Transactions of the Korean Nuclear Society Autumn Meeting
Pyeongchang, Korea, October 30-31, 2014

A Review of the Effects of Normal Conditions of Transport on Spent Fuel Integrity in Transportation Casks

Junggoo Kim*, Youngik Yoo, Seongki Lee, Chaejoon Lim
Korea Nuclear Fuel Co., 242, Daedeok-daero 989beon-gil, Yuseong-gu, Daejeon, 305-353
junggoo@knfc.co.kr

1. Introduction

Occurrence of spent fuel (SF) by nuclear power generation is inevitable, and SF management and disposal problem must be solved for sustainable development. SF storage capacity of each domestic nuclear power plant will reach a saturated state in the near future. Although there are several methods of SF disposal, interim storage is suggested as the most realistic and promising alternative.

SF integrity evaluation is a regulatory requirement that is described in Part 71 of Code of Federal Regulations, Title 10 of the U.S. NRC licensing requirement.[1] NRC regulation states that retrievability of SF after storage should be ensured and SF integrity under the normal condition must be guaranteed during transportation and handling process that is entailed before/during/after the interim storage.

In this paper, the report is reviewed written by EPRI in US and it is helpful to a development of domestic SF integrity evaluation technology.

2. Spent Fuel Transportation Applications at Normal Conditions of Transport

The report, EPRI 1015049, describes the response of a high-burnup fuel assembly to dynamic forces that result from a one-foot drop onto a rigid surface in the most damaging orientation.[2] This condition corresponds to a surrogate loading configuration for normal conditions of transport of spent fuel, as prescribed in 10CFR71. Until now, test items and regulatory requirements related with integrity evaluation of spent fuel are not specified in Korea. Analysis methodology stated below will be expected to utilize establishing domestic regulatory requirements in the future.

2.1 Structural Modeling to determine Fuel Rods Dynamic Forces

A modeling hierarchy is as follows. A one-foot drop onto a rigid surface of a fully loaded cask is considered. The worst-case cask drop orientation is a side-drop. The dynamic forces acting on the fuel rods and guide tubes are determined from a global model. One of the fuel assemblies is modeled as a “Control Assembly”, and is modeled in detail differ from each of the remaining assembles. Control Assembly is divided in two types illustrated in Figure 1. Emphasis in the analysis is on calculating rod-to-rod interaction forces (pinch forces), bending moments, and axial forces wherever they occur. The 3D finite element model for the Control Assembly in Figure 1 is sufficiently detailed to allow accurate determination of the axial variation of the dynamic forces consisting of pinch forces, bending moments and axial-extension forces.

Considering various types of spent fuel exist in Korea, it is necessary to save entire analysis time by modeling interested assemblies in detail and simplifying remaining parts.

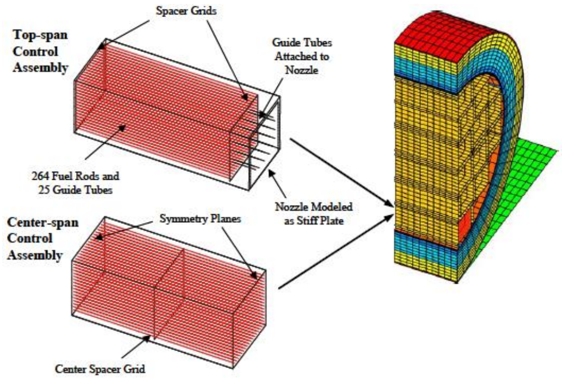


Fig. 1. Control Assembly Models

2.2 Dynamic Analysis by FEM

In order to analysis, explicit finite element computer model is used. Local sub-models of a 3D slice through a representative cask and rigid surface are employed as illustrated in Figure 1. By using this model, velocity and displacement of cask and basket are calculated.

The regulations governing “Normal conditions of transport” require that the geometric form of the package contents not be substantially altered. The analysis results of deformation patterns indicate that structural integrity is maintained. Conservative approach is needed to evaluate integrity maintaining of spent fuel assemblies. In case of Korea, the weakest assembly should be selected and evaluated among various types of spent fuels.

2.3 Fuel Rods Dynamic Forces

The structural modeling and analysis represents the dynamic response of all the fuel assemblies in the cask. It is necessary to quantify the extent of geometry alteration of the cask’s contents when subjected to the calculated dynamic forces. For this, pinch force, section force and moments on fuel rods and guide tubes are calculated. The results are presented as time-force graph and frequency/probability of exceedance graph.

2.4 Failure Analysis

As mentioned earlier, 10CFR71 states that fuel assembly structural elements should be shown to remain substantially undamaged, with no significant distortion of the fuel assemblies.

It is modeled as Figure 2 to evaluate fuel rods failure, forces calculated earlier are applied here. From the analysis results, cladding shows elastic behavior and tearing is not occurred.

