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# Evaluation of Long-term Integrity of Spent Fuel Storage Rack

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## 1. Introduction

Domestic nuclear power plants operate wet spent nuclear fuel pools to store spent nuclear fuel generated during operation. The main structural materials that make up the spent nuclear fuel pool include concrete (wall surface), storage pool liner, neutron absorber material, and stainless steel(storage rack), and each structural material is exposed to long-term radiation irradiation, which can change the properties of the material. In this study, degradation characteristics were evaluated according to radiation irradiation on stainless steel, which is a major material for spent nuclear fuel storage racks.

## 2. Evaluation Methodology

Austenitic stainless steel is widely used as a major material for reactor internal structures and wet storage racks due to its excellent strength, toughness, and corrosion resistance. However, long-term exposure of materials to high-temperature, high-pressure, and high-energy radiation environments not only leads to microstructure defects, but also to irradiation deterioration and hardening, which can lead to irradiation-induced stress crack corrosion (IASCC).

In the case of spent nuclear fuel storage racks in domestic fuel buildings, most of them are installed as dense storage racks in the Region II area for the continuous and stable operation of nuclear power plants. The distance between these dense storage racks and spent nuclear fuels is installed very closely, so neutron irradiation emitted from spent nuclear fuels in long-term storage can cause changes in the properties of the storage zone (SA240 Type 304). In order to evaluate the change in the physical properties of the storage rack by neutron irradiation, an investigation test reflecting the characteristics of the spent nuclear fuel in an environment similar to the actual spent nuclear fuel pool should be conducted. However, in this study, instead of an irradiation test, the amount of radiation generated from spent nuclear fuel was evaluated and the effect on the storage rack was verified through computer simulation. [1]

USERMAT allows us to examine changes in the properties of materials according to various factors (such as stainless-steel type, fabrication conditions, temperature, dose rate and dose, initial dose, inflating and creep effects, etc.). This is because USERMAT programming simulates changes in the physical properties of stainless steel according to DPA (dose) under various conditions. In order to analyze changes in material properties according to DPA in terms of evaluating long-term structural soundness, which is the purpose of this study, it was evaluated according to the procedure for evaluating DPA influence as shown in Figure 1. [2]

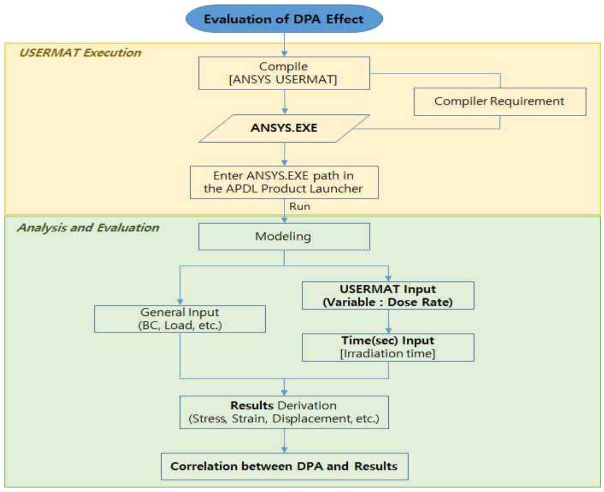



Fig. 1 DPA Impact Assessment Procedure

### 2.1 Structural analysis

The storage rack was modeled and input data was prepared to analyze changes in material properties caused by the effects of IASCC in the spent nuclear fuel storage rack applied with USERMAT. The evaluation method examined the timing of the change in material properties by deriving stress changes under various dose rate (dpa/s) conditions in consideration of the operation period of the spent nuclear fuel storage tank. The following model (Cell 9EA: 3×3) applied to the irradiation damage assessment is recommended to reflect the dose rate (dpa/s) according to the neutron irradiation damage assessment results of the spent fuel dense storage rack. In order to consider the boundary conditions of the centrally located cell, the edge was fixed in the longitudinal direction as shown in Fig. 3, and a fine displacement was applied in the vertical direction to cause a decrease in yield stress depending on the dose in the elastic area. The material properties were analyzed in three cases, as listed below, only the FFLUX of "Basic Model Parameters" was used as a variable to examine stress changes caused by doses over time. The time applied to the analysis was assumed to be 70 years in consideration of the storage rack design life period.

- 1E-08dpa/s: reactor internal structure dose rate
- 1E-10dpa/s: dose rate at a level where material properties change (in 40-year terms)
- 1E-17dpa/s: conservative value for dense storage rack dose rate (4.84E-18dpa/s)

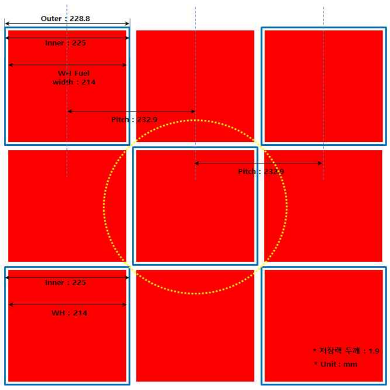


Fig. 2 Neutron Irradiation Damage Assessment Model for Spent Fuel Storage Rack (Cell 9EA)

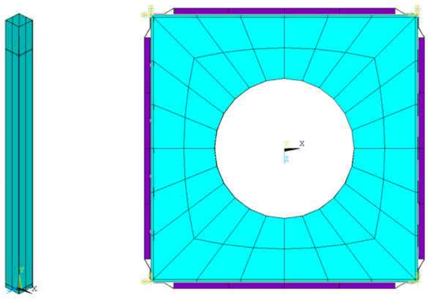


Fig. 3 Geometry & Boundary Condition of Storage Rack (Cell 1EA)

## 2.2 Evaluation results

For the spent nuclear fuel dense storage rack, stress distributions for the three cases and the case without dose were derived, and are presented in Figure 4 below. As a result of the evaluation, it was found that the stress distribution fluctuates only when the dose rate is very large (1E-08 dpa/s).

