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Spent Fuel Status in Korea and Integrity Evaluation

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ABSTRACT

The spent fuel (SF) disposal is to be hot issue since the year of plant storage capability is coming soon in Korea. To solve this facial problem, interim storage is a realistic countermeasure other than many other back-end cycle options. To this end, the SF integrity evaluation is considered as a sort of key technology to implement this process. 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 and evaluation of SF has risen to be more important than ever before. The physical behavior of SF, however, is quiet complex, not easily tractable and exactly predictable since this is connected with the environments of its previous in-reactor operation conditions and cooling time. Fewer activities have been performed including even regulation field in Korea as of now because of various kinds of situations such as political, social, industrial matters etc. In order to draw the future pictorial system of SF integrity, this study suggests a promising candidate practice for SF integrity evaluation approach suitable for domestic environment.

1. Introduction

Around ten thousand tons and various kinds of spent fuels (SF) in Figure 1 have been stored in Korean plants, and the year of storage capability is coming soon. Therefore, the SF disposal comes to be hot issue. Among the many back-end fuel cycle options, Figure 2 is to be an expected nuclear cycle scenario in Korea. Thus, dry storage of SF is one of the promising countermeasures to handle SF in Korea. To implement this process, SF integrity evaluation is an essential item. Especially, to avoid the release of radioactivity from an irradiated assembly, 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 under postulated normal or accident events. [1, 2]

Towards this end, the evaluation is required to use various kinds of the in-reactor performance data such as oxidation, hydrogen, hydride orientation, creep, irradiation etc. and the structural mechanical characteristics. Actually the fuel is irradiated in a reactor under the environment of extremely high-level pressure and temperature.

During the fission process the fuel produces energy and its composition physically changes.

Initially a simple composition of various isotopes of uranium, after irradiation, the fuel contains around 200-300 other isotopes. A typical LWR discharges around 20 tons of SF per year which are placed in special racks and submerged under water to shield personnel from the radioactivity and to cool the fuel which customarily stays in the cooling pool for around 5-10 years. When the fuel is removed from the nuclear reactor core, it is not only still highly radioactive but also physically hot. The heat output from the fuel immediately after removal is still 7% of that produced when running the reactor. This heat is not easily quenched, so SF must be immediately cooled to prevent degradation. This previous history of the fuel right before preforming any fuel cycle activities is an initial condition of SF and very complex, not easily tractable and exactly predictable.

Since Fukushima Daiichi nuclear disaster, the higher safety requirements have been stressed in the nuclear industry and also SF disposal has also been troublesome to the country running nuclear power plant. Going along with this mood, SF interim storage has been highlighted and implemented worldwide in US, EU, Japan etc.

Regarding the interim storage of SF, the integrity of SF is to be a main stream to do make it out. Fewer activities, however, have been performed as of now including even regulation field in Korea because of various kinds of situations such as political, social and industrial stuff like that. Thus to draw the future pictorial system of SF integrity, this study suggests a promising candidate practice for SF integrity evaluation fit for the domestic environment and the guarantee of sustainability for nuclear power generation.

