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Integrity Evaluation of the Spent Fuel Storage Rack by the Neutron Irradiation

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1. Introduction

Austenitic stainless steels are excellent in strength, toughness and corrosion resistance, and are widely used as the materials for reactor internal structures and spent fuel storage rack. However, irradiation induced stress cracking (IASCC) such as irradiation embrittlement may occur if exposed to high temperature, high pressure, and high radiation environments for long period. Especially, the material property can be changed by the neutron irradiation emitted from the spent fuel in long term storage because the distance between the storage rack and the spent fuel in the fuel building is very close. Therefore, in this paper, the neutron irradiation emitted from the spent fuel is evaluated and the integrity of the storage rack is verified through the computer simulation.

2. Damage mechanism and evaluation methodology

1) Damage mechanism by the neutron irradiation

The neutron incident on the material generates PKA (Primary Knockon Atom), and PKA causes the irradiation damage such as point defects and line defects in the material, thereby degrading the materials properties [1]. Figure 1 shows the mechanism of material damage by high-energy neutrons incident on the material. Basically, the factors affecting the material are not only the neutron irradiation but also the temperature gradient by the gamma ray generated during the fission. However, in this paper, only the influence of the neutron irradiation is considered since the environment of the spent fuel storage rack is at low temperature and the gamma rays are attenuated with the cooling period.

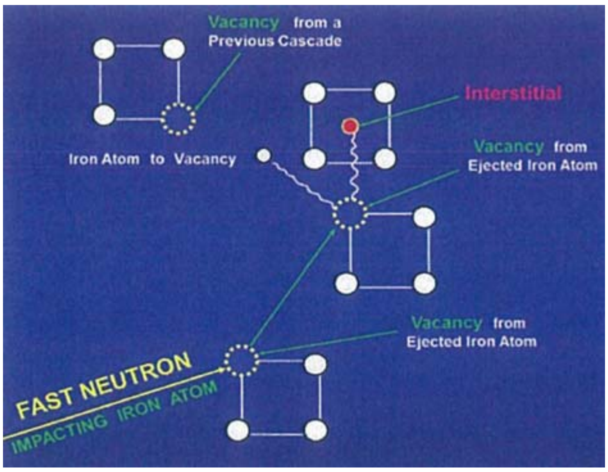

Figure 1. Damage mechanism by the neutron irradiation

2) Evaluation Methodology

Figure 2 shows the procedure for evaluating the effect on the material by neutron irradiation. First, the neutron flux irradiated on the storage rack was evaluated through a three-dimensional radiation analysis model. DPA (Displacements per atom) was calculated by MCNP code reflecting the neutron flux irradiated on the storage rack [2].

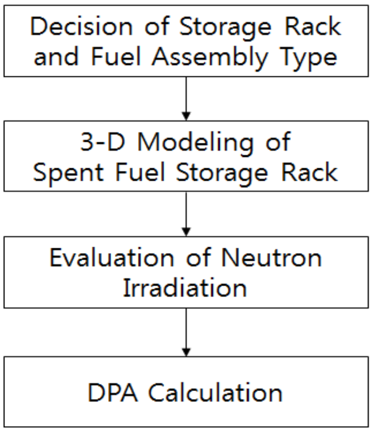

Figure 2. DPA calculation by the neutron irradiation

Here, DPA is a unit that represents the quantitative values that the material is damaged by ions or neutrons. For example, 10 DPA means that all of the atoms are displaced 10 times in the lattice. DPA is defined as follows.

$$DPA/s = \int_{E_d/A}^{\infty} \sigma_d(E_n)\phi(E_n)dE_n$$

Where, $\sigma_d(E_n)$: DPA cross section of SUS304
$\phi(E_n)$: Neutron flux

Total DPA by the accumulated neutron irradiation during the operation period is as follows.

$$\text{Total DPA} = \sum DPA/s \times Cooling\ Period(sec)$$

3) Evaluation of the neutron irradiation

17ACE7 with a concentration of 5.0wt% and a burnup of 60,000MWD/MTU was assumed for neutron irradiation evaluation. Figure 3 shows the 3×3 array model of the storage rack, and the neutron irradiation on the storage rack was evaluated. Figure 4 shows the distributions of the neutron flux with the cooling periods from 100hr to 60years.

