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EFFECTS OF CONDENSATION MODELING ON TRANSIENT BEHAVIOR OF PRESSURIZED WATER REACTORS*

by

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In simulating pressurized water reactor (PWR) transients with large-scale systems codes such as TRAC and RELAP, the effect of condensation has been recognized as a controlling mechanism in the prediction of plant response. For transients involving contraction of or loss of primary coolant, the rate of condensation (primarily in the pressurizer) controls the system refill characteristics.

Several separate but interacting phenomena occur during the process of pressurizer refill: steam compression, system heat losses, thermal stratification or mixing of liquid, and condensation. The relative importance of each of these processes and the degree of interaction between them during different transients is very complex. The existing condensation models do not adequately describe the interplay between these effects and this leads to uncertainties in the predicted system response. Further experimental data and code assessment are required to provide data necessary for improving condensation models.

Three examples of transients involving uncertainties introduced by condensation modeling are (1) pressurized thermal shock (PTS) transients, (2) small break loss-of-coolant accidents (SBLOCA), and (3) steam generator tube ruptures (SGTR).

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*Work performed under auspices of United States Nuclear Regulatory Commission.

Pressurized thermal shock refers to a sequence of events in which rapid primary cooling followed by repressurization may lead to initiation of defects or propagation of existing defects in the embrittled section of vessel walls. The pressure stresses coupled with the thermal stresses are necessary for this to occur. Calculations of the system overcooling, refilling, and repressurization, therefore, depend greatly on the condensation models employed. The rate and amount of pressurization are important to the prediction of defect initiation or propagation, and the uncertainties associated with the condensation must be resolved to allow accurate predictions of this behavior.

The response of a Babcock-and-Wilcox lowered-loop plant following a break in one of the main steam lines was calculated with TRAC-PD2[1]. Primary coolant temperatures and pressures calculated with TRAC for somewhat different assumptions on the feedwater flows (cases 1 and 2) are compared in Figs. 1 and 2 with results obtained from the IRT code[2]. The plant model for case 1 had a 4-node pressurizer model, while for case 2, a 20-node model was used. The cold-leg temperatures for the three calculations are in good agreement, whereas the transient pressures differ markedly after about 600 s, when the pressurizer begins to refill. This difference is ascribed to the differing condensation models in TRAC and IRT. For the pressurizer being refilled with subcooled liquid, the TRAC-calculated condensation rates were found to be much too large, while the IRT calculations had no condensation. The large condensation rates in TRAC were a result of a turbulent flow assumption and the use of the bulk fluid temperatures in the calculation of interfacial heat-transfer coefficients.

Analyses of the TRAC results showed that primary repressurization was very sensitive to both the condensation rate and the noding in the pressurizer. The sensitivity of TRAC-calculated repressurization to changes in the condensation rates is shown in Fig. 3. For this illustration, the pressure response shown by the solid line was obtained by filling the fine-mesh pressurizer (20 nodes) with subcooled liquid assuming a surge line velocity of 10 m/s. The upper and lower dashed lines in this figure show the effect of 'order-of-magnitude' changes in the interfacial heat transfer coefficients. The effect of pressurizer noding is shown in Fig. 4, where the pressures for coarse and fine nodings are compared The pressure response varied according

to the number of nodes used, and approximately 20 nodes were required to achieve reasonable results.

Small-break loss-of-coolant accidents also involve system refill and repressurization. The rate and amount of pressurization during refill affects the rate of emergency coolant injection and, in B&W plants, the recovery of natural circulation flows in the primary coolant loops. Calculations of a small-break loss-of-coolant accident in a B&W plant were performed with the TRAC-PF1[3] computer code. In these calculations, the break was closed after the pressurizer, the upper head and the hot-leg 'candy canes' had filled with steam, blocking natural circulation flows. The primary refilled with subcooled liquid from the high pressure injection system. The resulting primary repressurization was accompanied by steam condensation in the upper head, pressurizer and candy canes. The recovery of natural circulation flows depends on condensing or collapsing steam bubbles in the candy canes, and this is affected by condensation in the pressurizer.

