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INTEGRATION OF PTS STUDIES TO CALCULATE THROUGH-THE-WALL CRACK PROBABILITIES*

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This paper describes a NRC-sponsored research project formed to help confirm the technical basis for the proposed Pressurized Thermal Shock (PTS) rule, to aid in the development of guidance for licensee plant-specific PTS analyses, and to examine the effects of proposed corrective measures. The research project, still under way (10/84), consists of PTS pilot analyses for three PWRs: Oconee Unit 1, designed by Babcock and Wilcox; Calvert Cliffs Unit 1, designed by Combustion Engineering; and H. B. Robinson Unit 2, designed by Westinghouse. The study team consists of Oak Ridge National Laboratory (ORNL), Idaho National Engineering Laboratory (INEL), Los Alamos National Laboratory (LANL), Brookhaven National Laboratory (BNL), and Purdue University, with the results being integrated by Oak Ridge National Laboratory (ORNL).

The overall objectives of the PTS studies at ORNL are: (1) to provide for each of the three plants an estimate of the frequency of a PTS-induced through-the-wall crack (TWC); (2) to determine the dominant overcooling sequences, plant features, and operator and control actions, as well as the important uncertainties, in the PTS risk; and (3) to evaluate the effectiveness of potential corrective measures for reducing the TWC frequencies. ORNL is also to determine what parts of the studies might have generic applicability.

Thousands of hypothetical overcooling sequences were constructed for each plant analysis using computer-generated event trees based on quantified event initiating frequencies and branch probabilities. A screening frequency of 1.0E-7 per reactor year was used to screen out those sequences (scenarios) which had a very low probability of occurring. All remaining scenarios were considered explicitly, and those scenarios screened out were grouped into "residual" groups to ensure that their contributions to the TWC frequency were included in the study.

Full-scale thermal-hydraulics analyses were performed for a selected number of the scenarios. For Calvert Cliffs the analyses were performed by LANL using the TRAC computer code, and for H. B. Robinson they were performed by INEL using the RELAP5 code. For Oconee both LANL and INEL used their respective analysis tools to analyze selected Oconee transients. The remaining scenarios were analyzed with simpler models by Science Applications, Inc. (Oconee and Calvert Cliffs) and INEL (H. B. Robinson). In addition, mixing calculations were performed by Purdue University for some of the scenarios.

Probabilistic fracture-mechanics calculations were performed by ORNL for all the scenarios for which thermal-hydraulic analyses were performed. The results of these analyses, performed with the computer code OCA-P, were then integrated by ORNL to predict the TWC frequency for each plant. The best estimate values determined for each plant are as follows:

	TWC frequency at 32 EFPY*	TWC frequency at RTNDT+2σ = 270°F**
Oconee Unit 1	5E-6/yr	5E-6/yr
Calvert Cliffs Unit 1	1E-7/yr	2E-7/yr
H. B. Robinson Unit 2	<1E-11/yr	1E-8/yr

*EFPY = effective full power years.
**RTNDT = nil-ductility reference temperature.

It should be noted that the Oconee analysis was the first plant study performed, and the analysts felt that certain assumptions may have led to an overprediction of the actual PTS risk for this plant.

An uncertainty analysis performed for each plant indicated that a factor of about 100 is an appropriate 95% confidence interval, assuming a log-normal uncertainty distribution. The uncertainty in the flaw density in the pressure vessel was found to be the most important contributor to the overall uncertainty in the risk.

For Oconee the dominant risk sequences were basically secondary side initiating events. The vent valves tended to mitigate cooldowns dominated by high-pressure injection (HPI) flow under low loop-flow conditions. This virtually eliminated the importance of loss-of-coolant accidents (LOCAs) as PTS transients. The presence of an integrated control system tended to increase the probability of PTS-type events, and the full pressure head system provided a means by which repressurization could be performed rapidly relative to the other two plants. The most important operator action was determined to be the isolation of the steam generator during an excess steam flow event (either a steam-line pipe break or a steam-line valve failure). This action was especially important since Oconee does not have main steam isolation valves (MSIVs). Reduction of the vessel fluence appeared to be the most beneficial risk reduction action for this plant. Fluence rate reduction factors of 2, 4, and 8 reduced the estimated TWC frequencies by factors of approximately 5, 20, and 50, respectively, at 32 EFPY.

For the Calvert Cliffs plant, which does not have vent valves, the LOCA events were much more important than for the Oconee plant. In fact, the top three dominant risk sequences for Calvert Cliffs involved a small-break LOCA in which total loop flow stagnation was predicted. (It should be noted that each of these sequences occurred at low decay heat condition, and loop flow stagnation was not predicted for small-break LOCA events occurring at full power. In fact, none of the sequences occurring from full power were considered major contributors to the overall PTS risk.) The relative importance of each initiator class for Calvert Cliffs can be seen in Figure 1, in which the TWC frequency is plotted as a function of RTNDT, fluence, and EFPY for each initiator class as designated below:

