Proceedings of the 18th International Symposium on the Packaging and Transportation of Radioactive Materials
PATRAM 2016
September 18-23, 2016, Kobe, Japan

Paper No. 5017

R&D activities of spent nuclear fuel integrity evaluation during handling and transportation for long-term storage

OC Kwon[*1], SY Kim[1], YI Yoo[1], NG Park[1], SK Lee[1], JS Yoo[1]
[*1] R&D Center, KEPCO Nuclear Fuel Co.
989 beon-gil 242, Daedeok-daero, Yuseong-gu, Daejeon, Korea

Abstract

In Korea, starting Hanbit unit, the on-site storage capability for Spent Nuclear Fuel (SNF) is expected to be saturated, and Kori unit 1 will be shutdown permanently in 2017. Therefore the management of SNF is a rising issue in Korean nuclear industry. Interim storage is suggested as one of the most promising options to solve this hard situation among many management scenarios. Handling and transportation of SNF are inevitable processes for its long-term storage even under the other ways such as its final disposal, recycling and others. According to the related regulation guidelines of many countries, SNF integrity is the major concern during the transportation and storage since it is not easily tractable comparing to the facility systems that are successfully commercialized worldwide. To prepare the upcoming events, the relevant R&D has been embarked on the SNF integrity during shipping and handling area and performed now. Those activities are (1) analysis of the characteristics of various SNF and database (DB) construction, (2) selection technology among various kinds of SNF for evaluation (3) characteristic test of simulated SNF and (4) development of computer simulation model for SNF evaluation, etc. In this paper each item is briefly outlined and future plan is also touched. Especially, the representative spent nuclear fuel (R-SNF) selection techniques are mainly focused.

1. Introduction

Starting from Kori unit in Korea, 20 pressurized water reactors (PWRs) and 4 pressurized heavy water reactors (PHWRs) have been operating since 1978, so approximately 13,000 tons of SNFs and a wide variety of PWR SNFs as shown figure 1 have been stored in the spent fuel pool of power stations[1]. The storage capability in water is going to be saturated in the foreseeable future and the SNF disposal is now coming to be a hot issue. To solve this upcoming problem, Korean government issues the management plan for high level nuclear wastes in 2016. The plan states a geological survey for 12 years before selecting the right interim and permanent disposal site for the nuclear waste disposal program in around 2028. For the interim storage and the permanent disposal, handling and transportation of SNF are inevitable processes.

According to the regulation guidelines of many countries and the Electric Power Research Institute (EPRI) report[2], SNF integrity is a major concern during transportation and storage since it is not easily tractable comparing to the facility systems that are successfully commercialized worldwide. Therefore, the SNF integrity evaluation is essential and to evaluate the SNF it 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. Those are to be used for the detail modeling of SNF behavior under handling, transportation and dry storage since the initial condition of SNF is the status right after irradiation.

As mentioned above, there are various kinds of SNFs in spent fuel pool so it is not an efficient way performing evaluation for all the SNFs. Most of the international leading institutes such as EPRI and SANDIA have approached this matter from a selection of R-SNF at the first stage for more effective evaluation[2,3]. Moreover, a lot of tests are performed to acquire mechanical characteristics of SNF, and thereafter the detailed simulation model is to be generated using SNF component-wise or assembly-wise test results. Finally, the mechanical integrity evaluation is executed during its carrying and storage under postulated normal or accident events.

