the stub runner and the divider plate in some steam generators consists of Alloy 600 material. This metal is susceptible to primary water stress corrosion cracking (PWSCC).

EPRI began Phase II work in 2007 to identify the impact of a degraded divider plate to stub runner weld on plant accident analyses, ASME stress report fatigue limits, alternate repair criteria, and installed plugs and sleeves.

This report summarizes a detailed analysis of the effect of a cracked divider plate on the behavior of the steam generator during normal operating and accident conditions. Section 2 provides a bounding crack opening area (COA) analysis. The final COA value is used in the accident analyses. Section 3 summarizes the impact of a degraded divider plate on loss of coolant accident (LOCA) forces. Section 4 summarizes the impact of a degraded divider plate on non-LOCA transients. Section 5 summarizes the quantitative analyses that were necessary for a few of the transient operating conditions.

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BOUNDING CRACK OPENING AREA ANALYSIS

The static finite element analysis (FEA) in Reference 1 calculated the displacements of the tubesheet assuming a constant maximum difference in pressure between the primary and secondary side of the tubesheet.

Figure 2-1
Plot of COA FEA Estimate for FLB Loading Assuming Zero Displacement of the Lower Crack Edge

The COA calculations assume that the lower edge of the crack is horizontal and the upper edge of the crack conforms to the tubesheet displacements. See Reference 1 for a sketch of the assumed crack geometry for the calculations. The COA for the divider plate crack is calculated using the trapezoidal rule, assuming that the displaced shape of the upper edge of the crack can be accurately represented by a series of trapezoids. This is a conservative assumption because approximating the curved shape using straight edges will tend to over estimate the COA. The area of a trapezoid is calculated using the following equation:

Equation 2-1

Table 2-1
COA Summary

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ANALYSIS OF LOSS OF COOLANT ACCIDENT FORCES

Impact of Steam Generator Vertical Divider Plate Cracking on LOCA Forces

Impact of Steam Generator Vertical Divider Plate Cracking on Post-LOCA Long Term Cooling Analyses

There are three types of analyses performed to ensure long term cooling following a postulated LOCA.

Calculation of the Minimum Mixed Mean Sump Boron Concentration

Hot Leg Switchover Time Calculation

Flow Verification

Conclusions

4 ANALYSIS OF NON-LOSS OF COOLANT ACCIDENT TRANSIENTS

Qualitative Scoping Analysis of Non-LOCA Transients for Steam Generator Divider Plate Crack Open Condition

A qualitative analysis was performed to determine if any Non-LOCA transients would be affected by a cracked divider plate. The qualitative analysis suggested that the following conditions could be adversely affected by an open crack in the SG divider plate to stub runner weld:

Quantitative analysis of the above events was necessary to determine the impact to the safety margins. These events can be analyzed with the existing licensing basis RETRAN (Reactor Transient Analysis) models, with some modifications required to appropriately model the leakage pathway created by the cracked divider plate.

In the assessment of the non-LOCA transients, cracking is assumed in the weld between the steam generator tube sheet and the divider plate such that an opening is created along the top of the divider plate. No cracking is assumed between the divider plate and the channel head bowl. The cracking is assumed only in one steam generator, and no cracking is assumed in other steam generators. It is also assumed that the SG tubes are not excessively bent or deformed by any lifting of the tube sheet.

Plant Conditions with Divider Plate Crack Open

It is necessary to first determine the amount of the loop flow bypassing the steam generator tubes as a result of the bounding COA between the steam generator tubesheet and the divider plate. The larger the amount of the bypass flow, the more pronounced the effect of the COA is expected. Hence, the minimum possible value of the form loss coefficient is assumed for the bypass geometry.

Qualitative Assessment of Bypass Flow

Category #1

For the Non-LOCA transients in this category, the most limiting conditions for the primary criteria occur in a very short time, i.e., within one reactor coolant system (RCS) loop cycle. As a result, the reduced SG heat transfer by the COA would have either no impact or a negligible impact.

Category #2

The most limiting conditions for the primary criteria for the Non-LOCA transients in this category occur after several loop cycles. These transients assume that all loops are available, i.e., all reactor coolant pumps running. Asymmetric steam generator tube plugging (SGTP) conditions are analyzed with the maximum +/-5% difference among the loop flow rates. As these Non-LOCA events are primary system heat-up events due to reactivity anomalies (either positive or negative reactivity addition), the primary heat generation is more dominate than the reduction in steam generator heat transfer area. Consequently, these Non-LOCA transients would have either no impact or an insignificant impact due to the COA. Hence, the current analyses results remain unchanged.

Category #3

Category #4

COA Resulting in Less Cooling in the Faulted Loop

COA Resulting in Cooler Water on the Intact Loop

Category #5

Category #6

Category #7

Category #8

Conclusions of Qualitative Assessment on Non-LOCA Transients

Table 4-1
Non-LOCA Transients Based on Standard Non-LOCA Design Basis Events

Table 4-1 (continued)
Non-LOCA Transients Based on Standard Non-LOCA Design Basis Events

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QUANTITATIVE EVALUATION OF NON-LOCA STEAM GENERATOR TRANSIENTS

The qualitative evaluation of the non-LOCA analyses for the impacts of the crack opening between the steam generator divider plate and tubesheet summarized in Section 4 is documented in Reference 4. The qualitative evaluation stated that the COA would reduce the steam generator heat transfer due to some of the loop flow bypassing the active heat transfer region of the tubes. The reduction of the heat transfer was expected to be small, and therefore, the reduced heat transfer would not have an impact for a short duration. However, longer transients may have been adversely affected by the COA, and the evaluation identified the following transients that may be adversely affected by the COA:

Evaluation for Steady-State Conditions with the COA

Transient with the COA

Conclusions

6
CONCLUSIONS

7
REFERENCES

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