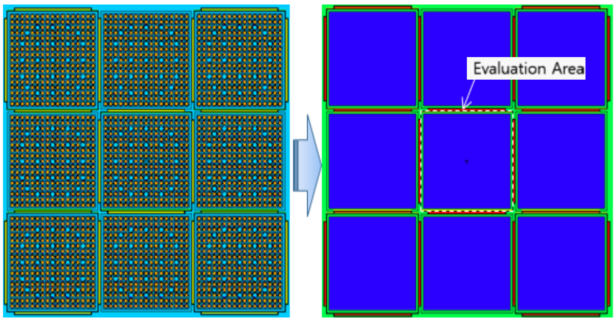

Figure 3. 3×3 array model of the storage rack

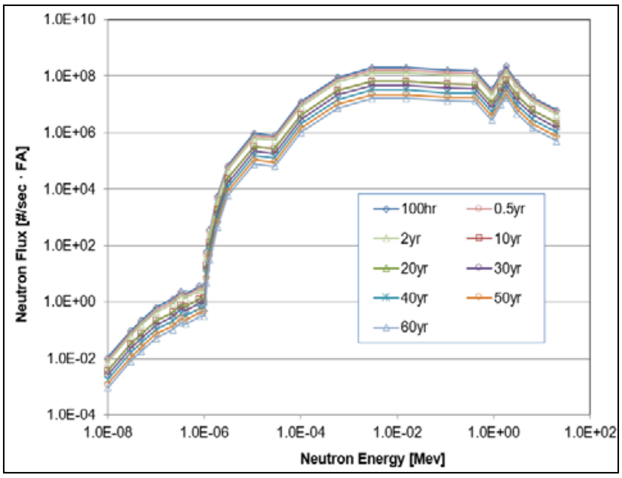

Figure 4. Neutron flux with the cooling periods

3. Result

As the evaluation results for 3x3 array model, the largest neutron flux and DPA occurs at 160 ~ 200cm in the axial direction. Table 1 shows DPA results with the storage period. As shown in the table, the total cumulative DPA is about 3.1E-09 in case that the operating period is about 60 years.

Table 1. DPA with the cooling periods

Time	**DPA**
100hr~0.5yr	4.84E-18
0.5yr~2yr	4.01E-18
2yr~10yr	3.21E-18
10yr~20yr	2.31E-18
20yr~30yr	1.60E-18
30yr~40yr	1.11E-18
40yr~50yr	7.79E-19
50yr~60yr	5.51E-19
Cumulative DPA	**3.1E-09**

In accordance to EPRI's MRP-135 rev.1, which contains the evaluation results of Austenitic stainless steels by the neutron irradiation, it is reported that the neutron irradiation below 3DPA doesn't act as a stress on the structural material because it doesn't cause the microscopic structural change and damage of the material [3]. Therefore, it was confirmed that there is no effect on the integrity of the storage rack even if exposed to the neutron irradiation during the operating period.

4. Conclusion

The long-term integrity of the storage rack was evaluated since it is exposed to the neutron irradiation generated from the fuel assemblies in the spent fuel pool during the operation period. First, the neutron flux was calculated after modeling the 3×3 array of the storage rack and the total cumulative DPA was calculated with the operating period. As a result, the total cumulative DPA is about 3.1E-09 even though the operating period is about 60 years. In accordance with EPRI's MRP-135 rev.1, the neutron irradiation below 3DPA doesn't cause the microscopic structural changes or damage of the material. Therefore, we confirmed that there is no effect on the integrity of the storage rack by the neutron irradiation during the operation period.

REFERENCES

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