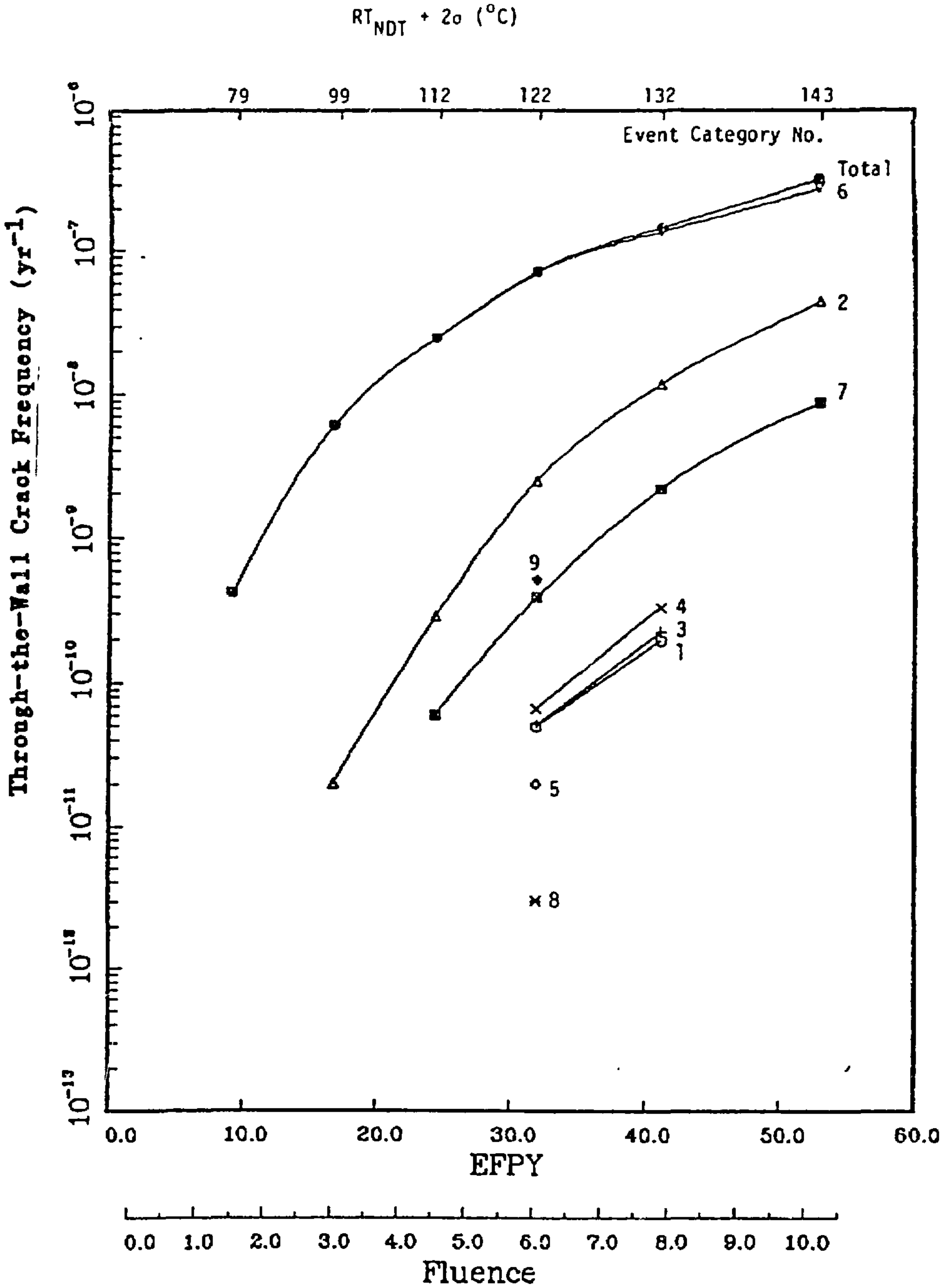

Figure 1. Risk associated with each category of events.

1. Large main steam-line break at low decay heat.
2. Small main steam-line break at low decay heat.
3. Large main steam-line break at full power.
4. Small main steam-line break at full power.
5. Small-break LOCA (<0.16 sq. ft.) at full power.
6. Small-break LOCA (<0.05 sq. ft.) at low decay heat.
7. Small-break LOCA (>0.016 and <0.05 sq. ft.) at full power.
8. Steam generator overfeed.

The HPI shutoff head design for Calvert Cliffs (1275 psi) had a major impact by slowing the repressurization process and thus reducing the PTS risk. Operator actions associated with the overcooling initiating events considered in this analysis appear to be less important with respect to PTS than in the analysis for the other two plants. This is due to the automatic function design of the MSIVs and auxiliary feedwater block valves. Heating of the HPI water was found to have a major impact on the risk values since the dominant risk sequences involved cooldowns associated with HPI water. Increasing the HPI water by about 30°F was found to decrease the TWC frequency by nearly a factor of 10. In addition, as in the Oconee analysis, fluence reductions were found to be a reasonable means for decreasing the potential for a through-the-wall crack.

Since the H. B. Robinson conclusions are still being developed, they are not presented in this paper. However, there are some general findings which can be addressed. First of all, the very low RTNDT value at 32 EFPY (<200°F) resulted in very low conditional failure probabilities, making the fracture mechanics calculations difficult. As a result, conservative extrapolations were used to bound the estimated TWC frequency at 32 EFPY, and most of the calculations were performed for a hypothetical H. B. Robinson plant which had a RTNDT value of 270°F. Secondary side initiating events were found to be the dominant sequences for this plant condition. The LOCA events did not result in stagnant flow for break sizes less than 2 in., and thus the cooldown was not severe. For LOCAs 2 in. in size or slightly larger, stagnation did occur very early and downcomer temperatures of approximately 100°F were obtained within 45 min. However, although many cracks were initiated, the pressure drop associated with the transient was rapid. Thus, there was no driving force on the crack and nearly all initiated cracks arrested.

The H. B. Robinson analysis will be completed and a separate report will be issued in the coming year for each plant studied. In addition, a comparison of the three studies will be made to provide a better understanding of the PTS issue.