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Spent Fuel Integrity Evaluation Approach Considering Statistical Treatment and Succeeding Activities

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1. Introduction

Around ten thousand tons and various kinds of spent fuels (SF) in Fig.1 [1] have been stored in the domestic plants, and the year of storage capability is coming soon. Therefore, the SF disposal comes to be hot issue.

The SF integrity evaluation is considered as a sort of key technology for the related dry interim storage recently. In particular, since Fukushima Daiichi nuclear disaster, the higher safety requirements have been stressed in the nuclear industry. Going along with this atmosphere, the integrity of spent fuel is to be an emerging issue. The physical behavior of spent fuel, however, is quiet complex, not easily tractable and not exactly predictable. Above trends have been focused on this agenda and also the consequence has been employed in a chain of succeeding evaluations such as shielding, thermal and critical analysis of a dry cask system for spent fuel. On the other hand, in the domestic situation, although a series of research and development has been performed for this SF related items, no activities have been performed including even regulation field. In order to draw a set up on pictorial system of this SF integrity analysis, this study suggests a promising practice fit for domestic environment.

2. Scheme of SF Integrity with Statistical Approach

As a result of surveying and analyzing the numerous background information related to the SF integrity, two way approaches could be realistic and desirable in the right of engineering judgment and Korean situation that SF information is limit. This is a combined methodology of deterministic and probabilistic analyses. Under normal and hypothetical accident conditions, considering end of dry storage conditions, the closed form or numeral simulation is used to know dynamic responses of storage-to-spent fuel system as shown Fig. 2[1]. In this analysis, we can evaluate the amount of load path from external to internal of the system. Finally, clad tube integrity can be evaluated with statistical analysis using the experimental data information, i.e. the force resultant as results of a series of analysis and on-shelf data such as the irradiated characteristic material properties since this information is restrictive and the determination process quite complicated.

On the stage of this probabilistic analysis, the previous researches defined the 3 failure modes as shown in Fig. 3[2]. These modes use both the deterministic local-effects modeling and analysis methodology with a probabilistic approach, aimed at determining the failure probability of each failure mode. Two-tier failure criteria are considered and also they have their own sets of random variables representing the resultant strength side and the capacity side of the analysis process [3]. One is the Strain Energy Density (SED), which is the cladding response to forces that can be calculated as previously mentioned. The other is the capacity side of the analysis procedure that is the Critical Strain Energy Density (CSED), which provides the criterion for cladding failure. This value is just the integrated area under a stress-strain curve from mechanical property tests:

$$\mathrm{CSED} = \int \sigma ij \ d\varepsilon ij$$

where σij and εij are the stresses(MPa) and strains(mm/mm) measured in the test.

The failure probability can be then determined from solving the probability density function of SED and CSED over the failure domain defined by SED $\geq$ CSED. This solution can be obtained numerically using Monte Carlo simulation. Overall process of this work is depicted in Fig. 4. This approach has a merit to employ the domestic data as mentioned in the following section, to save time and cost.

3. Succeeding Activities after Structural Evaluation

Under accident conditions of transport the neutron multiplication is substantially affected by the condition of the fuel elements and the basket. In general, the impact behavior of spent fuel elements is not completely known and therefore conservative assumptions are taken for criticality safety assessment. Thus, the SF structural analysis results are applicable to criticality evaluation and even thermal performance, confinement/shielding for both storage and transportation by addressing fuel rod lattice deformations, fuel cladding failure etc. This scheme can relieve conservatives like burnup credit analysis of criticality.

4. Data Acquisition of Korean SF for the Evaluation

The poolside examination (PSE) and post-irradiated examination (PIE) are demanded to get the aforementioned data. The former performs a variety of examinations in assembly and single rod state such as visual inspection, fuel growth, bowing and twist, rod-to-rod spacing, spacer grid width, fuel rod diameter, and fuel rod oxide thickness. On the other hand, latter one is to measure further information of clad through the destructive methods. Those data can cover the SF integrity analysis within restricted range of quantity and items so some more information is needed. KEPCO NF has regularly established the related infra as shown in Fig. 5, solely has acquired these necessary PSE data and also generated PIE data with aid of KAERI. All the data is owned by KEPCO NF proprietary so this data will be necessary for licensing acquisition activities of dry storage and transportation system in the foreseeable future, Korea.

