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Development of Hydride Reorientation Fraction Evaluation Program

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1. Introduction

In Korea, nuclear power plants have been operated for more than 40 years since the Kori 1 started commercial operation in 1978. Approximately 18,500 spent fuels generated during that period have been stored in a wet storage system at each plant site. As the amount of spent fuel increases, the wet storage capacity is getting saturated, therefore, it is managed by means of dense rack installation into the existing wet storage system and transportation of spent fuel to other neighboring plant storage to avoid a saturation of the wet storage capacity and to secure enough storage space for maintaining the sustainable reactor operation. However, these management methods have a limitation as well because the amount of spent fuel has been continuously increasing. A dry storage of spent fuel is considered as an alternative way to extend the saturation of wet storage system. In many countries, spent fuel dry storage has been already utilized since the middle of 1980s and many studies related to dry storage have been carried out. One of the main issues is integrity of spent fuel during the dry storage. Although there are many known degradation mechanisms during dry storage, it is important to ensure that these degradation mechanisms do not damage the fuel during the storage period. Significant degradation mechanisms of spent fuel are known as creep, reorientation of hydrides, delayed hydride cracking and etc. In particular, hydride reorientation has been reported as one of the major degradation mechanisms. Hydride reorientation is the phenomena that absorbed hydrogen during reactor operation is precipitated and oriented to radial direction driven by a rod internal pressure. These reoriented radial hydrides degrade mechanical properties of cladding [1-4]. Because it is known that hydride reorientation is occurred if a hoop stress is higher than a specific threshold stress value, several researches try to find out the threshold stress [1, 2]. A few of studies had developed a hydride reorientation model to predict the hydride reorientation ratio [3, 4]. EPRI has also developed a hydride reorientation model and compared with experimental data [5] and suggested fitting parameters for each cladding type.

In this study, the software program has been developed, which calculates hydrogen content and hydride reorientation fraction of spent fuel associated with its condition. Reactor operation record and dry storage condition were analyzed using Falcon fuel performance code developed by EPRI [6]. Then, a hydride reorientation fraction for domestic spent fuel was evaluated using hydride reorientation model suggested by EPRI [5].

2. Methods and Result

In this section, an assessment procedure applied to the software program to evaluate hydride reorientation are described. This procedure contains initial conditions of spent fuel, calculation of hydride contents and hydride reorientation fraction respectively. In this study, computer language, PERL, was used for developing the software program.

2.1 Initial conditions of fuel

EPRI's Falcon fuel performance code was used to evaluate initial condition of spent fuel. To evaluate the condition of spent fuel after reactor operation, linear power density and axial shape index were needed to make inputs of Falcon code. These values were calculated by nuclear design code. For evaluating the dry storage condition, decay power history of spent fuel during the dry storage period was calculated by ORIGEN code and heat transfer coefficient of dry storage condition was calculated by Falcon code [7]. Axial power shape was assumed as a constant normalized value. Because normal dry storage casks are filled with helium, it is assumed that no additional oxidation is occurred during the dry storage period.

2.2 Hydride Contents

The Falcon code does not calculate hydride contents of a fuel cladding. Therefore, to calculate hydride content of a cladding, the formula included in MATPRO was used [8]. Because hydride contents were directly proportional to oxide thickness of a cladding, oxide thickness was obtained from the Falcon results. Then, hydride contents were calculated along the axial stations.

2.3 Hydride Reorientation Fraction

The hydride reorientation fraction was calculated using EPRI's hydride reorientation model. This model is dependent on several variables and kinds of alloys, etc. Variables which affect hydride reorientation fraction are hoop stress, initial dry storage temperature and kind of alloy. These variables were obtained from the Falcon results according to various dry storage scenarios. Fig. 1 shows hydride reorientation fraction associated with stress and temperature modeled by EPRI.

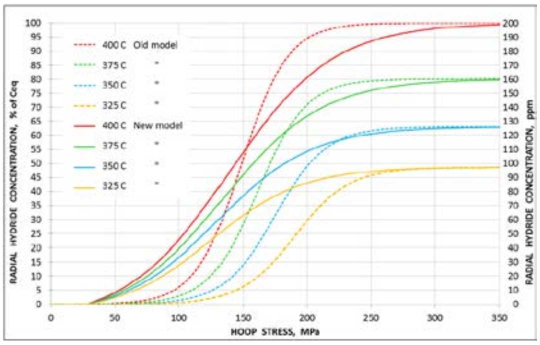

Fig. 1. Model Simulation of Hydride Reorientation [5]

2.4 Program description

The flowchart shown in Fig. 2 describes the process of calculating a hydride reorientation fraction. All the procedure described in previous sections were included in the calculation software program flow chart.

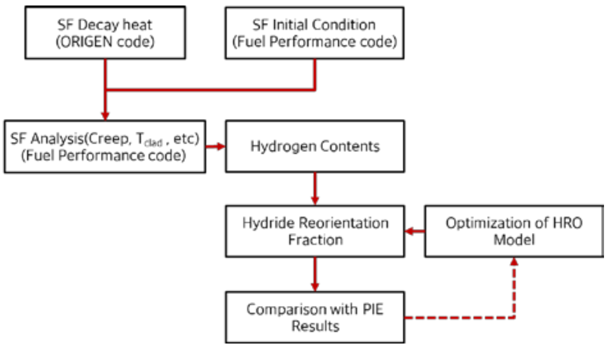

Fig. 2. Flowchart of hydride reorientation calculation program

3. Conclusions and Future Works

In this study, the program for calculating hydride reorientation ratio has been developed. Several test cases have been investigated and the evaluation results were agreed with EPRI's results. The differences between the previous and modified model are due to that threshold stress and slope are lower than those of previous model. It reflects recent research about threshold stress and initial radial oriented hydride. It is reported that the lower temperature, the less radial hydride concentration a fuel cladding gets because the initial dissolved hydrogen is low.

As a future study, hydride reorientation ratio for the domestic spent fuel will be performed. In addition to that, post-irradiation examination results will be compared with evaluation results to validate and modify the EPRI's hydride reorientation model.

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REFERENCES

[1] J.S Kim et al, Journal of Nuclear Materials, 456, 235, 2015
[2] Y.J Kim et al, Journal of Nuclear Science and Technology, 52, 717, 2014
[3] M. Puls, Solute-Defect Interaction: Theory and Experiments, eds. Pergamon, Toronto 1986, p. 426
[4] C.E. Ells, Journal of Nuclear Materials, 35 306-315, 1970
[5] A Hydride Reorientation Model for Irradiated Zirconium Alloy Cladding. EPRI, Palo Alto, CA: 2014. 3002004237
[6] Fuel Reliability Program: Falcon Fuel Performance Code: Version 1.4.0. EPRI, Palo Alto, CA: 2018. 3002011623
[7] Y.D Kim, et al, Evalation Study on the Advanced Creep and Hydride Reorientation Model for Spent Nuclear Fuel during Dry Storage, Transactions of the Korean Nuclear Society Spring meeting, 2018
[8] W.G. Luscher, et al, Material Property Correlations: Comparision between FRAPCON-4.0, FRAPTRAN-2.0 and MATPRO. PNNL-19417 Rev. 2