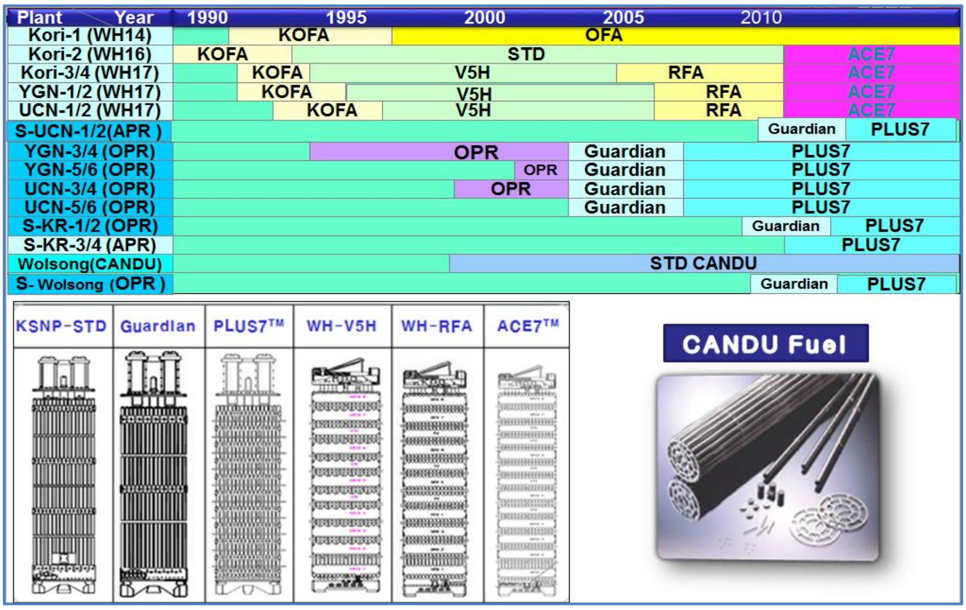

Figure 1. Nuclear Fuel Loading History in Korea

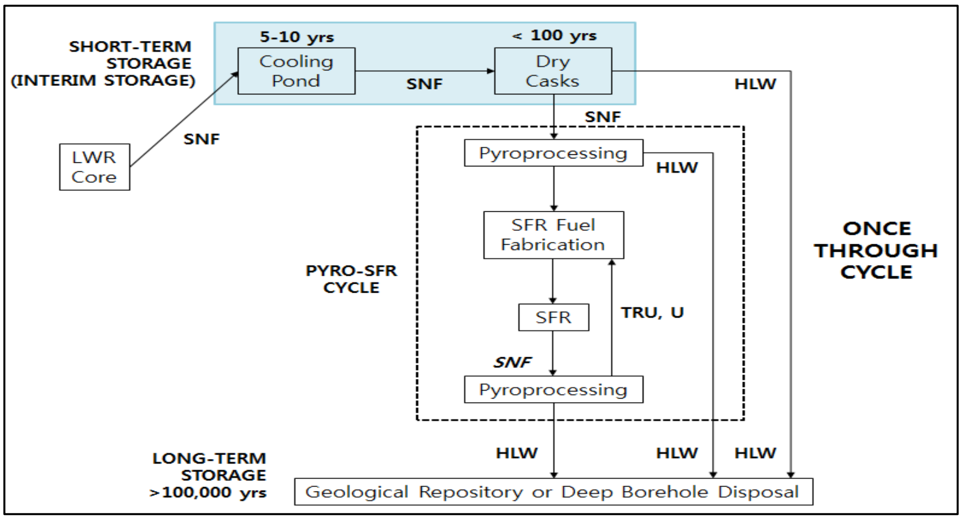

Figure 2. The Expected Fuel Cycle Scenario in Korea

2. SF Status and Necessity for Dry Storage

Korea runs 23 nuclear power reactors; 19 is PWR type and the other 4 is PHWR. From those reactors, about 8 hundred tons of SF is unloaded every year. Around ten thousand tons and various kinds of SF in Figure 1 have been stored in SF pool of each plant up to now.

Korea has operated several techniques to delay SF storage capacity from being reached, such as "burn-up extension, storage re-racking, installation of a dry storage facility and transshipment between neighboring units, to solve SF storage problem." While there have been difficulties with transshipments between sites because of the transportation infra, these efforts should allow more time to develop a permanent solution. However, these techniques have their limitations, and the country's SF pools will likely reach their capacity before and after 2020. Moreover, densely packing SF pools raises nuclear safety and security concerns.

The related authority is trying to designate an interim storage site, beginning in 2024 which is about 10 years later. Therefore, SF interim storage is to an inevitable option in the light of Korean nuclear status. To carry out this system, SF integrity is to be demonstrated at first since the other hardware infra can be imported from abroad countries while SF integrity evaluation needs the local own features. Simultaneously, it is necessary to be made on the detailed concrete specifications of dry storage such as installation location, operation time, target SF and storage system types.

