

Consequence Analysis of Release from KN-18 Cask during a Severe Transportation Accident

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1. Introduction

Korea Hydro & Nuclear Power (KHNP) has launched a project entitled “Development of APR1400 Physical Protection System Design” and conducting a new conceptual physical protection system(PPS) design. One of mayor contents is consequence analysis for spent nuclear fuel cask. Proper design of physical protection system for facilities and storage and transformation involving nuclear and radioactive material requires the quantification of potential consequence from prescribed sabotage and theft scenarios in order to properly understand the level of PPS needed for specific facilities and materials.

An important aspect of the regulation of the nuclear industry is assessing the risk to the public and the environment from a release of radioactive material produced by accidental or intentional scenarios. The transport and storage of radioactive materials is of particular concern to the public. Although no breach in the robust cask or storage module containment is expected to occur for many severe transportation accidents, in alignment with sabotage concerns for transportation, KHNP has analyzed the impact on the cask and the resulting effects to the used fuel during severe transportation accident.

This paper describes the consequence analysis methodology, structural analysis for KN-18 cask and results of release from the cask during a severe transportation accident.

2. Consequence Analysis for KN-18 Cask

2.1 Consequence Analysis Methodology

The general methodology for the analysis of a severe transportation accident with release of spent nuclear fuel (SNF) is shown in figure 1. This methodology is the same as used in NUREG-2125¹. First, the cask type and accident conditions are defined. A finite element (FE) model is created to capture the bulk displacement and rigid body response of the cask system. The FE modeling gives two important pieces of information needed to define the source term, namely the plastic strain incurred by the fuel cladding and the leak path in the cask system.

The plastic strain is input into models first proposed in Sanders (1992) and modified in Sprung (2000) in order to predict the probability of cladding failure. The rod-to-cask release fractions are summarized in NUREG-2125, but Hanson (2008) is a key reference

used to define the release fractions for the fuel matrix and volatiles. The cask-to-environment release fractions are taken from Sprung (2000). The Yucca Mountain Final Environmental Statement (DOE 2002) is used to define the fuel inventory at the time of the accident.

Finally, the source term is input into a Gaussian plume dispersion model for assumed meteorological conditions, i.e. atmospheric stability and wind speed. This analysis yields a wide variety of information about the hypothetical exposure of the public to the postulated release. For simplicity, this paper will focus on the centerline dose as a function of downstream distance.

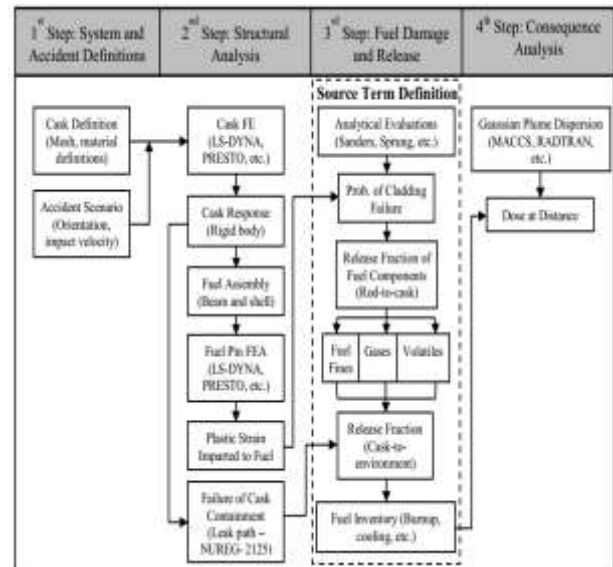


Fig.1. Flow diagram for a severe transportation accident consequence analysis.

2.2 Structural Analysis for KN-18 cask

The KN-18 cask is designed to ship 18 spent fuel assemblies discharged from PWR reactors. The dynamic impact characteristics of a cask are analyzed using an explicit nonlinear dynamic finite element analysis method using the commercial FE code LS-DYNA^{2,3}. Full scale model was used for the numerical analysis, and showed that it can hold up fuel assemblies without damaging them up to a certain velocity. Originally in NUREG-2125, a three-step analysis was used to see the plastic strain on fuel which eventually leads to a fuel failure; Impact on cask, cask to fuel assembly, fuel assembly to fuel rod with boundary conditions respectably. While in this paper, an one-step analysis method was hired to calculate the plastic strain on fuel with detailed LS-DYNA model for KN-18.

