5-5 Analysis of Rod Failure Mechanism in Accident Conditions
－Development of the RANNS Code－

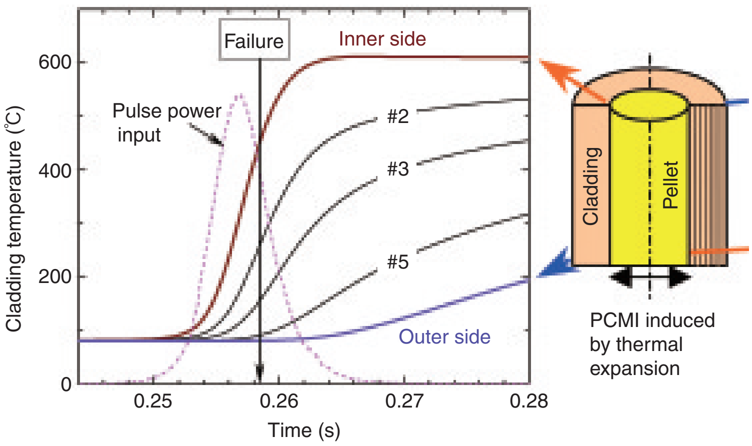

Fig.5-9 Calculated temperature distribution of cladding
#2, #3 and #5 are ring elements between the inner and outer sides. Upon pulse power input, the temperature rises faster in the inner region than the outer region. PCMI-failure time was observed. Temperature difference between the inner and outer sides is as much as 400C at the failure instant.

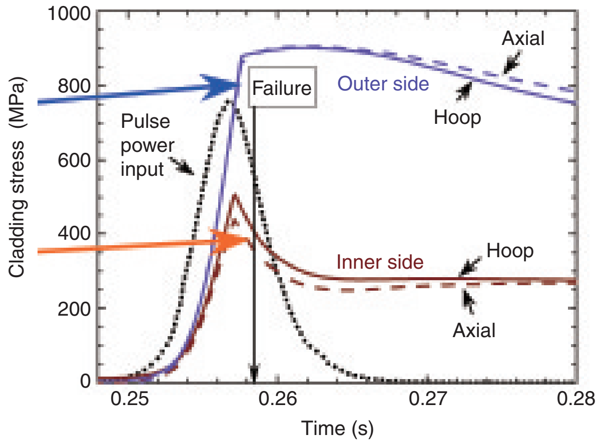

Fig.5-10 Axial and hoop stresses in the inner and outer sides of cladding, analyzed in FK-10 experiment
Stress is mitigated in the inner side of cladding by thermal expansion, and stress in the outer side is relatively higher. The rod failed when a slight plastic deformation occurred, indicating a low-strain breakage mechanism.

The RANNS code was developed for the analysis of thermal and mechanical behavior of high-burnup LWR fuel rod in reactivity-initiated accident (RIA) conditions and in loss-of-coolant accident (LOCA) conditions. Its primary purpose is to investigate the mechanism underlying the observations made during a limited number of accident-simulating experiments, and to support the determination of failure threshold of rods for the purpose of enhancing the credibility of safety evaluation. In high burnup fuel rods, pellet-clad gap is closed, which generates a “bonding layer”. Also, cladding ductility is reduced by radiation damage and waterside oxidation (hydrogen absorption). In these rod conditions, when an abrupt power increase occurs in an RIA, thermal expansion of the pellet directly pushes the cladding outward and gives severe mechanical loading. Focusing on such pellet-clad mechanical interaction (PCMI), the RANNS model was designed to have multi-layer ring elements in both the pellet stack and cladding to perform an accurate evaluation of stress and strain in the radial direction and distributions of temperature. Numerical analysis of the RIA-simulating experiments in the NSRR (Nuclear Safety Research Reactor) with high burnup BWR rods showed that the cladding inner side is heated up rapidly upon pulse power input, while the temperature rise in the outer side is much delayed (Fig.5-9). Consequently, thermal expansion is larger in the inner region, which relieves the PCMI-induced tensile stress of cladding significantly, and the stress is relatively higher in the outer region (Fig.5-10). Considering that a failure crack occurs at the outer surface of cladding in many experiments, it is obvious that this quantitative analysis can successfully explain such observation. Also, as shown by the broken lines in Fig.5-10, the code predicts that axial stress also occurs, and the cladding fails in bi-axial stress state. The above analyses demonstrate the usefulness of the RANNS code in the study of high burnup fuel behavior in RIA conditions, particularly in PCMI, and the code allows a quantitative clarification and evaluation instead of qualitative interpretation of experimental data. Besides, RANNS can analyze the fuel behavior in postulated conditions. If the pulse power input does not bear a sharp shape as shown in Fig.5-9 and Fig.5-10 but has a broader shape, or the pulse has a lower peak value, it is anticipated that the cladding temperature gradient and PCMI-induced stress are mitigated. In such situation, the code can predict specific cladding conditions and evaluate the threshold level of failure. In the near future, subjects of analysis will be expanded, and practical failure prediction capability will be studied.

In addition, since the RANNS code can calculate the cladding high temperature oxidation and thermal stress generated in a rapid temperature transient, the code will be applied to the analysis of the fuel rod behavior in quench phase of a LOCA.

Reference

Suzuki, M. et al., Analysis on Split Failure of High Burnup BWR Rods in Reactivity-Initiated Accident Conditions by RANNS Code, Nuclear Engineering and Design, vol.236, 2006, p.128-139.