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Short communication

Preliminary safety analysis of criticality for dual-purpose metal cask under dry storage conditions in South Korea

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HIGHLIGHTS

- DPC is under development led by Korea Radioactive Waste Agency in South Korea.
- The results of criticality analysis with respect to design requirements.
- The k_{eff} under normal and off-normal conditions were 0.36 and 0.46, respectively.
- In addition, the k_{eff} under a postulated accident condition was evaluated to be 0.94.

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ABSTRACT

A dual-purpose metal cask is under development led by Korea Radioactive Waste Agency (KORAD) in Korea, for the dry interim storage and long-distance transportation. This cask comprises a main body made of carbon steel and a stainless steel Dry Shielded Canister (DSC), with stainless steel baskets inside to contain spent fuel assemblies. In this study, nuclear criticality safety analysis was conducted as a part of safety assessment of the metal cask. Analysis to show criticality safety in accordance with regulatory requirements of PWR spent fuel storage was carried out. 10CFR72.124 "Criteria for nuclear criticality safety" and the Regulatory Guide of the American Nuclear Society, ANSI/ANS-57.9 "Design Criteria for an Independent Spent Fuel" and US NRC's "Standard Review Plan for Spent Fuel Dry Storage Systems at a General License Facility" were employed as regulatory standard and criteria. This paper shows results of criticality analysis with respect to each designated criterion with modeling of a virtual nuclear fuel assembly and a cask body that induces the maximum reactivity among various design basis fuels of the metal cask. In addition, the sensitivity analysis of nuclear criticality taking into account the various modeling deviation such as manufacturing tolerance and modeling assumptions of conventional models was carried out to ensure the reliability of the analysis result. The criticality evaluation result of the metal cask and the maximum k_{eff} under normal and off-normal conditions were 0.36884 and 0.46255, respectively. The maximum k_{eff} under a postulated accident condition triggering flux trap reduction between baskets was evaluated to be 0.37854. In addition, the maximum k_{eff} under a postulated accident condition of a natural disaster in case of a flooding, was evaluated to be 0.94658 as a maximum reactivity. The criticality evaluations under the above storage conditions showed values below the regulatory requirement (0.95) and the values confirm adequate safety in terms of nuclear criticality.

1. Introduction

As of the second half of 2011, 13,000 assemblies of Spent Nuclear Fuel (SF) had been produced from domestic PWR nuclear power plants (NPPs), and they are stored in the reactor storage pool of each NPPs. The amount of spent nuclear fuel converted into uranium corresponds to approximately 6000 MTU. Although the temporary storage pools of each nuclear power plant are saturated, indetermination of government policy on reprocessing or disposal is increasing the demand for the construction of interim storage facilities for SF.

Therefore, Korea Radioactive Waste Agency (KORAD), supervising projects dealing with radioactive waste, is reviewing various plans for the construction of interim storage facilities. Of the various plans, 'decentralized' storage construction of interim storage facilities in suburban areas of Kori/Yeong-Gwang/Ul-jin Nuclear

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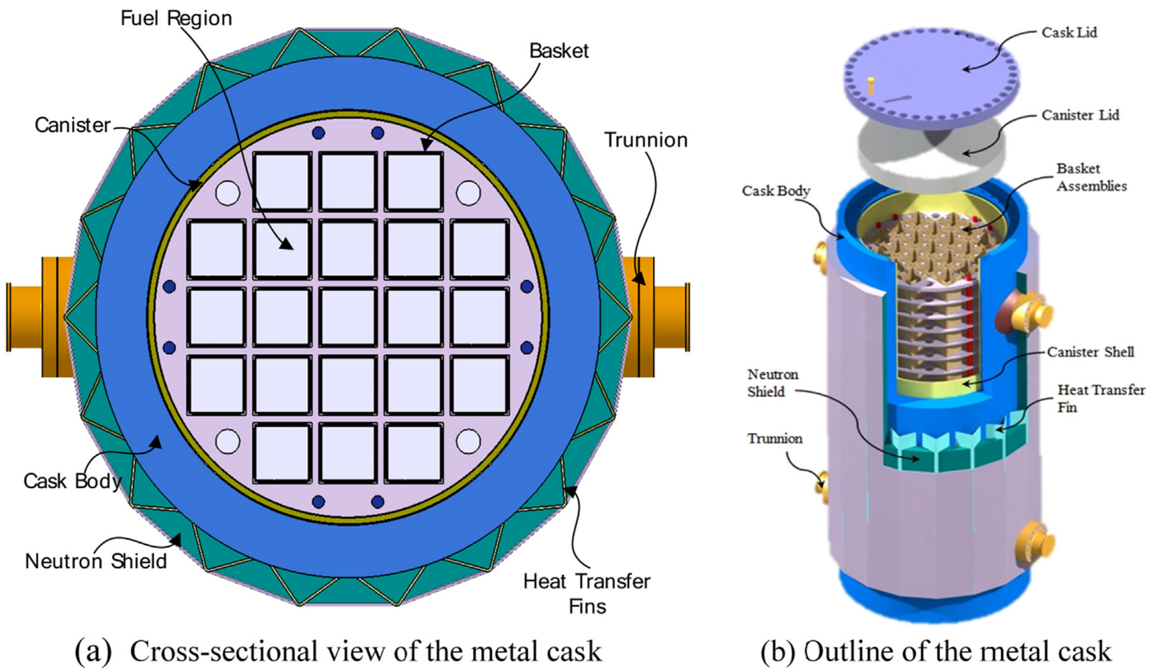