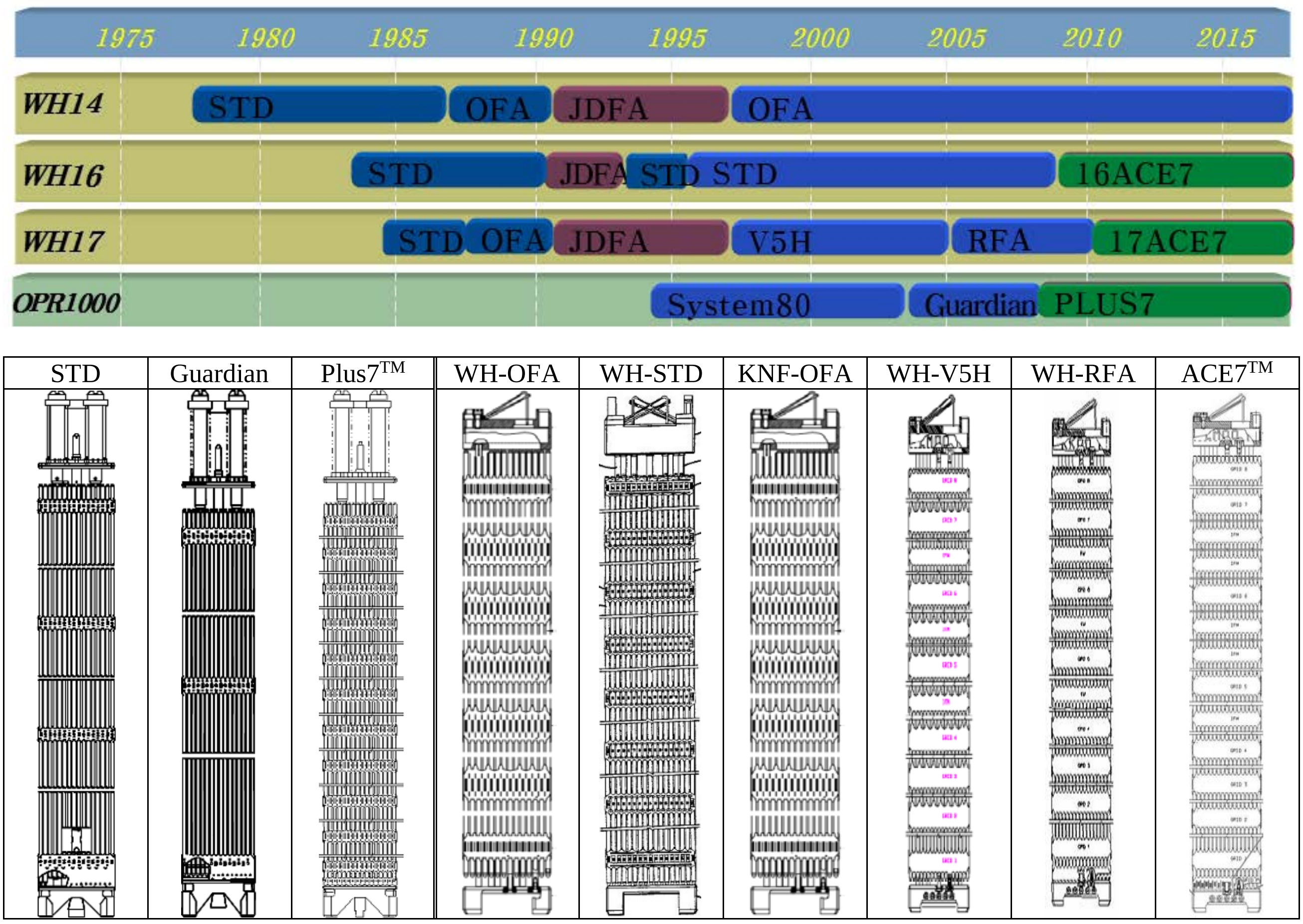


Figure 1 Stored spent fuel in Korean nuclear power plants

2. SNF Integrity Evaluation Scheme

One of the top tier requirements of SNF during transportation and storage are that the SNF must maintain the mechanical integrity. The SNF integrity depends on fuel loading data, burn-up history, and fuel status after depletion. Those items directly and indirectly impact on the SNF integrity behavior, which is quite intricate and intractable since this is connected with its previous in-reactor operation and cooling time in the spent fuel pool. The first one as a fresh fuel includes component materials, dimensions, composition of fuel rods (FRs), temperatures of the heat treatment etc. The second one stands for loading pattern, measured burn-up data based on fuel assemblies (FAs) and FRs, operation histories, unloading data, initial enrichment etc. The last one means fission product, oxidation, hydrogen re-orientation, creep, stress, irradiation, temperature, FR internal pressure etc. Those of the data are used for the theoretical prediction of FA and FR failure, criteria establishment, and final integrity evaluation in detail. Some data will be constructed from test and study on existing reports and the others will be acquired from some of the energy institutes.

