5-5 Evaluating the Fracture Resistance of a Reactor Pressure Vessel under Pressurized Thermal Shock

— Structural Reliability Evaluation of Aged Components in Nuclear Plants Based on Probabilistic Fracture Mechanics (PFM) —

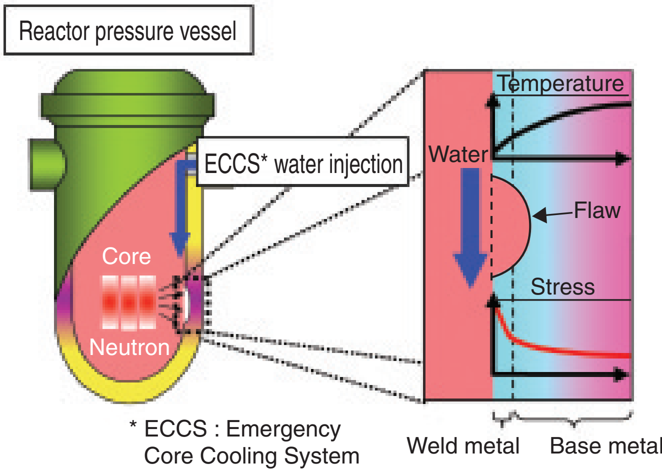

Fig.5-11 The concept of PTS
When a loss-of-coolant accident occurs in a reactor, the emergency core cooling system injects water in the RPV, resulting in cooling of the inside of the vessel with high pressure maintained. This induces a high tensile stress at the inner surface of the RPV, so called PTS. The structural integrity of the RPV during PTS should be evaluated assuming the existence of a flaw at the inner surface.

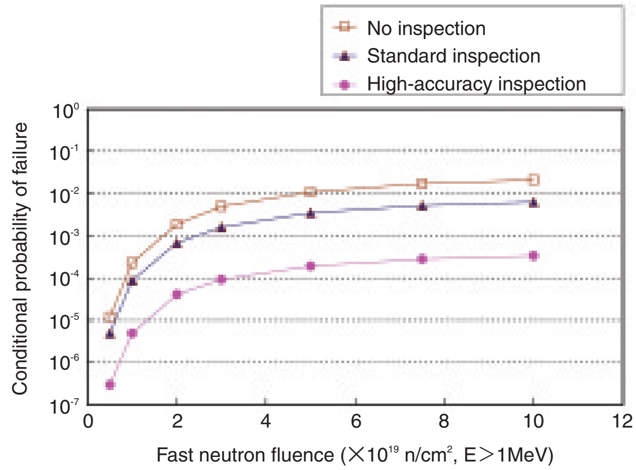

Fig.5-12 The conditional probability of failure of an RPV as a function of fast neutron fluence computed with PASCAL
The fast neutron fluence is the number of neutrons accumulated during an operation period per unit area at the vessel wall in an LWR. It increases as the operation time of the LWR increases. The conditional probability of failure increases with increase in the fast neutron fluence, as shown in the figure. It is clear that nondestructive inspection significantly reduces the probability of failure due to the occurrence of PTS.

Some of the light water reactors (LWRs) in Japan have been operated for over 30 years. To assure the structural integrity of components is an important issue for the safe operation of these aged LWRs. Probabilistic Fracture Mechanics (PFM) has attracted a great deal of interest as a useful tool for evaluating the failure probability of aged components appropriately. In the PFM approach, the uncertainties of loads applied to structural components, the distributions of flaw size, and the probability of occurrence of flaws are considered.

We have developed a PFM analysis code PASCAL. This code evaluates the conditional probabilities of failure of a reactor pressure vessel (RPV) under transient loading conditions such as pressurized thermal shock (PTS), the concept of which is shown in Fig.5-11. The following is a brief description of the analysis function of PASCAL.

RPV steel is subjected to neutron irradiation from the reactor core, so that it tends to embrittle as operation continues. This phenomenon is evaluated using the embrittlement prediction equation formulated in Japan. For the assessment of structural integrity of the RPV, a flaw in the RPV wall is assumed to exist. The flaw size is chosen from among a distribution of flaw sizes using a random number (i.e. flaw sampling). The flaw is evaluated as to its growth and whether it penetrates the RPV wall during a PTS. The sampling is repeated, and the conditional probability of failure is calculated as the ratio of the number of failed flaws to the number of samples. In PASCAL, one can analyze easily by setting various parameters on graphical user interface (GUI) including the type of a transient, the chemical compositions in steel, and the accuracy of nondestructive inspection.

The effect of nondestructive inspection on the conditional probability of failure is shown in Fig.5-12. Any nondestructive inspection reduces the failure probability. Especially, the failure probability after an inspection with high accuracy was reduced to approximately 1/100 that where there was no inspection.

We are continuing research to incorporate the latest knowledge about evaluation items such as residual stress distributions in PASCAL, focusing on making a contribution to possible revisions of codes and standards.

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Reference

Osakabe, K., Onizawa, K. et al., Development of Probabilistic Fracture Mechanics Analysis Code PASCAL ver.2 for Reactor Pressure Vessel, Nippon Genshiryoku Gakkai Wabun Ronbunshi, vol.6, no.2, 2007, p.161-171 (in Japanese).