Transactions of the Korean Nuclear Society Spring Meeting
Jeju, Korea, May 18-19, 2023

A Comparative Study on Spent Nuclear Fuels under Normal and Postulated Conditions of Transportation

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1. Introduction

Interest in Spent Nuclear Fuel (SNF) is increasing in Korea due to saturation of storage systems and following management process. It must be treated carefully for its hazardous characteristics like high temperature and radioactivity. Regulation 10 CFR 71 proposes that each package design should maintain integrity in Normal Condition of Transportation (NCT) and Hypothetical Accident Condition (HAC) [1]. Especially, fuel rod with cladding is most crucial component for safety assessment and its behavior needs to be quantified during management process.

In the United States, lots of researches have focused on shock and vibration caused by transportation and following cladding's response. Recently, Korea conducted NCT test by using surrogate fuel assembly and following loads are evaluated [2].

In this study, simplified SNF sub-assembly model was generated and transient analyses were performed according to original and postulated NCT loading. Furthermore, fatigue analyses were conducted.

2. Analysis model and conditions

2.1. Material properties

Uniaxial tensile tests (UTTs) data with unirradiated Zircaloy-4 were converted into irradiated one. Detailed process about UTTs and calculation is depicted in other work [3]. The results were used for cladding properties. Additionally, other components' properties were determined following previous research and overall values are in Table I.

Table I: Material properties for analysis

	Elastic modulus (GPa)	Yield strength (MPa)	Poisson's ratio
Cladding	81	1,133	0.33
Pellet	92	2,146	0.21
Spacer grid	114	379	0.296

2.2. Analysis model

The real-world Pressurized Water Reactor (PWR) 17X17 SNF assembly consists of lots of rods, spacer grids and complex components. For efficiency of analysis, 3X3 sub-assembly Finite Element (FE) model was generated and used for assessment. As shown in Fig.1, 4 spacer grids, 1 fuel rod with solid pellet and cladding, 8 beam fuel rod and springs/dimples were considered. The number of elements and nodes are depicted in Table II. The commercial software ABAQUS [4] was used for modeling and analysis.

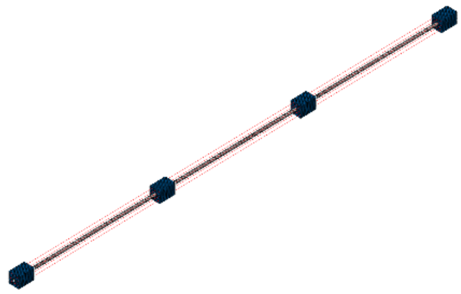


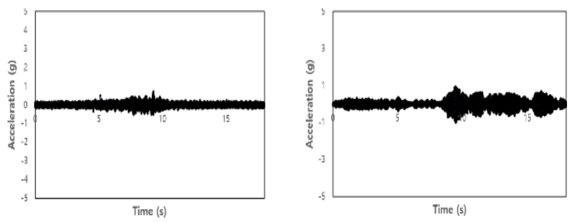
Fig. 1. Schematic of 3X3 sub-assembly model

Table II: Mesh information

	Number of elements	Number of nodes
B31	1,296	1,304
S4R	7,680	7,392
C3D8R	8,032	12,227
Total	17,008	20,923

2.3. Loading and boundary conditions

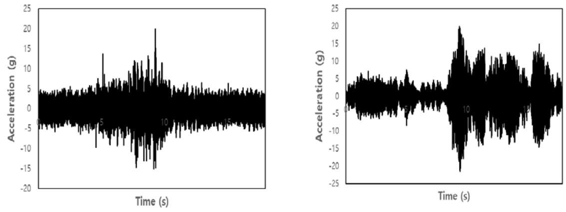
First, time-acceleration history from Korea NCT test data [2] was used as loading condition as shown in Fig. 2.



(a) Original case A (b) Original case B

Fig. 2. Time acceleration data from Korea NCT test

For assessment of more harsh condition, new data were generated according to previous research [5]. The maximum acceleration value was converted into reference data, and its difference ratio was multiplied to each acceleration for maintain tendency of Korea. They are depicted in Fig. 3. Finally, the calculated data were applied to each rod for simulation. With regard to bending effect, ends of cladding were fully fixed.



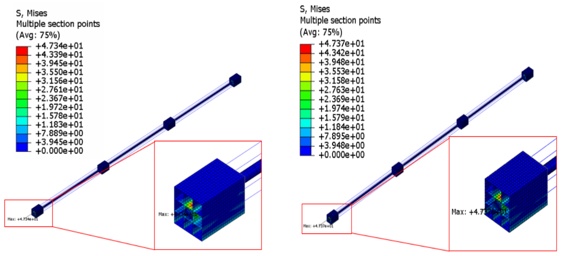
(a) Modified case A (b) Modified case B

Fig. 3. Modified time-acceleration data

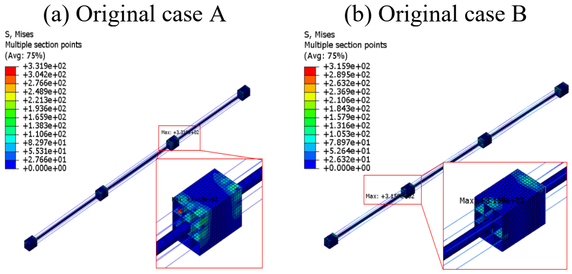
3. Analysis results

3.1. Stress analyses

Fig. 4 shows total von-Mises stress distribution of 3X3 sub-assembly model following loading conditions. The maximum values were occurred at spacer grid. In original cases and modified cases, the values were about 47 MPa and 330 MPa respectively. The results of cladding were in the range of 0.02 to 10 MPa in both cases. When modified data were applied, higher von-Mises stresses were generated.



(a) Original case A (b) Original case B



(c) Modified case A (d) Modified case B

Fig. 4. von-Mises stress distribution

3.2. Fatigue evaluation

Fatigue analyses were also conducted for same model and loading conditions. Among the 3X3 sub-assembly model components, only cladding was considered in this assessment. Rainflow Cycle Counting was performed and lower bound S-N curve was reconstructed from Oak Ridge National Laboratory fatigue test data [6] for damage fraction calculation. It was assumed that case A takes 18 hours and case B takes 6 days considering the distance between nuclear power plants in Korea. Finally, by using Miner's rule, cumulative damage fraction was determined and all the results were less than 1. The results are in Table III.

Table III: Fatigue evaluation result

	Cumulative damage fraction
case A	0.00029
case B	0.0022
Modified case A	0.0003
Modified case B	0.0024

4. Conclusions

In this research, by using original and modified time-acceleration data from Korea NCT test, integrity assessment of SNF was conducted. The conclusions of this research are as follows:

(1) By original and postulated loading condition, spacer grids' von-Mises stress was 12-87% of yield strength respectively, then it will maintain its integrity.

(2) The results of solid cladding are lower than 1% of yield strength in both conditions, therefore there will be no failure in this component too.

(3) In view of fatigue, modified case loading caused slightly high damage fraction, but failure will not be occurred in the same condition.

(4) All the results were slightly high in modified condition, but SNF will maintain its integrity in both conditions.

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. 20211710200020).

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