A Study on the Impact and Seismic Characteristics for Spent Fuel Storage and Transport Cask by Irradiation Effects

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ABSTRACT

The spent fuel storage and transport cask must withstand various accident conditions such as fire, free drop and puncture in accordance with the requirement of the IAEA and domestic regulations. The spent fuel storage and transport cask should maintain the structural safety not to release radioactive material in any condition. And also the effects of the irradiation should be considered because the spent fuels stored in the cask for a long time.

In this study, the mechanical properties of the cask after irradiation are assumed and applied to the impact analysis using ABAQUS/Explicit code and seismic analysis using ANSYS code. The stress on the cask is calculated and the effects of irradiation are studied.

INTRODUCTION

The spent fuel storage and transport cask should withstand a 9m free drop impact onto an unyielding target in a direction causing maximum damage[1,2,3]. Also in a seismic condition, the cask should maintain the structural integrity.

As the period of storage of spent fuel increasing, the amount of irradiation has been gradually increased. These effects may degrade on the mechanical properties and induce irradiation damage to steel materials which used major materials for the spent fuel storage and transport cask. However, the studies of irradiation effects on the impact and seismic characteristics of the spent fuel storage and transport cask are not conducted in detail. Therefore, the effects of the irradiation for impact and seismic characteristics of the spent fuel storage and transport cask should be studied because the spent fuels are stored in the cask for a long time.

In this study, the mechanical properties of the spent fuel storage and transport cask after irradiation are assumed[4]. The original and irradiated mechanical properties of the cask materials are applied to the impact analysis and seismic analysis of the cask. Impact analysis is conducted using ABAQUS/Explicit code for vertical, side and 20° oblique drop, respectively[5]. ABAQUS/Explicit code is usually used in the impact analysis. Seismic analysis is conducted using ANSYS5.5 code for storage condition. In the seismic analysis using ANSYS code, used response spectrum analysis method[6].

In the impact analysis and seismic analysis, stress intensity and deformation shape are calculated. From the analysis results, the effects of the irradiation for the impact and seismic characteristics of the spent fuel storage and transport cask are compared and evaluated.

ANALYSIS MODEL

A storage and transport cask for 12 PWR spent fuels, as shown in Figure 1, is assumed in this analysis. The cask is a right circular cylinder with an impact limiter at each end. The stainless steel and solid resin shielded cask is chosen for the main part of the cask body as it provided maximum shielding efficiency within the weight limits. The impact limiter made of red and balsa wood. In the impact and seismic analysis, the mechanical properties of balsa and red wood applied impact limiter. The mechanical properties of the impact limiter are not presented in this paper.

The dimensions of the spent fuel storage and transport cask are as follows;

Cavity diameter	1,192mm
Cavity length	4,190mm
Cask body outer diameter	1,942mm
Cask body length	4,809mm and
Total weight	75ton.

In the impact analysis, performed with a three-dimensional model of a half section using brick elements. IDEAS/SDRC software is used for pre/post processor of the impact analysis.

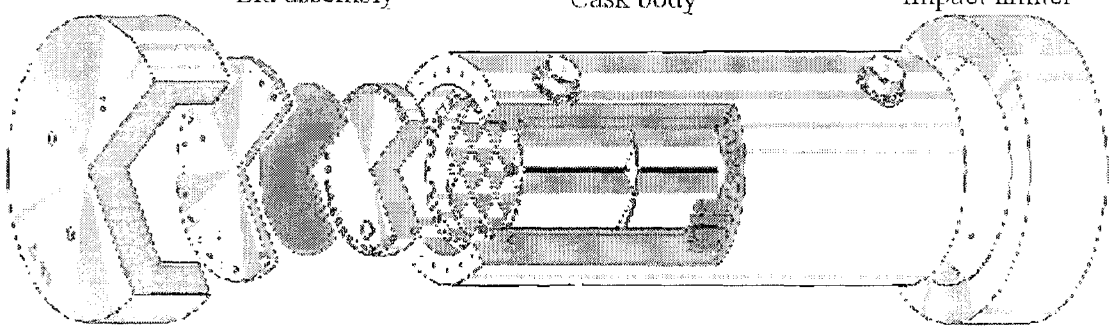


Figure 1 Overview of the spent fuel storage and transport cask

In the 9m free drop analysis, the unyielding target is modeled as a rigid wall and the contact of impactable parts is fully considered. For the effect of internal spent fuel weights, the dummy fuel element is used. The C3D8R element is used on the FE model of the spent fuel storage and transport cask[5]. Total numbers of elements and nodes are 5,329 and 6,644 respectively. The initial velocity for the 9m free drop analysis is 13.3m/sec.