There are lots of SNFs in spent fuel pools and they all have different loading histories and unloading behaviors. The testing evaluation of all SNFs are not efficient way, thus selection and concentration strategies have been taken. The classical evaluation and the computer simulation techniques are used in order to select the R-SNF. From the view point of structural strength, the former evaluates FR buckling load, grid stiffness, grid buckling load etc. based on geometrical data, component weight, and materials so WH type 14x14 fuel is assessed as the weakest SNF and need to be evaluated in more detail[4]. The latter analysis simulates axial drop loads and fuel rod stresses after side drop. The detail computer simulation methodology is described in the next section.

The selected R-SNF is analyzed more detail in order to evaluate mechanical integrity during handling and transportation. Since the mechanical characteristics and properties are different from those of fresh FA, the SNF should be tested to determine mechanical characteristics and properties before constitution and evaluation of more detail SNF analysis modeling. A lot of grid assemblies, fuel rods, guide tubes, and grid straps are investigated by the static and dynamic conditions. Stiffness, elastic modulus, Poisson’s ratio, yield strength, tensile strength etc. are acquired and grid deformation shapes, load-deflection results, static buckling loads, dynamic buckling loads etc. are investigated based on those of tests. Finally, the more detail R-SNF simulation model is generated and evaluated in the normal and accident conditions during handling and transportation.

3. Introduction to Computational Analysis Technique for R-SNF

Computer drop simulations for three different types of SNFs using commercial analysis program are performed in order to identify the weakest SNF. The evaluation targets of SNFs for R-SNF are 16x16 KSNP(Korea Standard Nuclear Power Plant) type fuel, 14x14 WH type fuel, and 17x17 WH type fuel respectably. To develop SNF model, a singular beam and several mass elements are used. The singular beam element represents geometric characteristics of guide tubes and fuel rods, and several mass elements represent mass of grids, fuel rods, top/bottom nozzles, and guide tubes in accordance with span length. Moreover, analysis results of the developed SNF models are directly compared to those of FA test results of lateral vibration test, lateral impact test, and axial drop test for securing the model validity. Furthermore, the normal and accident condition simulations of 0.3m, 1m, 9m drop of vertical and horizontal directions in accordance with US Code of Federal Regulation are performed to confirm the weakest fuel.

16x16 KSNP type fuel consists of top/bottom nozzles, top/bottom grids(TG/BG), 9 mid grids(MGs), 4 guide tubes, 1 instrumentation tube, and 236 fuel rods. 14x14 WH type fuel consists of top/bottom nozzles, top/bottom grids(TG/BG), 5 mid grids(MGs), 16 guide tubes, 1 instrumentation tube, and 179 fuel rods. 17x17 WH type fuel consists of top/bottom nozzles, top/bottom grids(TG/BG), 6 mid grids(MGs), 3 intermediate flow mixer(IFM) grids, 24 guide tubes, 1 instrumentation tube, and 264 fuel rods. The geometrical characteristics are reflected in order to develop the computational analysis model for R-SNF selection. Figure 2 shows the lumped mass model of 16x16 KSNP type fuel for computational analyses. The others are developed with the same methodology.

