General Approach of Spent Fuel Integrity Evaluation for Transportation and Dry Storage

So Young Kim [a*], Seong Ki Lee [a], Byeong Soon Choi[a], Ki Sung Choi[a], Chae Joon Lim[a]
[a]*KEPCO NF Co., 989 beon-gil 242, Daedeok-daero, Yuseong-gu, Daejeon, Korea*

1. Introduction

Long-term dry storage of spent fuel (SF) is one of the promising countermeasures to handle it in Korea. To implement this process, SF integrity evaluation is an essential item. This evaluation is required to use various kinds of the in-reactor performance data such as oxidation, hydrogen re-orientation, creep, stress, irradiation etc. and the structural mechanical characteristics. This information is to be used to evaluate and model of SF behavior under dry storage environment. In general, the initial condition of SF is status of the very–after irradiation. That's the reason why in-reactor data and response behavior are necessary to perform it. This primary information can be employed.

In Korea, however, when it comes to SF, the related R&D activities have been inactive compared to other nuclear ones because of Korean specific situation. Around ten thousand tons of SFs has been stored in each plant, and the year of storage capability limit is coming soon. Considering this time pressure, one of the related key technologies is to evaluate SF integrity. Currently, roadmap has been setup and the related study has been performed since a couple of years ago. To prevent something inattentive and to proceed with the further developed tasks, in this paper some evaluation approach of SF integrity will be suggested.

2. Nuclear Fuel Behavior in Reactor

The fuel behavior in reactor is very complex. The characteristics of unloaded fuel rod (SF) depend on in-reactor history such as power uprating, longer-cycle or high burn-up operation, fuel design features (material, geometry etc.) and the like. Consequentially the fuel experiences several physical and chemical changes. Fig. 1 shows the typical mutation of these fuel clad characteristics.

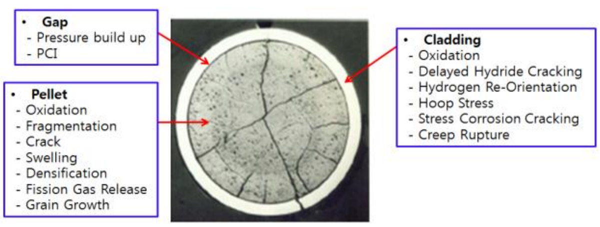

Fig. 1 Fuel Characteristic Changes in Reactor

Regarding the evaluation of fuel assembly in reactor, all of the conditions are considered and evaluated under normal or accident conditions such as exposure of high speed coolant, handling, earthquake etc. Fig. 2 shows the general fuel assembly structural behavior and its responses. As shown the figure, many loading source makes fuel impacted and deformed. These responses are a cause of physical property changes such as structural stiffness, transfigured geometry etc.

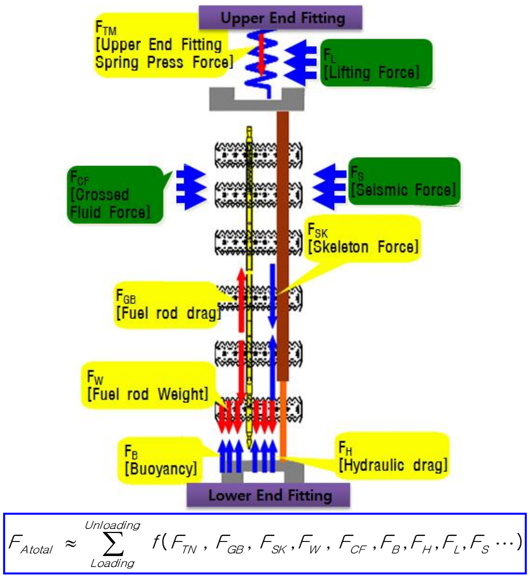

Fig. 2 Free Body diagram of fuel assembly

Thus, the property changes of fuel in reactor are inevitable during irradiation under a rigorous environment. As of now, there have been various kinds of fuels supplied to NPPs in Korea (Fig.3). Viewed historically, the fuel designs have been constantly improved in almost five-year interval. For this reason, the features of SF are not easily definitive and get various. This fact would give us some difficulties in performing the related projects such as object, methodology, scope etc. of evaluation. Since an analytical approach is so limited due to the aforementioned obstacles, almost all the evaluation approach must strongly depend on the practical data by using the related computer codes. This information is normally available from Poolside Examination (PSE) and Post-irradiated Examination (PIE). KEPCO NF has regularly established the related infra, acquired these necessary PSE and also generated PIE data with aid of KAERI. All the data is owned by KEPCO NF proprietary and could be used for diverse purpose such as SF evaluation and licensing acquisition activities of dry storage and transportation system [1,2].