MECHANICAL PROPERTIES

The subject materials of the investigation are SA240 TYPE304 and SA350 LF2 which are major materials of spent fuel storage and transport cask and applied to cask separately. The mechanical properties of irradiated material are assumed because there is no actual irradiation test data. The assumed mechanical properties of the cask steel after 30 years and more irradiation are presented Table 1. In general, the Young's modulus and Yield strength of the steel material are decreased after irradiation. But in this study, after irradiation, assumed that the Young's modulus is decreased by 20 percent and the Yield strength is increased by 20 percent to the original mechanical properties. These mechanical properties are applied to the impact analysis and seismic analysis of the cask using by FEM.

Table 1 Mechanical properties of the cask materials for free drop impact analysis

Property	SA240 TYPE304	A350 LF2	Irradiated SA240 TYPE304	Irradiated A350 LF2
Young's modulus, GPa	195.1	207.0	156.1	165.6
Poisson's ratio	0.3	0.3	0.3	0.3
Yield strength, MPa	206.4	260.0	247.7	312.0
Ultimate strength, MPa	517.1	485.0	517.1	485.0
Density, kg/m^3	7913	7850	7913	7850

IMPACT CHARACTERISTICS

The regulations describe that the package should withstand a 9m free drop impact onto an unyielding target in a direction causing maximum damage[1,2,3]. The 9m free drop impact analysis is performed for vertical, side and 20° oblique drop, respectively. A case of original and irradiated mechanical properties are applied, the analysis results are presented as stress intensity in Table 2.

Table 2 Maximum stress intensity for each drop of the storage and transport cask by finite element analysis with original and irradiated mechanical properties (Unit : MPa)

Drop conditions		SA240 TYPE304	SA350 LF2	Irradiated SA240 TYPE304	Irradiated SA350 LF2
Vertical drop	Bottom end	237	290	280	340
Side drop	Center	240	310	290	360
20° oblique drop	2^{nd} end	235	300	265	359
Allowable stress	Sy*	206.4	260	247.7	312.0
	3.6Sm (Su)**	517.1	485	517.1	485.0

* Sy : yield strength

** Su : ultimate strength, Sm : design stress intensity

The maximum stresses are occurred in the side drop with SA350 LF2 after irradiation among all cases, which is caused by bending effect of the cask.

In case of the 20° oblique drop impact, the maximum stresses are occurred at the 2^{nd} impact more than the 1^{st}. One of the reasons for this results seems to be the by effect of inertia of the center of gravity. The stress time history and deformation contour for the 20° oblique drop with SA350LF2 are presented Figure 2 and Figure 3 respectively. Figure 2 presents that the 2nd impact stresses are higher than the 1st stress for the both of original and irradiated material properties. Figure 3 shows the deformation configuration of the cask when 1st and 2nd impact is occurred.

As a result of impact analysis for the spent fuel storage and transport cask, the maximum stress in 360MPa, and occurred at the corner of the bottom of the cask.

After irradiation, all stresses somewhat increased comparison with the case of original material properties. The cask under various impact conditions maintain the structural integrity because the stresses occurred lower than allowable stress of the material.

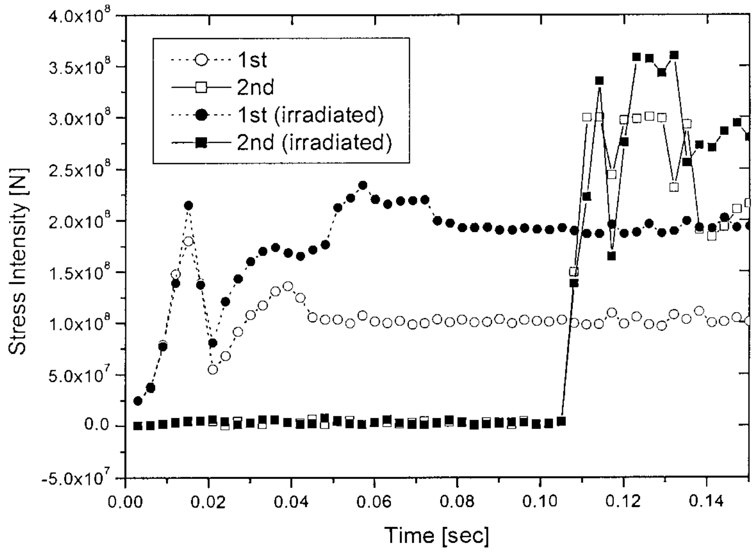
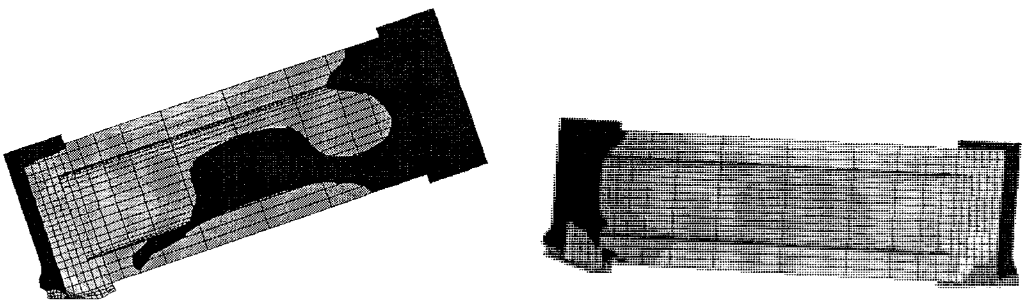