And also SF characteristic data is essential components for the integrity evaluation and could have a significant influence on the dry storage system. As this data acquisition demands lots of time and money consuming stuffs, a cautious approach should be made and reasonable technical strategy is set up far before introducing the storage system design. The further related methods are to be treated in the following section referring to the existing research results[3, 4].

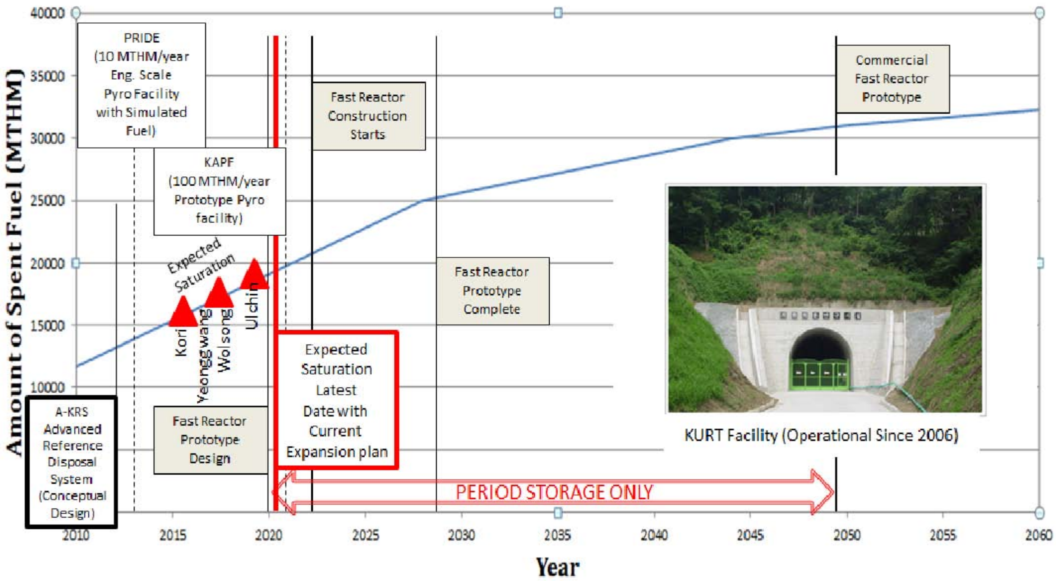

Figure 3. SF Accumulation Trends in Korea with Management Options.

3. Suggested SF Integrity Evaluation Scheme

As previously mentioned, one of the top tier requirements of SF during its transportation and storage is the integrity of SF. The SF integrity generally is the function of many parameters such as fuel design, in-reactor performance etc. Those items directly or indirectly impact on the SF integrity behavior, which is quite intricate since this is connected with its previous stage of in-reactor operation and cooling time in SF pool. The physical status of fuel after burn-up is initial condition of SF.

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. The former case mainly handles the integrity of SF clad during long-term 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 wind storm etc.) conditions. Mostly SF becomes degraded during the long-term storage in some degree and sometimes these phenomena get worse to be failure. Carrying and retrieving this SF with the material and structural degraded status, the safety margin of SF could be lowered. Thus, it is very important to understand the prediction of a degradation mechanism of fuel clad during the above campaign. Therefore, the existing fuel evaluation tools are extensively employed to evaluate fuel clad integrity using the code for the analysis of fuel rod performance during the in-reactor conditions. In this case, some improvement is necessary for it to apply to the evaluation by reflecting some extra evaluation items.

The other evaluation under the dynamic impact is also performed by building up data base for failure criteria such as strain energy density function, SF physical information such as geometry and material characteristics etc. and SF-cask load path system. This paper suggests a pictorial system of this SF integrity evaluation by analyzing current R&D activity scheme and restructuring them.

The characteristics of unloaded fuel rod (SF) are contingent on the in-reactor history such as power uprating, longer-cycle or high burn-up operation and fuel design features (material, geometry etc.). Also, the basic phenomena of fuel include thermal and mechanical behavior, fission gas behavior radiation effect. Figure 4 shows the typical mutation of these fuel clad characteristics and various parameters that affect fuel rod behavior.