Fig. 1. Conceptual design of dual-purpose metal cask and canister.

Power Plants (NPPs) releasing PWR SF and 'centralized' storage which hosts large-scale storage at a specific separate location are considered together (KROAD, 2011).

In storage systems employing dry interim storage facilities, metal or concrete casks are most frequently utilized globally, and various forms of storage systems are being actively developed in many countries.

With the purpose of interim storage and long-distance transportation, a dual-purpose metal cask (DPC) containing 21 SF assemblies is under development by KORAD. This cask comprise a main body made of carbon steel, a stainless steel dry shielded canister (DSC), with stainless steel baskets inside to contain spent fuel assemblies as shown in Fig. 1.

This research aimed to establish assumptions in normal/off-normal/accident conditions for the storage of dual-purpose metal casks of PWR SF derived from the 1st stage (2009–2011) research, and preliminary safety of criticality was analyzed.

The criticality safety evaluation results of metal dual-purpose casks in normal/off-normal and accident conditions were first shown, and evaluated to determine whether they satisfied the Code of Federal Regulations 10CFR72.124 "Criteria for Nuclear Criticality Safety" and the technology code of PWR SF storage listed in NUREG-1536, the standard screening guideline of the NRC.

The main performance contents may be summarized as follows:

o Verification of computer program effectiveness.
o Sensitivity analysis of modeling conditions and of manufacturing tolerance.
o Evaluation of criticality safety in normal operation analysis.
o Evaluation of criticality safety in off-normal operation analysis.
o Evaluation of criticality safety in accident operation analysis.

1.1. Technical standards and application requirements

The evaluation requirements of criticality safety proposed in technical standards and regulation of the storage conditions of PWR SF are summarized as follows (US DOE 10. CFR.72, 2012) (IAEA SS-116, 1994) (ANS, 2000):

- The SF handling, transportation and storage system must maintain subcritical conditions before two rare independent criticality accidents occur.
- The maximum effective neutron multiplication factor (k_{eff}) of a storage system is calculated by applying design dimensions and modeling conditions inducing the maximum nuclear reactivity, and it must be proved that the model used in the safety analysis is the model having the maximum value.
- The storage system for normal/off-normal and accident conditions must be designed to maintain a subcritical state even in the condition of criticality increasing the SF loading arrangement due to a natural disaster.
- The safety evaluation of an SF handling and storage system follows the technology standard of ANSI/ANS-8.17.
- Assuming that a moderation effect due to SF does not occur, the assumption must be proved through a safety analysis of nuclear criticality, and safety must be ensured by varying the SF loading amount and design.
- The neutron poison level is conservatively evaluated to a reduced value of 75%, and the burnable poison of SF is ignored. The designer must prove the performance of the neutron poison level when the 75% reduction condition is not reflected.
- The effective neutron multiplication factor, k_{eff}, including all biases and uncertainties at a 95% confidence level, should not exceed 0.95 under all credible normal, off-normal, and accident-level conditions.

The SF storage container must maintain a subcritical state under every condition, and the reliability of the calculated effective neutron multiplication factor for the validation must be secured. Therefore, quantitative evaluation of each of the criticality uncertainties proposed in Eq. (1) based on a methodology with adequate credibility is required (ANS, 2004).

$$k_p + \Delta k_p + \Delta k_b \le 1 - \beta - \Delta k_c - \Delta k_m \quad (1)$$

where k_p: calculated effective neutron multiplication factor of storage condition dual-purpose metal cask, Δk_p: uncertainty of calculated effective neutron multiplication factor ($2 \times$ sigma), Δk_b: uncertainty with respect to mechanical tolerance and modeling