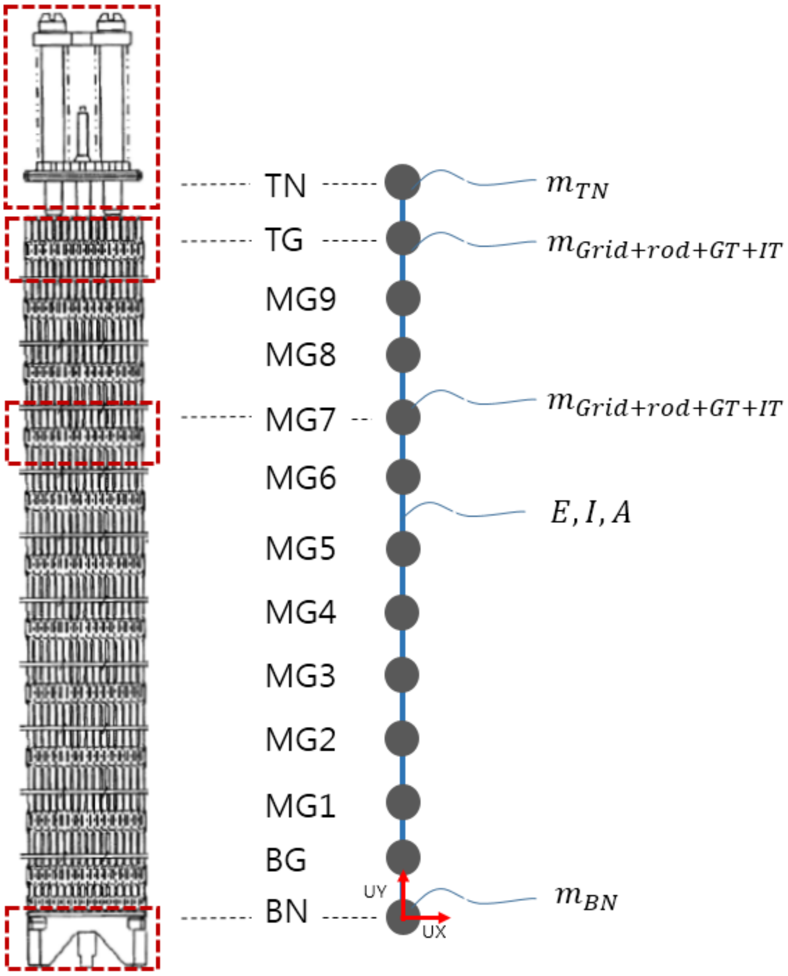
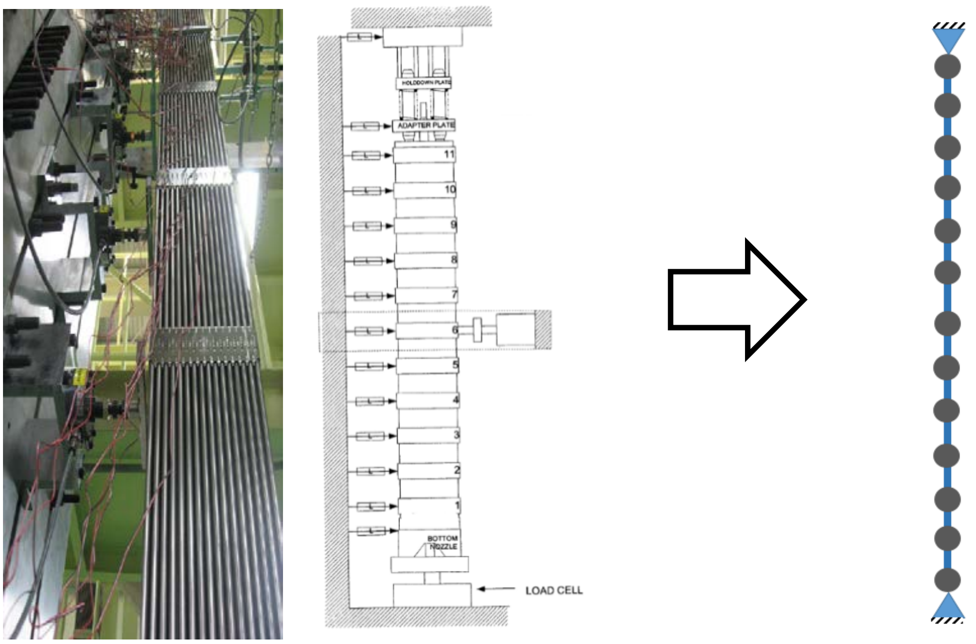