The facts that there have been various kinds of fuels supplied to NPPs in Korea would give us some difficulties in performing the related projects such as object, range, methodology, scope etc. of evaluation. And also an analytical approach is so limited due to the aforementioned obstacles so almost all the evaluation approach must strongly depend on the practical data measured from test or other sources like PSE(Pool Side Examination) or PIE(Post-irradiated Examination). Thus, 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 circumstance that SF information is very scanty. This is a combined methodology of deterministic and probabilistic analysis. 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. To proceed it, it is necessary to select the representative SF among the many types of SF in Figure 1 through parametric analysis to save time and money consumptions. After followed by this analysis, more detailed analysis is to be performed on the representative SF. In this process, coupled models of cask system-SF are to be used to get the response data such as forces, dynamic parameters, stresses, displacements.

Another important element is setting up of failure criteria. Even if many kinds of necessary data can be acquired from the literature survey, this is not enough to fully evaluate SF stored in the all domestic plants. So additional data cannot help being measured and tested for the target components. This is normally available from PSE and PIE. The former performs a variety of examinations in assembly and single rod state such as 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 like hydrogen status. Those data can cover the analysis within restricted range of quantity and items so some more information is required to do it. KEPCO NF has regularly established the related infra, solely has produced 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 during licensing acquisition activities of dry storage and transportation system in the future, Korea. A series of process from data acquisition to DB setup is shown to Figure 5 following EPRI[5] methodology and using SF data of Korean plants.

The general performance system and procedure of integrity evaluation of SF can be summarized as shown in Figure 6. This approach is drawn in the frame of big picture in performing future R&D scheme and directivity in Korea for SF management.

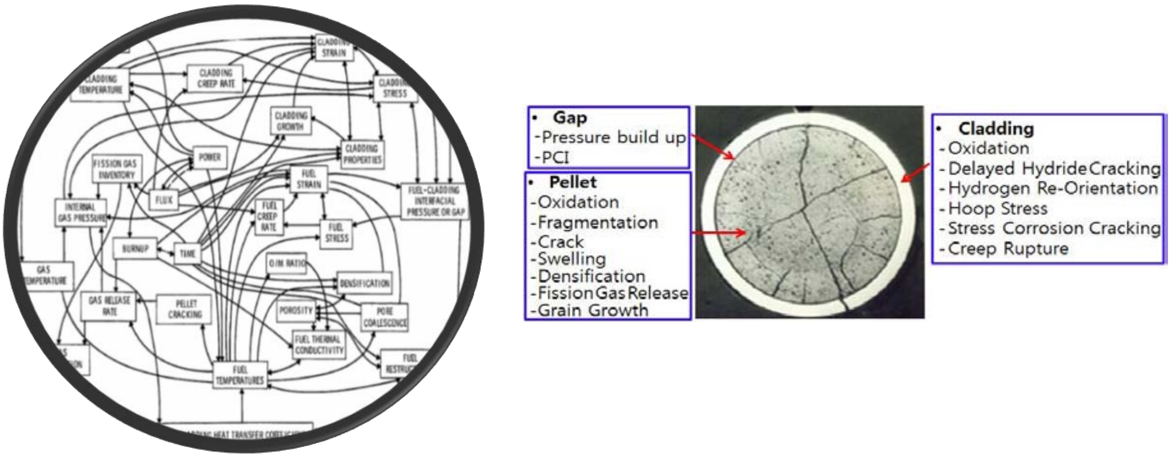

Figure 4. Fuel Characteristic Changes in reactor (left) and various parameter that affects fuel rod behavior (right)