Figure 2 Stress intensity time histories on the bottom for 20° oblique drop of the cask for SA350 LF2 by finite element analysis.



(a) 1st impact (b) 2nd impact

Figure 3 Stress intensity and deformation contour for 20° oblique drop of the cask for SA350 LF2 with original mechanical properties by finite element analysis.

SEISMIC CHARACTERISTICS

The spent fuel storage and transport cask should withstand to the seismic conditions[7,8]. The floor response spectrums for a fuel building of the nuclear power plant are applied and the seismic analysis is performed using the

ANSYS5.5 code[6]. In this study, the Safe Shutdown Earthquake(SSE) conditions are considered and 7 percent damping ratio is applied. The floor response spectrums to the x-direction for seismic analysis presented in the Table 3 and Figure 4.

The floor response spectrums in y and z directions are not presented here. The seismic analysis is conducted with a three-dimensional full model using Solid45 element. For the seismic analysis in ANSYS5.5, FE-model is newly generated with the same size and material properties as the impact analysis model.

The total numbers of elements and nodes are 11,718 and 12,546 respectively. The MASS21 element is used to consider the effect of internal spent fuel weights. Because the cask is stored in the vertical direction, the simply supported boundary condition applied on the bottom impact limiter.

Table 3 Smoothened floor response spectrum of fuel handling building for KORI-1

(SSE, Horizontal – X direction, EL. 70', Damping 7%)

Period [Sec]	Frequency [Hz]	Acceleration [g]
0.01	100.00	0.45
0.03	33.33	0.45
0.05	20.00	0.60
0.07	14.29	1.74
0.114	8.77	1.74
0.16	6.25	1.00
0.173	5.78	0.76
0.40	2.50	0.76
2.00	0.50	0.30

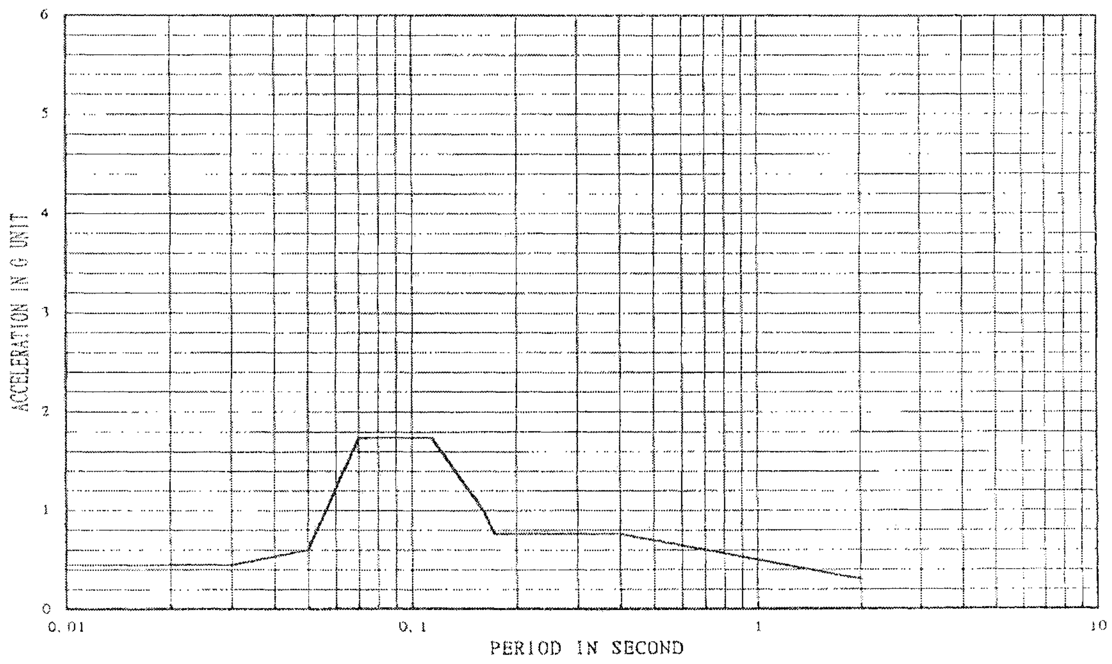


Figure 4 Smoothened floor response spectrum of fuel handling building for KORI-1

(SSE, Horizontal – X direction, EL.70', Damping 7%)