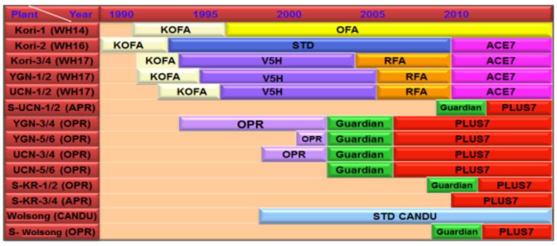

Fig. 3 Fuel Loading History in Korea Nuclear Plants [2]

3. Spent Fuel Behavior under Dry Storage Condition

One of the top tier requirements of SF during its transportation and storage is that the SF must maintain the integrity during its carrying and storage. The SF integrity relies on temperature, creep, stress, inner pressure etc. of fuel under this circumstance. Those items directly or indirectly impact on the SF integrity behavior, which is quite intricate and intractable since this is connected with its previous in-reactor operation and cooling time in pool. From the view point of evaluation, two fields can be classified as one is related to the static mode and the other is dynamic one, similar to the scheme of in-reactor evaluation as upper mentioned. The former case mainly handles the integrity of SF clad during long-term dry storage. The latter is to evaluate SF structural integrity under handling and transportation or even storage which forms a load path from outside of cask to fuel clad through fuel structural components like spacer grids during normal operation(normal drop event) or accident(higher drop accident, seismic events, severe win storm etc.) conditions. Mostly SF becomes degraded during the long-term storage in some degree and sometimes these phenomena get worse to be failure. And also to carry and retrieve this SF in the degraded status, the integrity margin can be lowered. Thus, it is very important to understand the prediction of a degradation mechanism of fuel clad during the above campaign. To evaluate the SF integrity under the various situations, the information as described in previous section is necessary and based on DB as shown in Fig. 4 using partly statistical and deterministic approaches, further evaluation is to be executed more clearly.

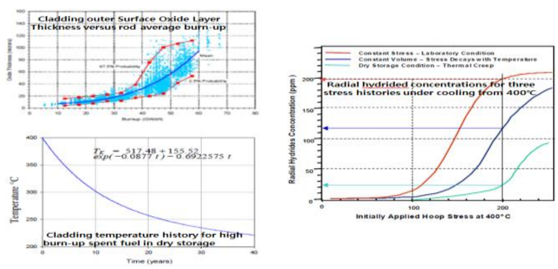

Fig. 4 SF performance information [3]

Therefore, the existing fuel evaluation tools are extensively employed to evaluate fuel clad integrity using the code for the analysis of fuel rod performance. In this case, some improvement is necessary for it to apply to the evaluation by reflecting the in-reactor behavior data and some extra evaluation items. The other clad integrity evaluation under the dynamic impact is also performed by setting up DB for failure criteria such as strain energy density function [2], SF physical information such as geometry and material characteristics etc. and SF-cask load path system.

Speculating a series of assessment process, some approach can be systemized as shown in Fig. 5. This approach is drawn in the frame of big picture in performing future R&D scheme and directivity. Keeping pace up with this, a detailed working is to be made out.

4. Conclusions

The evaluation of SF integrity is the key technology, and it is necessary to strengthen and reinforce it.

The performance of fuel rod after burn-up is initial condition of SF. The SF can be evaluated by improving the existing fuel evaluation tools. This paper suggests a pictorial system of this SF integrity evaluation by analyzing current R&D activity and restructuring them. The performance system of integrity evaluation of SF can be summarized as shown in Fig.5.

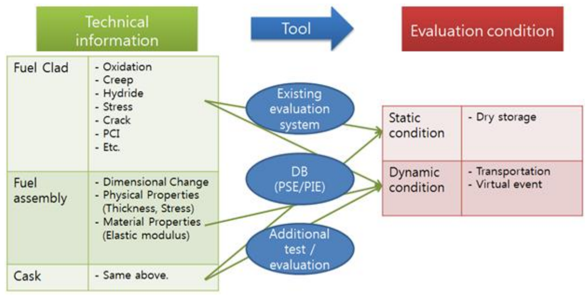

Fig. 5 System of integrity evaluation for SF

Acknowledgements

This work was supported by the Ministry of Knowledge Economy (MKE) through the Korea Institute of Energy Technology Evaluation and Planning (KETEP).

REFERENCES

[1] S. K. Lee, Y. S. Nam, Y. H. Kim, S. Y. Jeon, C. S. Cho, Structural Deformation Evaluation of Spent Nuclear Fuel, KAERI/KNF, 2011.

[2] S. K. Lee, O. H. Kwon, K. S. Choi, J. I. Kim, C. S. Cho, J. H. Kim, Spent Fuel Integrity Evaluation Approach Considering Statistical Treatment and Succeeding Activities, Transactions of the Korean Nuclear Society Autumn Meeting, 2011.

[3] A. Machiels et al, Spent Fuel Transportation Applications - Assessment of Cladding Performance, EPRI, 2007.