The Probabilistic Approach to Hydrogen Content Acquisition for the Spent Fuel Integrity Evaluation

Soyoung Kim[a*], Seongki Lee [a], Kisung Choi [a], Chaejoon Lim [a]Seongho Park [b], Yunhee Lee[c]
[a]*KEPCO NF Co, 989 beon-gil 242, Daedeok-daero, Yuseong-gu, Daejeon, Korea*
[b]*Seoul National University, 1 Gwanak-ro, Gwanak-gu, Seoul, Korea*
[c]*Department of Statistics, Chungnam National University, Daejeon 305-764, Korea*
[*]*Corresponding author: soyoungkim@knfc.co.kr*

1. Introduction

During transportation (handling) & storage (T&S) of spent fuel (SF), the SF integrity is key essential issue. Especially, to avoid the release of radioactivity from an irradiated assembly, the integrity of the SFs must be maintained under postulated normal or accident events [1, 2]. Regarding this matter, some approaches have been developed by world leading institutes such as US national laboratory (Sandia, Argonne, EPRI etc.), Areva etc. On the other hands, in Korea, the technology of the SF integrity evaluation under the SF transportation & handling (T&H) has not been developed even if the transportation of the SF station-to-station is performed. This technology shall be developed as soon as possible since ultra-safety is required for nuclear public acceptance especially after Fukushima accident. Also US regulation law requires the SF integrity evaluation (SFIE) during T&H of SF and Korean nuclear industry mostly comply with this regime.

In general, the physical behavior of SF, however, is quite complex, not easily tractable and not exactly predictable. Especially the dynamic response of both SF and its cladding tubes that have intrinsically complex features as depicted in Fig. 1 shows quite intricate mechanism in T & H activities. Thus some aforementioned institutes have developed and similar approaching methodology was proposed through benchmarking work with the tangible reference literatures [3].

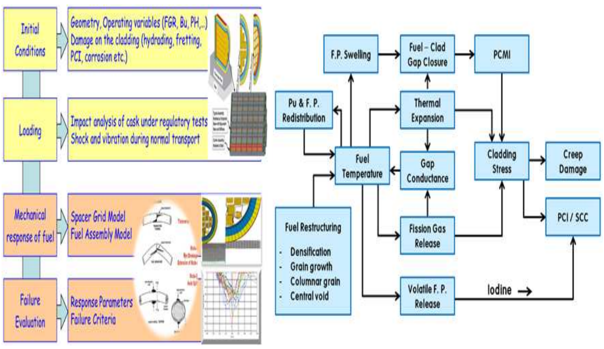

Fig. 1. General SFIE Procedures (Left) and Fuel Rod Behavior through various Parameters (Right)

The tremendous work is necessary to map out fully. In this paper, the first step is to be deployed to simulate the EPRI's retrieving methodology of hydrogen content through the probabilistic treatments since we can only access the outlined information.

This statistical method are commonly used in other analytical fields for whole SFIE so once the detailed black box technique about this is obtained, this is applicable to grasp an overall process of SF integrity methodology.

2. Methods and Results

2.1 Probabilistic analysis Methodology

As upper-mentioned, due to a complexity of SFIE, two approaches are to be applied, i.e. deterministic and probabilistic ones. The former is a system in which no randomness is involved in the development of result of analysis and thus always produces the same output from a given initial state. Whereas, a probabilistic analysis is a measure of the expectation that a result occurs and formalizes each relationships among random variables in the form of mathematical equations. A probabilistic analysis describes how one or more random variables are related to one or more other parameters.

Regarding the hydrogen, because cladding wall thickness hydrogen content measurements require destructive examinations of irradiated fuel in hot-cell facilities, the available database of hydrogen content is limited and insufficient for statistical analyses. As a result, a statistical approach has been used to develop the hydrogen content as function of burnup from the available data on the outer surface oxide layer thickness and hydrogen pickup fraction. This data is to be utilized in building up SFIE failure criteria i.e. “Critical Strain Energy Density”. Detailed procedure is described in Fig. 2 and Mathcad is used as a tool for this probabilistic work.

2.2 Retrieving the hydrogen content vs. function of Burnup with probabilistic handling

The average hydrogen content (H) is calculated from the oxide thickness of cladding (t_{ox}) and hydrogen pickup fraction (f_{pu}). The hydrogen pickup fraction is defined as the ratio of the hydrogen absorbed over the total hydrogen generation due to corrosion reaction. The data of oxide thickness of cladding is a function of burnup and the data of hydrogen pick-up fraction is a function of oxide thickness [2]. The probabilistic analysis is used to determine hydrogen content as a function of burnup. As a result of a series of probabilistic simulation mentioned in Fig. 2, Fig. 3 is obtained. At this point, data of the oxide thickness and hydrogen pickup fraction is roughly selected from PSE data KEPCO Nuclear Fuel (KEPCO NF) has measured to show just a tendency of EPRI result.