Figure 2 16x16 KSNP type lumped mass model for computational analysis

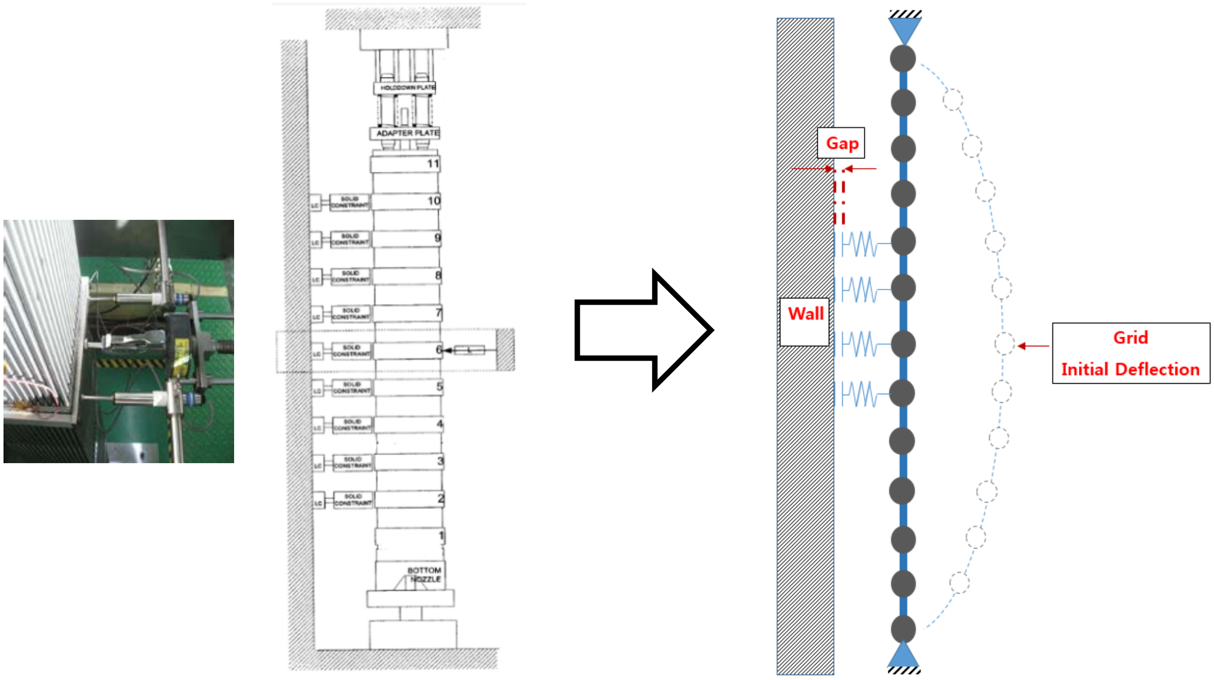
Three different types of analyses with the developed models are performed securing the model validity and effectiveness. First of all, the modal analysis results are compared to lateral vibration test results. Those analyses and tests show the natural frequencies and mode shapes that represent dynamic characteristics of SNF. Secondly, the lateral impact analysis results are compared to lateral impact test results. The purpose of the test is to identify the impact characteristics between a grid and a wall or the other structures so the grid impact stiffness and damping are acquired from the test. The grid impact characteristics are used for the side drop analysis in order to determine the FR bending stresses. Lastly, the axial drop analysis results are compared to axial drop test results. The test simulates accident condition during handling and transportation. The bottom nozzle impact force and impact duration are determined from the test and analysis comparison. The impact characteristics of the models are used for the axial drop analysis to determine the weakest one. Since the test results of three different type SNFs are well matched to analysis results, thus the simulation models are valid and effective. Figure 3 to 5 show the test setup and simulation model constitution example of lateral vibration, lateral impact, and axial drop.