The geometric continuity and integrity of the fuel assembly is dependent upon the response of the spacer grids and guide tubes to the dynamic forces. Through the structural integrity analysis performed earlier, it is already shown that plastic deformation of spacer grids and fuel rods is not occurred in one-foot drop case. From the analysis results of guide tubes, plastic deformation on dynamic force is not occurred and no fracture initiation is predicted.

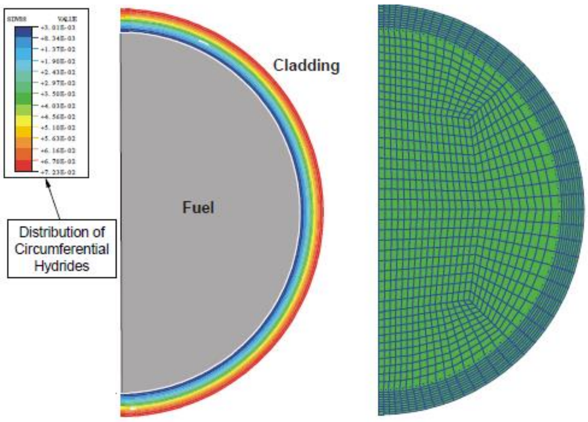
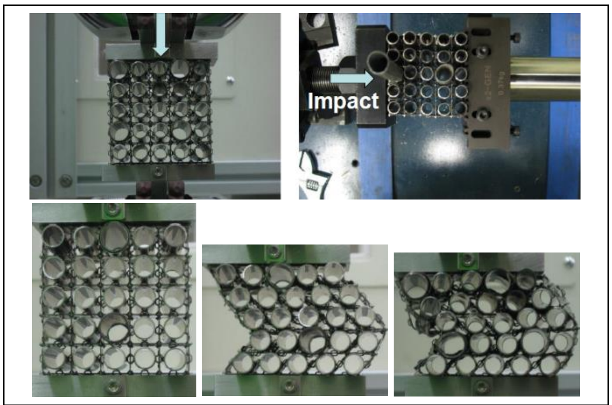
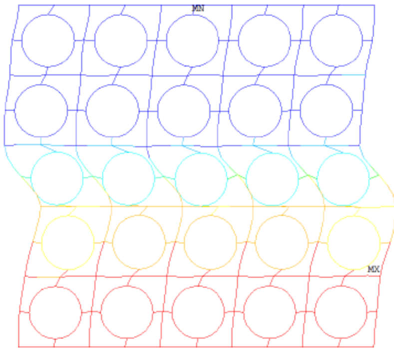


Fig. 2. Finite Element Model of a Fuel Rod Cladding

Since assembly structure of domestic spent fuel is similar basically with above, it is possible to evaluate integrity by analyzing deformation of structural parts. In KNF, as shown in Figure 3, buckling test and finite element analysis of spacer grid of domestic nuclear fuel assembly has been performed.[3] For the overall finite element analysis, developing material property database of irradiated cladding, obtaining material behavior through hot cell test and comparison/verification with analysis results are necessary.



(a) Static/Dynamic Buckling Test



(b) Finite Element Analysis

Fig. 3. Development of 2D Grid Model

3. Conclusions

EPRI report about integrity evaluation method on normal conditions of high burn-up spent fuel transport is reviewed. First, dynamic forces occurred in one-foot side drop are calculated. And deformation patterns and fuel rods responses by dynamic forces calculated from spent fuel and cask model are analyzed. It is shown that the damage of fuel rods is not occurred by the dynamic forces on normal conditions. Assembly distortion is not predicted, by virtue of the facts that the spacer grids do not experience significant permanent deformation. Axial forces, bending moments and pinch forces of fuel rods are calculated and compared with the results under the hypothetical accident conditions. No occurrence of transverse tearing mode that is the most serious damage mode in side drop case is predicted.

Till now, in Korea, regulatory requirements related with structural integrity of spent fuel are not specified such as 10CFR71. To establish own regulation standards, producing and analyzing sufficient experimental data must be performed preferentially. Based on this, failure analysis and criteria establishment are necessary through modeling and analyzing of spent fuel. As reviewed above, benchmarking integrity evaluation methodology by EPRI, time/cost saving is expected in technology development related with integrity evaluation of spent fuel in Korea.

REFERENCES

[1] NRC, 10CFR71, Packaging and Transportation of Radioactive Material, 2014

[2] EPRI, Spent-Fuel Transportation Applications: Normal Conditions of Transport, 2007

[3] Y. I. Yoo, N. G. Park, K. J. Kim, and J. M. Suh, Static Buckling Analysis of the Partial Spacer Grid of the Nuclear Fuel Assembly, ANSYS Conference & 32nd CADFEM Users' Meeting 2014, Jun.4-6, 2014, Nürnberg, German