4. Conclusion

Regarding the SF integrity evaluation, a systematic evaluation chain shall be setup. At first, the evaluation is to be a top-to-down analysis from cask to clad. During this process, it is recommended that deterministic and probabilistic approaches be developed considering various kinds of technical and environmental circumstances. Secondly, the analysis results are to be employed in criticality, thermal analysis etc. And also KNF has established the related equipment, solely has acquired these necessary PSE data and also generated PIE data for SF integrity analysis. All the data is owned by KEPCO NF proprietary so these data will be necessary for licensing acquisition activities of dry storage and transportation system in the future, Korea.

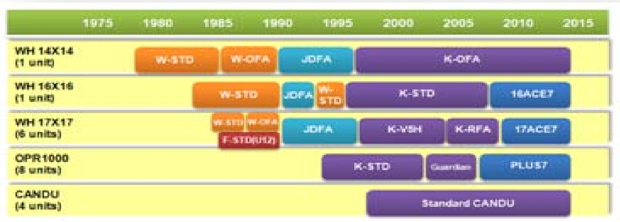

Fig. 1 Fuel Loading History in Korea Nuclear Plants

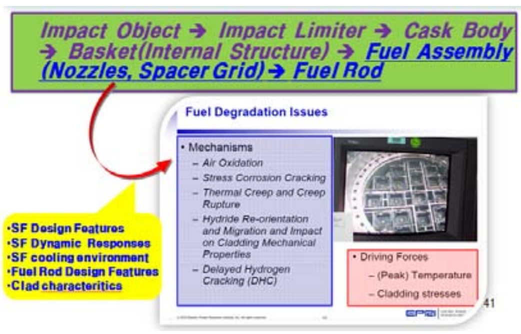

Fig. 2 Overall Scheme of SF Integrity Evaluation

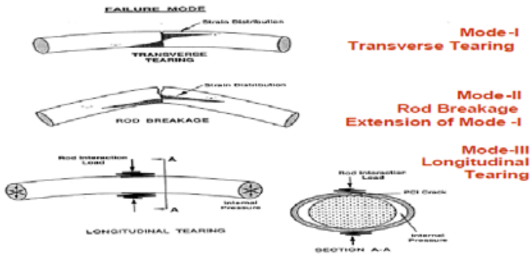

Fig. 3 Main Failure Modes of SF Clad Tube

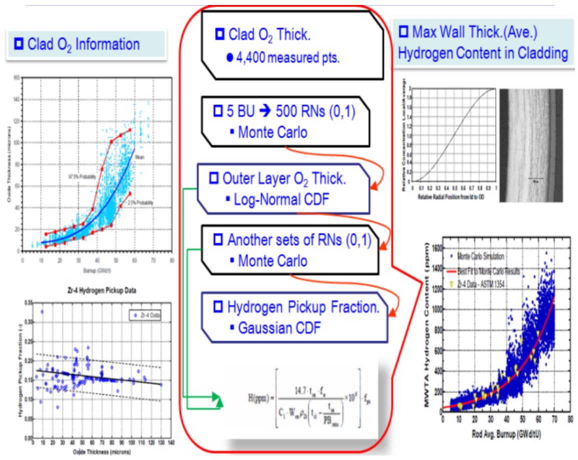

Fig. 4 Statistical Approach of SF Integrity Evaluation

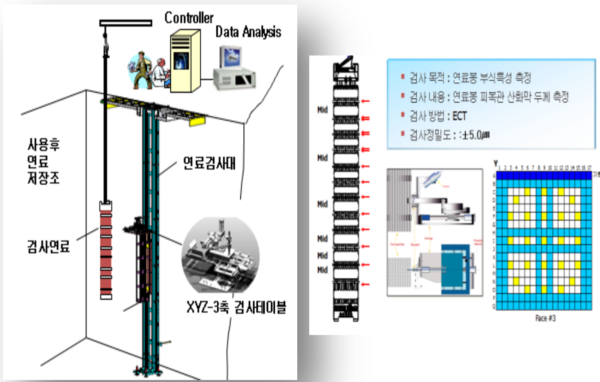

Fig. 5 KNF PSE Infra and Oxide Thick. Measure Sys.

REFERENCE

[1] S. K. Lee et al, "건식저장의 사용후핵연료 구조변형평가", KAERI/CM-1399/2010, KNF, 2011.
[2] T. L. Sanders et al., A Method for Determining the Spent-Fuel Contribution to Transport Cask Containment Requirements, SANDIA Report, SAND90-2406, TTC-1019, UC-820, November 1992.
[3] J. Rashid et al, SF Transportation Applications: Longitudinal Tearing Resulting from Transportation Accidents-A Probabilistic Treatment, EPRI, 2006.