Priority Subjects — **Further Improvement of Facility Operations and Maintenance Technologies**

Structural Integrity Evaluation of Reactor Pressure Vessels and Core Internals

Background and Objective

In order to accomplish the safe and stable operation of LWR plants, we will enforce the technical basis for structural integrity of reactor pressure vessels (RPVs) and core internals through better-understanding of various degradation mechanisms together with the development and the improvement of evaluation methods. In this project, we have conducted the following research.

Main results

1 Improvement in the method for integrity evaluation of irradiation embrittlement in RPV steels

Microstructural observation of a weld material cut out from a RPV of the Greifswald reactor in Germany was carried out using atom probe tomography (APT), which enables observation at an atomic level. Although the material was fabricated in accordance with the German standard differing from the Japanese one, the formation of small solute atom clusters due to irradiation was confirmed (Fig. 1). The results will be utilized for the analysis of Japanese decommissioned reactor materials.

2 Evaluation of irradiation effects on microstructural changes in stainless steels

Grain boundary segregation is one of the causal factors of irradiation-assisted stress corrosion cracking (IASCC). The segregation in a type 304 stainless steel irradiated up to 5.5 dpa*, at which the materials in commercial reactors are deteriorated, was investigated using APT. Both in a grain and at a grain boundary, segregation was observed (Fig. 2). Based on the APT observation, we will elucidate the effects of the segregation on IASCC.

3 Development of a practical application technique for the Master Curve evaluation

We developed the Master Curve testing and evaluation technique using miniature specimens machined from surveillance specimens. The fracture toughness based on the miniature specimens was equivalent to that of larger specimens (Fig. 3). We conducted an international round robin test and ensured the reliability of the technique. We will codify the new testing standard in collaboration with the related organizations[1].

4 Adequacy of stress intensity factor solutions for nozzle corner cracks

Japanese code[2] requires structural integrity for the supposed cracks in nozzle corners. We examined the applicability of the stress intensity factor solution in the code through a comparison with a finite element analysis result and ascertained that the solution gave reasonable prediction (Fig. 3).

* dpa (displacement per atom): A unit corresponding to the number of displacements per atom in the material due to irradiation.

[1] M. Yamamoto, et al., Sixth International Symposium on Small Specimen Test Techniques, 2014
[2] Japan Electric Association Code, "Method of Verification Tests of the Fracture Toughness for Nuclear Power Plant Components," JEAC4206-2007.

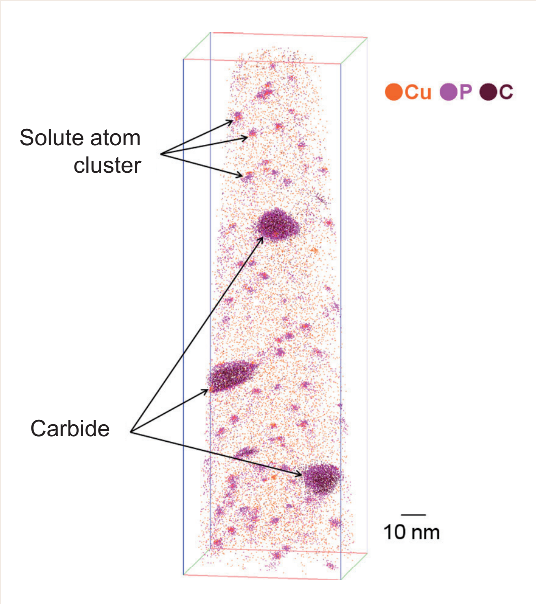

Fig. 1: Atom map of RPV weld material from a decommissioned commercial plant

This is the result of the APT observation of a weld material cut out from the RPV of the Greifswald Unit 4. The formation of solute atom clusters with the segregation of copper and phosphorous due to irradiation can be confirmed. Fine carbides and phosphorous segregation to the surroundings of the carbide are also observed.

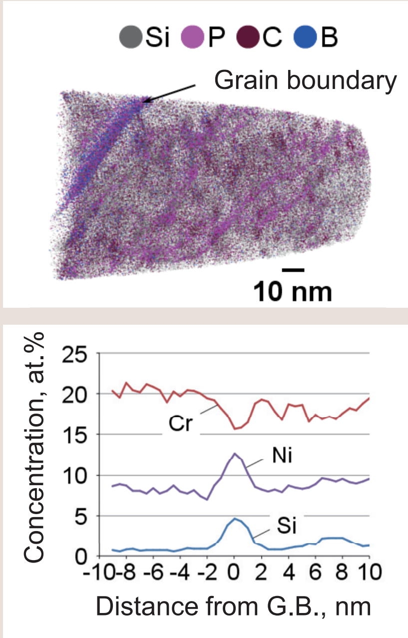

Fig. 2: Atom map (top) and result of grain boundary (G.B.) analysis (bottom) of irradiated type 304 stainless steel

This is the result of APT observation of type 304 stainless steel irradiated to 5.5 dpa. The segregation of nickel and silicon and the depletion of chromium at the grain boundary as well as the segregation of silicon, phosphorous, and carbon in the grain can be observed.

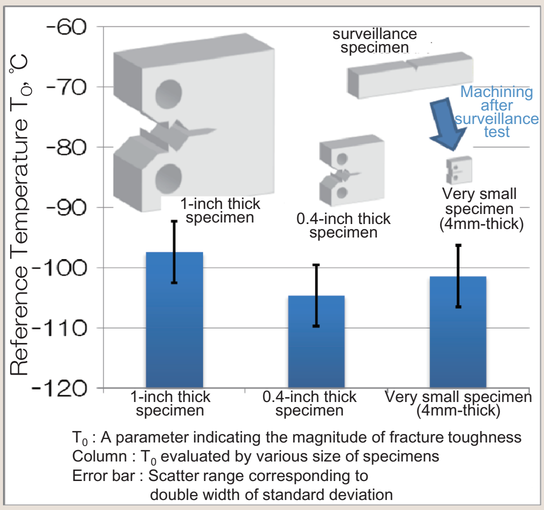

Fig. 3: Comparison of reference temperatures obtained from miniature and larger specimens

This compares the reference temperature (an index indicating the magnitude of fracture toughness in dimension of temperature) among various specimens. The reference temperature obtained from miniature specimen was equivalent to that of the larger specimens.

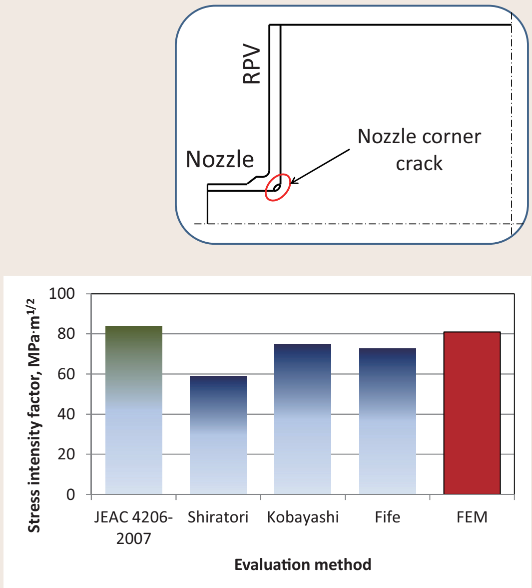

Fig. 4: Comparison of stress intensity factor solutions for nozzle corner crack

Compared with the finite element analysis result, every solution gives adequate stress intensity factors. The solution in JEAC4206 can treat membrane stress only, whereas the other solution can consider complex stress distribution at nozzle corner.