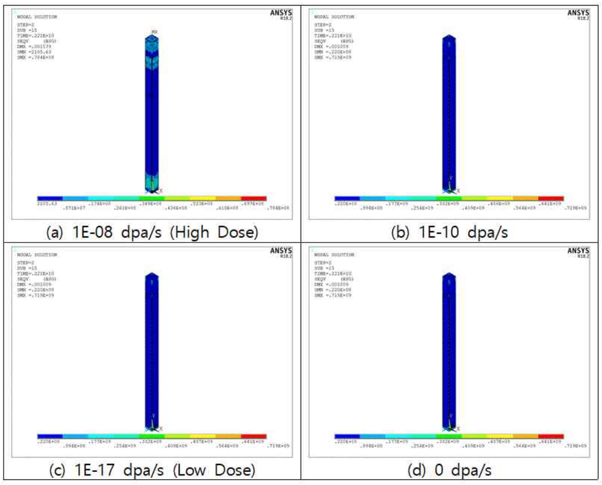


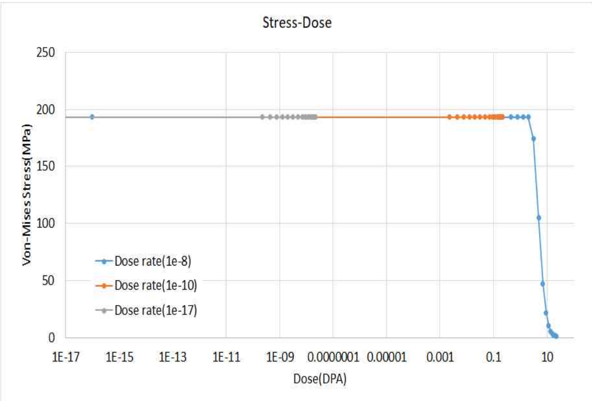

Figure 4. Stress Distribution according to Dose Rate (70 years)

To assess structural soundness, the expression described in the IASCC Sensitivity Model was modified as follows.

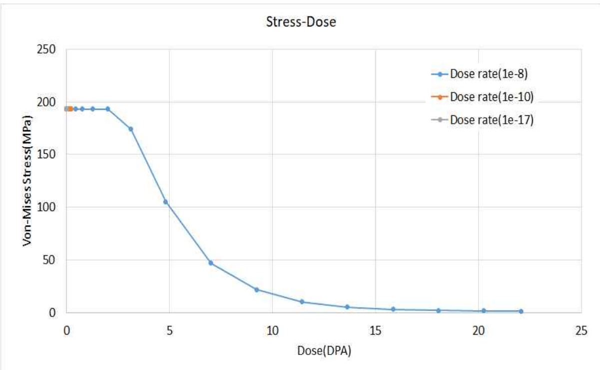
$$\sigma_{IASCC} = S(d)\sigma_y(T, d, \varepsilon_{eff}^{pl}) \rightarrow \sigma_{IASCC} = S(d)\sigma_y(d)$$

Temperature was not considered in the analysis, and micro-displacement was considered to prevent stress above the yield stress, so there was no effect on the effective plastic strain. Therefore, stress changes occur according to dose, which can be attributed to a decrease in yield stress due to an increase in dose. Accordingly, the analysis results show that the change in stress with dose can derive a dose with a change in material characteristics, and the dose comparison calculated in the installation environment of the storage rack can be used to examine the change in material characteristics of the storage rack. Therefore, a stress-dose diagram (Figure 5) for the three cases presented above was prepared to analyze whether the material properties changed. Since the analysis result is derived from stress over time, each dose rate (dpa/s) was converted into a dose (dpa) by multiplying the analysis time (70 years) to analyze the stress according to the dose.

As shown in the stress-dose diagram below, if the dose rate is 1E-10dpa/s or less, it remains constant without a change in stress, which means that there is no change in material properties through irradiation. In addition, the dose rate when the material properties change is 1E-08dpa/s. This requires a long-term structural soundness assessment for doses within the reactor (1E-08dpa/s) range, but structures in an environment with a relatively small dose rate do not show changes in material properties.




(a) Log scale




(b) Normal scale

Fig. 5 Equivalent Stress Distribution according to Dose Rate

### 3. Conclusion

The long-term structural soundness of the reservoir was evaluated by analyzing changes in the properties of the material by neutron irradiation generated in the environment where the spent nuclear fuel dense storage rack was installed. Structural analysis was performed in ANSYS using USERMAT with a built-in configuration model that simulates changes in the material properties of stainless steel by neutron irradiation. Part of the storage rack was modeled to examine whether the material properties of the storage rack changed due to changes in the dose rate, and 70 years of very long investigation could not change the material properties. Therefore, it was evaluated that there was no change in material properties due to neutron irradiation during the design life of the spent nuclear fuel storage rack. For reference, according to the IAEA report, long-term corrosion performance tests on storage (SS/BSS) and Pool Linar Plate specimens showed that the loss of the specimen was only 0.04g.m2/yr and the thickness reduction was only 1um/yr, so no significant defects occurred during the long-term wet storage period.[3]

### Reference

[1] EPRI, Material Program: Development of Material Constitutive Model for Irradiated Austenitic Stainless Steels (MRP-135, Rev.1)", 2010. 10

[2] Los Alamos National Lab., "A General Monte Carlo N Particle Transport Code, Version 6.0", MCNP6 User's Manual, LA-CP-13-00634. Rev.0, 2013

[3] IAEA, "Spent Fuel Performance Assessment and Research (SPAR-III)", IAEA-TECDOC-1771, 2015