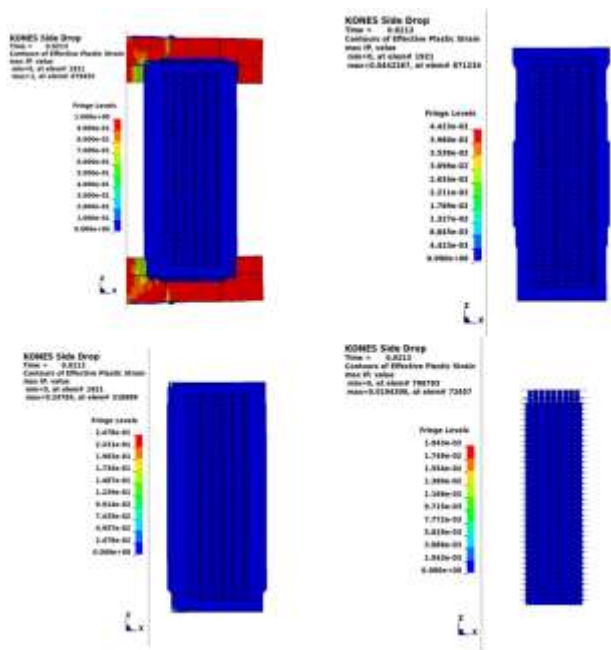


Fig. 2. Predicted plastic strain induced by the impact velocity of 13.3 m/s, in four views

2.3 Consequence Analysis

Although it was numerically calculated that the fuel assemblies and KN-18 cask itself would be free from failure in transportation accidents, for the analytic purpose a leak was assumed as size of $1 \times 10^2 \text{ mm}^2$. Figure 3 shows the cask-to-environment release fractions for different species as a function of leak area⁴.

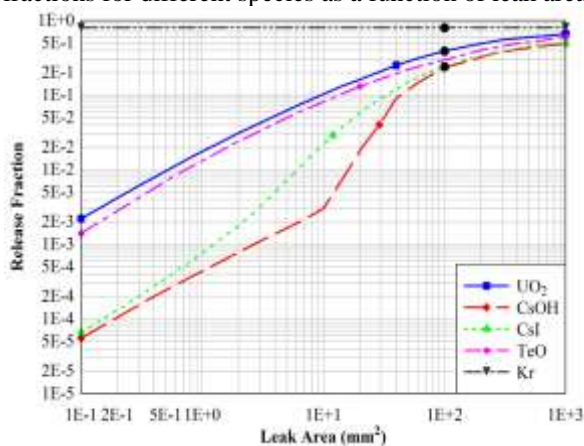


Fig.3. Cask-to-environment release fractions for an assumed $1 \times 10^2 \text{ mm}^2$ leak path.

Total Effective Dose Equivalent (TEDE) along the plume centerline calculated by MACCS2 and Hotspot are shown in Figure 4. The analyses assume the individuals are exposed for 24 hours. The difference in the MACCS2 and Hotspot results is primarily due to the codes using different models to estimate the dispersion parameters of the plume. In this analysis, the dose never exceeds 5rem, which is a public exposure limitation, at any distance.

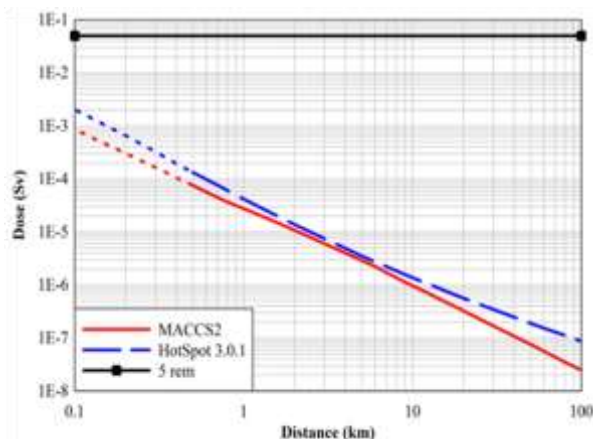


Fig.4. TEDE along the plume centerline

3. Conclusions

The general methodology for the analysis of a severe transportation accident with release of spent nuclear fuel has been set up as shown in figure 1. Accident during spent fuel cask transportation was numerically calculated for KN-18, and showed the integrity of the fuel assemblies and cask itself was unharmed on a scenario that is comparable to state of art NRC research. Even assumption of leakage as a size of $1 \times 10^2 \text{ mm}^2$ does not exceed for a certain criteria at any distance.

Acknowledgement

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Nomenclature

“TEDE” is used to indicate the total effective dose equivalent, which is the sum of the external exposure and committed effective dose equivalent from internal exposure

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