MATERIAL PROPERTIES AND DESIGN PROCEDURES
FOR ARREST OF UNSTABLE CRACK PROPAGATION
IN NUCLEAR REACTOR PRESSURE VESSELS

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SUMMARY

Crack arrest enters the evaluation of normal, upset, emergency and faulted conditions of nuclear pressure vessels. The intent of the ASME Pressure Vessel Code is to preclude the onset of fast fracture under normal and upset conditions and to limit the penetration of a fast fracture under emergency conditions. Present analyses rely heavily on the concepts of static linear elastic fracture mechanics to accomplish this. A more fundamental dynamic fracture mechanics approach to crack arrest, postulated and verified in recent work conducted for EPRI and the U.S. NRC, is described in this paper.

In the dynamic crack propagation theory, crack arrest occurs as the special case where unstable crack propagation is no longer possible. Quantitatively, a crack will arrest only when $G$, the crack-driving force calculated from a dynamic analysis, becomes less than $R$, the propagating crack fracture energy. The latter quantity generally depends upon temperature and crack speed $V$. The propagating crack fracture toughness, $K_{ID} = K_{ID}(V, T)$ can also be used as the material design parameter for crack arrest because of the equivalence that exists between the stress-intensity factor and the energy-release rate in dynamic conditions, $K_{ID}^T = A(V)RE/(1 - v^2)$. A companion paper (G1/e) describes the analytical and experimental details involved in measuring $K_{ID}$ and provides current data for reactor steels and other materials. This paper focuses on the design procedures needed to utilize this kind of information.

A critical part of this work is to demonstrate that, given a $K_{ID}$ crackspeed relation, an accurate prediction of a crack run-arrest event can be made using a properly formulated applied mechanics analysis procedure. This paper provides such a verification. This is done by comparing predictions based on a dynamic analysis (using $K_{ID}$-velocity data obtained from DCB specimens) with actual measurements of run arrest events in rectangular plates. In addition, the paper offers guidelines for a simplified approach to crack-arrest design that can be used by structural engineers. That is, there are a number of possible contributions to the crack-driving force beyond those occurring in a static analysis. These include the effect of kinetic energy, inertia forces in the equations of motion, and stress-wave reflections from free surfaces and other boundaries. But, while these factors must be considered in the analysis of small-size laboratory test specimens, it is not feasible to include them in routine structural analyses. Accordingly, it is shown that calculations based on the parameter $K_{im}$, the minimum value of $K_{ID}$ with respect to crack speed, produce reasonable results that are applicable to nuclear reactor pressure vessel design.