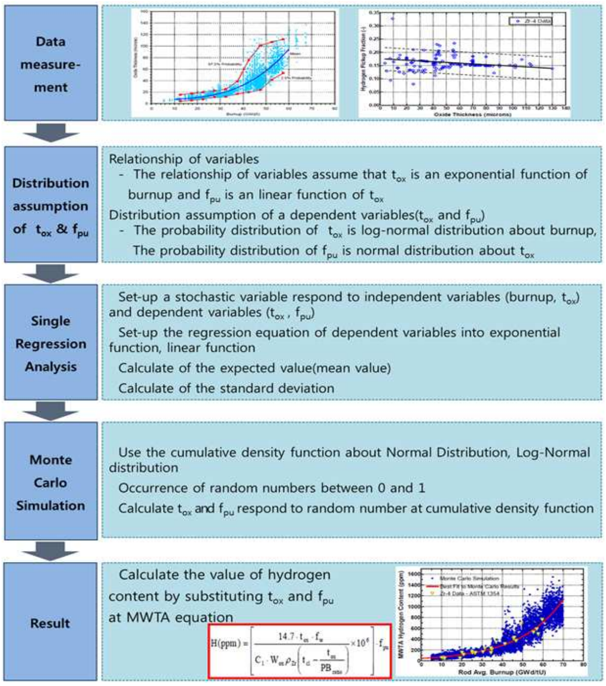

Fig. 2. Retrieving process of hydrogen contents

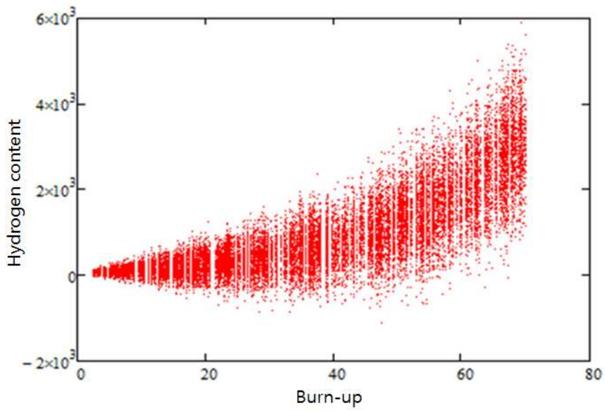

Fig. 3. Simulated Hydrogen Contents with Mathcad

2.3 In-reactor Performance Data through PSE(Poolside Examination) and PIE(Post-irradiation Examination)

Mostly SFIE strongly depends on the field data. PSE for outer surface oxide thickness data and PIE for direct acquisition of hydrogen contents are demanded. The PSE is to measure assembly and single rod state such as oxide thickness, growth, diameter of irradiated fuel rod, rod-to-rod spacing, etc. And the PIE is to measure further information of clad through the destructive methods [3]. KEPCO NF has regularly established the related infra, acquired these necessary PSE and also generated PIE data with aid of KAERI. Using those data and previous statistical methods, the criteria for SFIE can be set up for the made-in Korean SF. All the data owned by KEPCO NF could be used for diverse purpose such as SF evaluation and licensing acquisition activities of dry storage and transportation system [4].

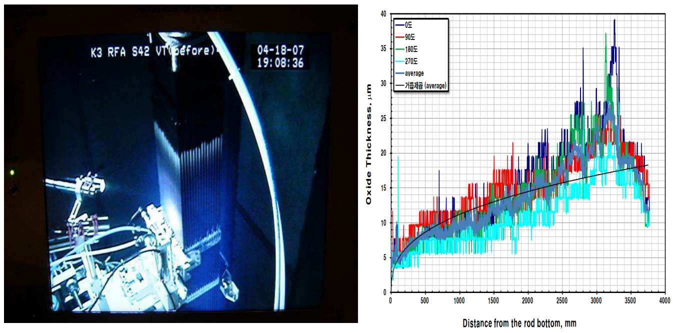

Fig. 4. Poolside examination (PSE) system (left) and Oxide Thickness results by PIE (right)

3. Conclusions

Hydrogen content of cladding is one of the essential factors to determine failure criteria for SFIE. So the benchmarking calculation referring to EPRI report was performed in this study. The simulation result shows quite similar trends to that of EPRI's using probabilistic approaches. This methodology can be applicable to other statistical works related to SFIE since SF data is very limited and SFIE has many inter-dependent parameters affecting SF behavior and response under the postulated events during T & S.

KEPCO NF has established the related infra, acquired from PSE and also generated PIE data with aid of KAERI. All the data is owned by KEPCO NF to be utilized SFIE proprietary and will be researched later for SF evaluation and licensing acquisition activities for dry storage and transportation (handling) system.

REFERENCES

[1] O. Ozer et al, Fuel-Assembly Behavior Under Dynamic Impact Loads Due to Dry-Storage Cask Mishandling, EPRI, 2008.
[2] J. Rashid et al, SF Transportation Applications: Longitudinal Tearing Resulting from Transportation Accidents-A Probabilistic Treatment, EPRI, 2006.
[3] Seong Ki Lee, Oh Hyun Kwon, Ki Sung Choi, Jae Ik Kim, Chang Sok Cho, Jae Hoon Kim, Spent Fuel Integrity Evaluation Approach Considering Statistical Treatment and Succeeding Activities, Transactions of the Korean Nuclear Society Autumn Meeting, 2011.
[4] So Young Kim, Seong Ki Lee, Byeong Soon Choi, Ki Sung Choi, Chae Joon Lim, General Approach of Spent Fuel Integrity Evaluation for Transportation and Dry Storage, Transactions of the Korean Nuclear Society Spring Meeting, 2012.