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PWR PRESSURE VESSEL INTEGRITY DURING  
OVERCOOLING ACCIDENTS\*

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Pressurized water reactors are susceptible to certain types of hypothetical accidents that under some circumstances, including operation of the reactor beyond a critical time in its life, could result in failure of the pressure vessel as a result of propagation of crack-like defects in the vessel wall. The accidents of concern are those that result in thermal shock to the vessel while the vessel is subjected to internal pressure. Such accidents, referred to as pressurized thermal shock or overcooling accidents (OCA), include a steamline break, small-break LOCA, turbine trip followed by stuck-open bypass valves, the 1978 Rancho Seco and the TMI accidents and many other postulated and actual accidents. The source of cold water for the thermal shock is either emergency core coolant or the normal primary-system coolant. In the latter case the coolant temperature is reduced by depressurization of the primary system or by the secondary system after it has been cooled by depressurization and/or excessive feedwater.

ORNL performed fracture-mechanics calculations for a steamline break in 1978 and for a turbine-trip case in 1980 and concluded on the basis of the results that many more such calculations would be required. To meet the expected demand in a realistic way a computer code, OCA-I,<sup>1</sup> was developed that accepts primary-system temperature and pressure transients as input and then performs one-dimensional thermal and stress analyses for the wall and a corresponding fracture-mechanics (FM) analysis for a long axial flaw. The cladding is included in the thermal analysis but not in the stress or FM analysis. Thus, if the flaw is assumed to extend through the cladding, the calculated stress

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intensity factors ( $K_I$ ) are somewhat low, and if the flaws are assumed to be under the cladding, the calculated  $K_I$  values are much too large.

A superposition technique was used for calculating the  $K_I$  values, and largely because of this feature the operating cost for OCA-I is very low, making parametric and sensitivity studies feasible. The accuracy of the  $K_I$  calculation has been checked against a finite-element-analysis code<sup>2</sup> for crack depths ranging from 3 to 90% of the wall thickness and found to be within 1%.

Another convenient feature incorporated in OCA-I is a plotting package that provides critical-crack-depth curves as well as more conventional plots.

Taking advantage of the parametric-type features in OCA-I, a limit analysis was conducted for OCA's to provide a "handbook" assessment capability. Six exponential coolant-temperature transients (decay constants ranging from  $0.015 \text{ min}^{-1}$  to  $\infty$ ) and two coolant-temperature asymptotes (66 to  $121^\circ\text{C}$ ) were used to represent a wide range of temperature transients. For a given thermal transient the pressure was held constant, but several different values in the range of 3 to 17 MPa were included. Two copper concentrations (0.1 and 0.35%) and a wide range of fast-neutron fluences were also included. Critical-crack-depth and  $K_I$  vs time-and-crack-depth curves are included in the handbook for over five hundred cases.

An OCA generic study was conducted with OCA-I, and some important flaw-behavior trends were revealed. It appears that very shallow flaws ( $\geq 3 \text{ mm}$ ) will initiate, and in some cases complete penetration of the wall will result. This is worrisome because shallow flaws are more likely to occur and more difficult to detect. The analysis indicates that the thermal shock initiates propagation of a shallow flaw, and failure occurs by plastic instability. In some cases arrest may take place on the upper shelf, but the methodology for including such an event is not yet a part of OCA-I. Another observation from the overall OCA study is that for some accidents there will probably be enough energy stored in the coolant above  $100^\circ\text{C}$  to result in a large opening in the vessel wall, if and when a long flaw penetrates the wall.

The generic analysis also indicated that if an OCA were to take place the OCA would be much more likely to result in vessel failure than would the double-ended-pipe-break LOCA, which was the postulated PWR accident that triggered the HSST thermal-shock investigations.

A few specific-plant analyses were also performed and these included the 1978 Rancho Seco accident,<sup>3</sup> a postulated main-steamline-break accident<sup>4</sup> and a postulated accident involving a turbine trip followed by stuck-open bypass valves.<sup>5</sup> The appropriate copper concentration and initial RTNDT were 0.31% and 40°F, and the fluence rate was  $0.046 \times 10^{19}$  n/cm<sup>2</sup>/EFPY. OCA-I results for this specific-plant analysis indicated a potential for vessel failure at 20 EFPY for the Rancho Seco accident, and about 4 EFPY for the other two.

The Rancho Seco case did not require a systems analysis since the actual temperature and pressure transients were recorded and were used as input to OCA-I. However, the temperature and pressure transients for the other two cases were derived from a systems-analysis code that is believed to be quite conservative (IRT). There may also be significant conservatism included in the OCA-I analysis, and suspect areas that will be evaluated further include the effect of cladding on flaw extension and propagation, radiation damage to cladding, flaw behavior on the upper shelf and the size of the opening in the wall.

#### References

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