A special variant of the SBLOCA is the steam generator tube rupture. To isolate the primary leakage during a SGTR, it is necessary to reduce the primary pressure to the pressure of the steam generator secondary. One strategy to aid in this depressurization is to open the relief valves on the intact steam generators, thereby enhancing the primary-to-secondary heat transfer. The resulting primary cooling increases the condensation rate, contracts the primary liquid and reduces the internal energy of the primary liquid. All of these affect the time necessary to decrease the primary pressure and involve feedback mechanisms associated with refilling the primary.

These transients exemplify the importance of accurate, comprehensive condensation models. Many synergistic effects occur during these transients and the dominant mechanisms must be identified and quantified to allow reliable predictions of the transient events and consequences.

Improved models for condensation are being developed and evaluated against experimental data. In the improved pressurizer model, wall condensation is handled by Nusselt's film analysis.[4] The interphasic exchange rates are calculated by suppressing heat transfer from the interface to the liquid during condensation. This is equivalent to assuming the liquid to be at saturation for condensation calculations, and enables modeling the pressurizer component using a single node. The foregoing approximation appears adequate

as only a small fraction of the total vapor heat loss (less than 10%) is attributable to condensation on the liquid surface.

Figure 5 shows a comparison between a TRAC-PF1 calculation using the new single-node pressurizer model and the experimental data of Saedi and Griffith[5] during an insurge. Although the results are encouraging and indicate a substantial improvement, it should be noted that the TRAC model uses condensation coefficients estimated from the same experimental facility, and generalizations about the adequacy of the model are not yet possible. More extensive code-data comparisons are needed to assess the validity of the model for a range of transient conditions.

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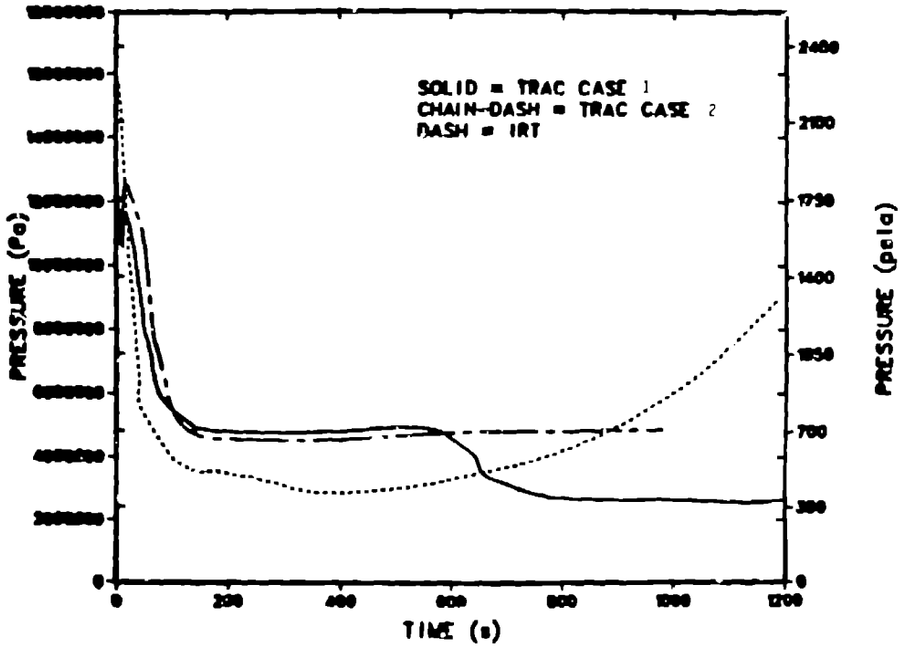

Fig. 1.
Comparison of primary coolant system cold-leg temperature from TRAC (cases 1 and 2) and IRT (Ref. 2).