The SA240 TYPE304 and SA350 LF2 are applied in the seismic analysis of the spent fuel storage and transport cask. Table 4 presents the seismic analysis results. In case of the cask with original material properties, the maximum stress is 7.7MPa at the inner surface of the cask with SA240 TYPE304. However, when the irradiated material is considered, the maximum stress is 10.3MPa at the same location of the cask with SA350 LF2. The cause of the maximum stress occurred at the inner surface is effect of internal spent fuels.

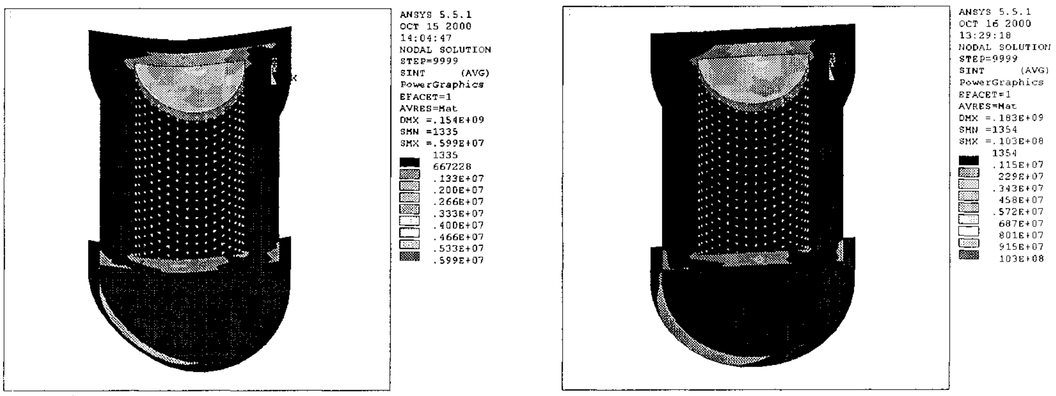
Table 4 Maximum stress of the storage and transport cask resulted from seismic analysis with original and irradiated mechanical properties (Seismic load: SSE) (Unit : MPa)

Position of cask shell		SA240 TYPE304	SA350 LF2	Irradiated SA240 TYPE304	Irradiated SA350 LF2
Inner surface		7.7	6.0	7.1	10.3
Outer surface		5.7	4.4	4.6	6.9
Allowable stress	Sy*	206.4	260	247.7	312.0
	3.6Sm (Su)**	517.1	485	517.1	485.0

* Sy : yield strength

** Su : ultimate strength, Sm : design stress intensity

After irradiation, the maximum stress with SA240 TYPE304 increased, but SA350 LF2 is opposite. This results require further examination.



(a) before irradiation (b) after irradiation

Figure 5 Stress contour of cask for SA350 LF2 result from seismic analysis (Seismic load : SSE)

Figure 5 presents the stress contour of the spent fuel storage and transport cask with SA350 LF2 resulted from seismic analysis. The maximum stresses are occurred at the internal surface of the spent fuel storage and transport cask for the all cases.

From the all cases, the maximum stresses are smaller than the allowable stress and the structure integrity is confirmed.

CONCLUSIONS

To investigate the effect of the irradiation on the impact and seismic characteristics of the spent fuel storage and transport cask, the mechanical properties are assumed and applied in the impact analysis and seismic analysis. In the impact analysis, the maximum stress is 360MPa for the side drop after irradiation of SA350 LF2 and all stress for irradiated materials somewhat increased comparison with the case of original material properties. For the seismic analysis, the maximum stress is 10.3MPa after irradiation of SA350 LF2.

From all analysis results, maximum stresses levels are satisfy the allowable limits and requirements of the related regulations.

For the applied study, the material irradiation test using the HANARO(Korea Multi-Purpose Research Reactor) was completed, and post-irradiation examination using Irradiation Material Examination Facility(IMEF) is in progress now. If post-irradiation examination is finished, the impact and seismic analysis using irradiated material properties obtained by the test will be conducted in near future.

ACKNOWLEDGEMENT

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