ASSESSMENT OF THE RELIABILITY OF NUCLEAR PRESSURE VESSELS

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SUMMARY

This paper outlines methods for evaluating the significance of weld defects in regions of complex geometry in thick walled reactor pressure vessels. Under accident conditions, such regions may lead to high strain and yield level stress, which are not amenable to treatment by linear elastic fracture mechanics. Elastic-plastic fracture mechanics methods based on fracture characterizing parameters such as critical crack opening displacement (COD) and the contour integral (J) are developed to analyze details such as nozzle penetrations. Such analysis methods are usually designed to yield a conservative result and at each step in the analysis method the conservative bound is used as input data. A more realistic procedure is to use, as input data, the probability function or density of each of the input parameters. Reliability can then be defined from the frequency function which results from the combination of the input data distributions. The engineering model, which is expressed as an equation, is deterministic and the parameters are treated as independent or dependent random variables with known or assumed distribution functions. The statistical analysis is accomplished numerically with a computer program that uses Monte Carlo simulation.

Two examples are presented to illustrate the technique. The residual life-time of a cracked structure is assumed to be related to four parameters through a fracture mechanics based model. The parameters considered are applied stress, material crack growth rate, and initial and final crack sizes. This first example is chosen and simplified to have an available probabilistic solution in order to test the accuracy of the applied computer program. Most engineering probability models will be too complex for available solutions and will require the computer program for numerical solutions.

The second example considers a crack growing out of the nozzle region of the reactor vessel. The crack grows in a nominal stress field characterized by significant stress gradients. These gradients are accounted for within the engineering model. The input parameters considered are the same as those considered in the first example. The variations in the input parameters are all estimated from actual data. For example, the initial flaw size distributions considered in both examples are estimated from the known detection and rejection rates of flaws in pressure vessels and from data which provide statistical description of the capability of the nondestructive inspection equipment. The final flaw size distribution comes from the elastic-plastic analysis.

Calculated distributions of residual fatigue lifetime, for the first example, and strength margin, for the second example are presented. These data, when combined with the design envelope of the reactor pressure vessels, result in an engineering estimate of the reliability. The advantage of this type of reliability estimate is that both systematic and random variations of the pertinent input parameters can be evaluated in terms of their effect on reliability. This probabilistic fracture mechanics approach is a rational technique for estimating such quantities as: the difference between nuclear and non-nuclear pressure vessel failure expectation; the cost and safety effectiveness of a new nondestructive inspection method or procedural change; the effect on reliability of a 10% increase in stress or a change of material; the significance of wear in or wear out during the design life of the pressure vessel. Such quantities cannot be effectively evaluated by observation and manipulation of currently available failure rate data on pressure vessels.