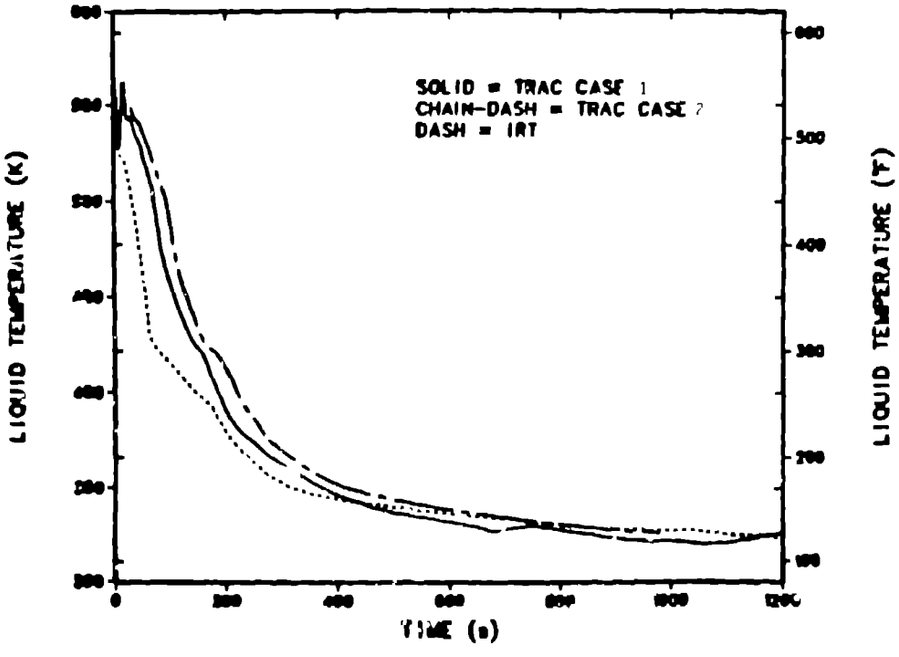

Fig. 2.
Comparison of primary coolant pressure from TRAC (cases 1 and 2) and IRT (Ref. 2).

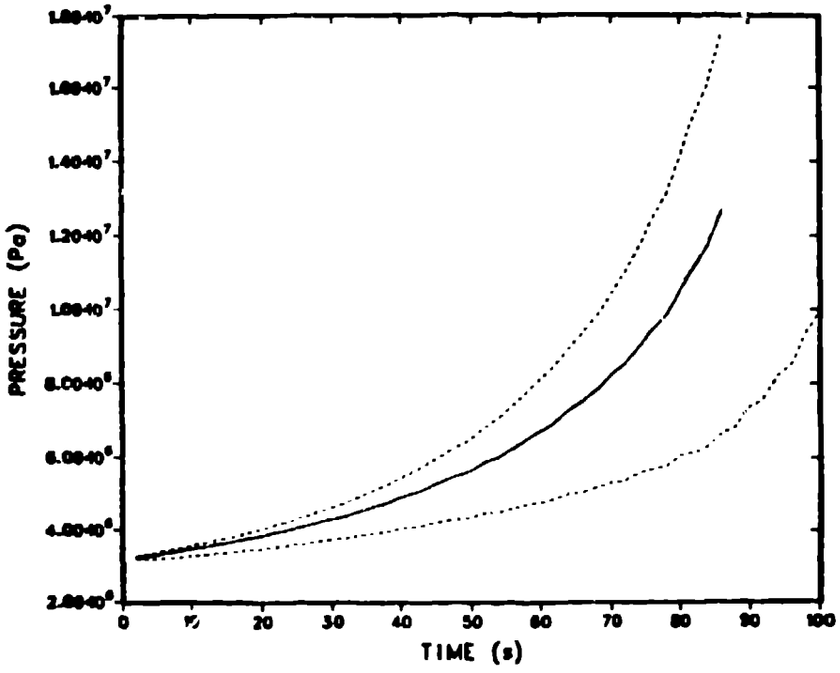

Fig. 3.
Condensation rate affects pressure response for constant surge line velocity of 10 m/s.