Finally, axial drop and side drop analyses are performed to identify the weakest SNF. The axial drop impact forces are represented by the ratio of Euler buckling loads and the SNF that marked the highest values is to be the weakest SNF. Moreover, the bending stresses of FR are compared to each other after the side drop and the SNF that has the highest bending stresses is to be the weakest SNF. The R-SNF is decided considering on the results of the axial drop simulation, the side drop simulation, and classical evaluation.



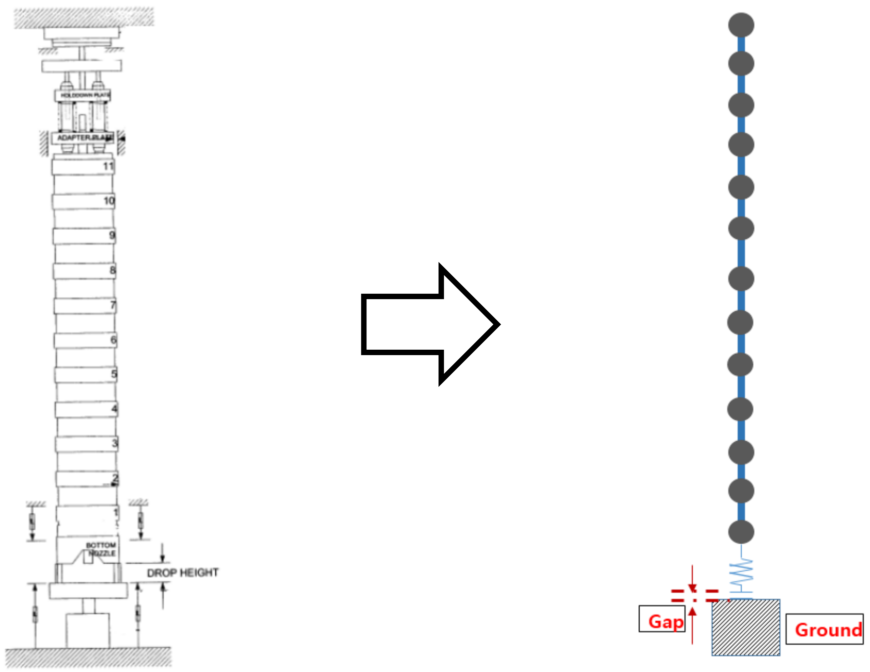
(a) Test **(b) Simulation**

Figure 3 Lateral vibration test setup and simulation model constitution on 16x16 KSNP type fuel



(a) Test **(b) Simulation**

Figure 4 Lateral Impact test setup and simulation model constitution on 16x16 KSNP type fuel



(a) Test **(b) Simulation**

Figure 5 Axial drop test setup and simulation model constitution on 16x16 KSNP type fuel

4. Conclusions

A series of R&D activities concerning spent nuclear fuel during handling and transportation have been introduced. A group of spent nuclear fuels are investigated to determine the weakest fuel and representative spent nuclear fuel is to be selected based on the method of the classical evaluation and the computational simulations. Then, the detail model of the representative spent nuclear fuel will be constituted and the detail analyses under normal, abnormal, and postulated drop accident conditions are to be executed for spent nuclear fuel integrity during handling and transportation.

5. Acknowledgments

This work was supported by the Korea Institute of Energy Technology Evaluation and Planning(KETEP) and the Ministry of Trade, Industry & Energy(MOTIE) of the Republic of Korea (No. 2014171020166C).

6. References

[1] SK Lee, et al., “Spent Fuel Status in Korea and Integrity Evaluation”, Proceedings of the 17th International Symposium on PTRAM 2013.
[2] O. Ozer et al., “Fuel-Assembly Behavior Under Dynamic Impact Loads Due to Dry-Storage Cask Mishandling”, EPRI, 2008.
[3] T. L. Sanders et al., “A Method for Determining the Spent Fuel Contribution to Transport Cask Containment Requirements”, DOE 1992.
[4] JJ Kim et al., “Structural Characteristic Analysis for R-SNF Selection during Transportation and Handling”, Spring Proceedings of KRS 2016.