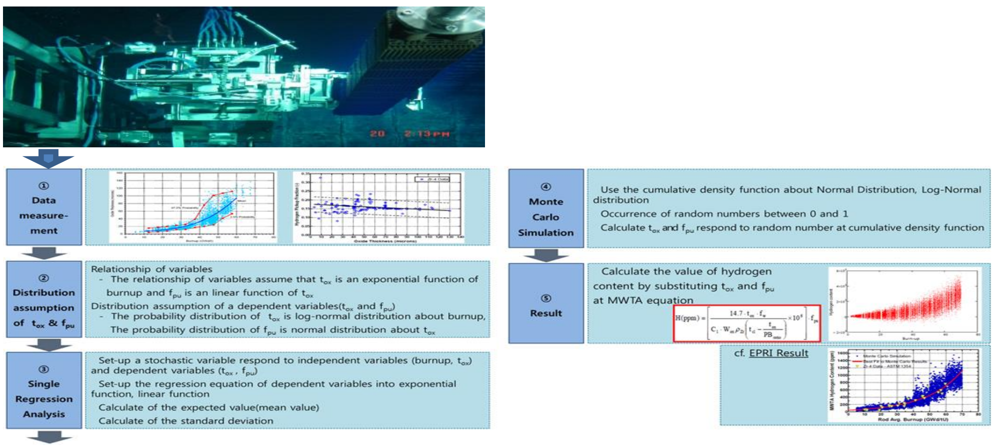

Figure 5. Data Retrieving and Example Process for Hydrogen Characteristic Data

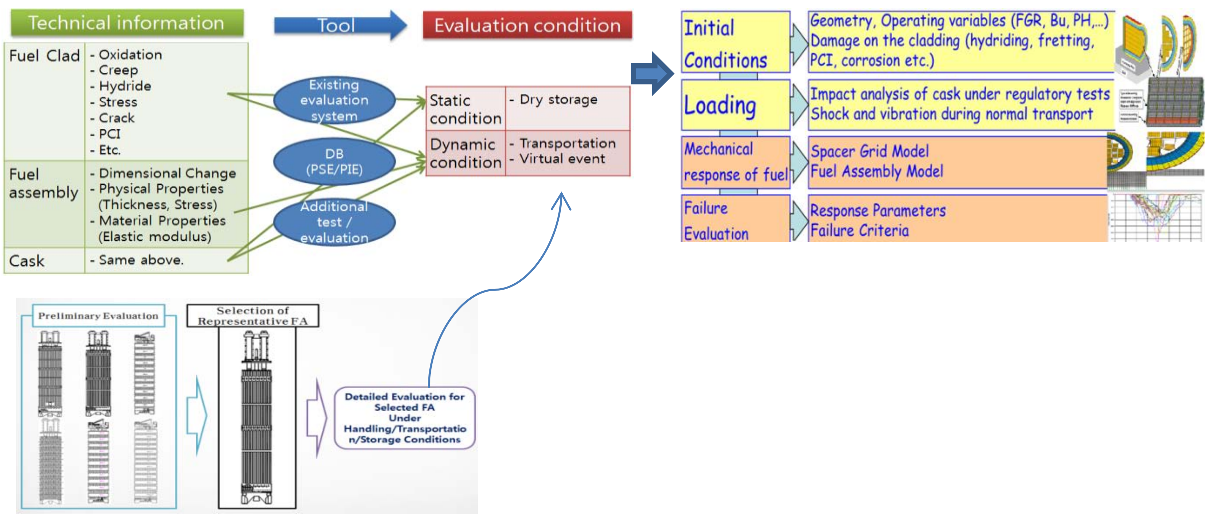

Figure 6. Approach of system (left) and procedure (right) for SF integrity evaluation

4. Conclusions

Long-term dry storage of SF is one of the promising counter measures to handle it in Korea. To implement this process, SF integrity evaluation is an essential item during handling, shipping and storing it. This evaluation is required to use various kinds of the in-reactor performance data and the structural mechanical characteristics. This information is to be used to evaluate and model of SF behavior under dry storage environment since the initial condition of SF is status of the very–after irradiation.

This paper suggests a pictorial system of this SF integrity evaluation and process by reviewing and analyzing current SF status in Korea.

5. References

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