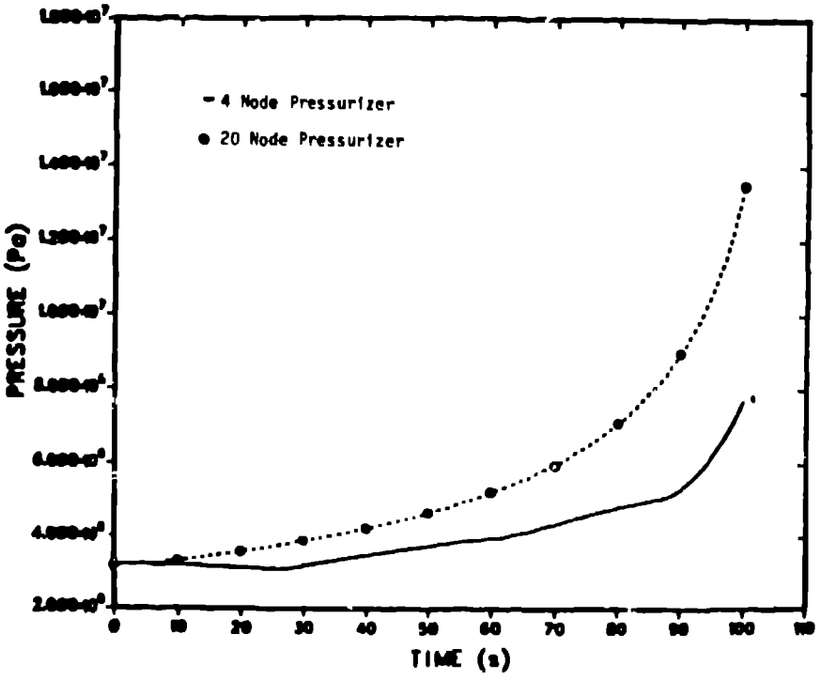

Fig. 4.
Pressurizer noding affects pressure response for constant surge line velocity of 10 m/s.

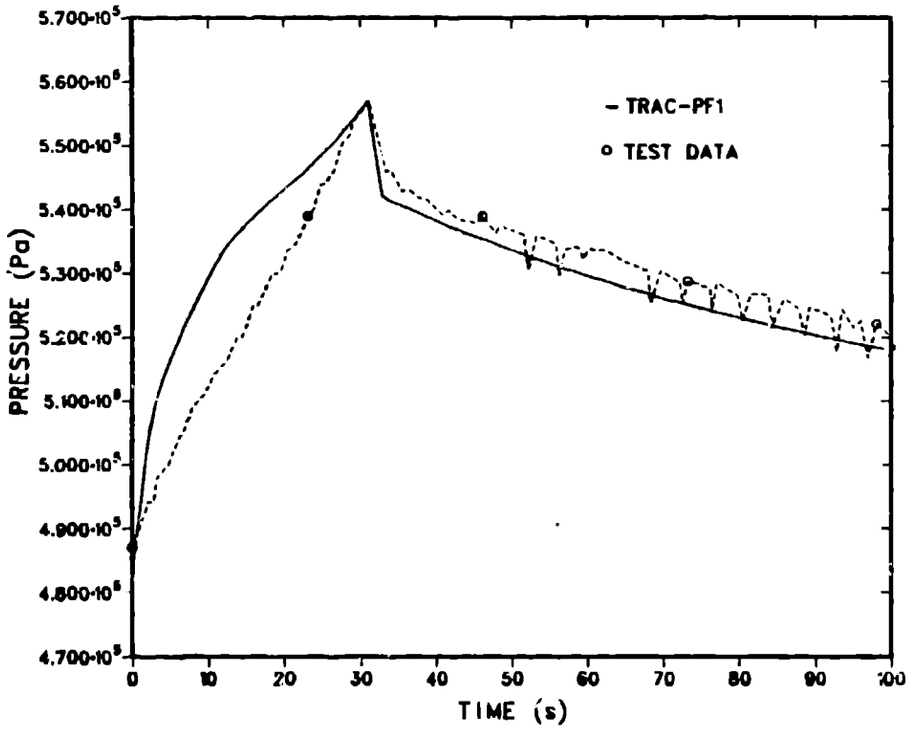

Fig. 5.
Pressure response calculated with improved condensation model compared with experimental results.