Basic Design Development of Spent Nuclear Fuel Dry Storage Module for PWR

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1. Introduction

Dry storage is a method of storing spent nuclear fuel (SNF) that has already been cooled in the spent fuel pool for a few years.[1] Dry storage systems are designed to contain radiation, manage heat, and maintain nuclear sub-criticality. They must resist earthquakes, projectiles, tornadoes, floods, temperature extremes, other anticipated operational occurrences, and design basis accident conditions.[2] The heat and radioactivity decrease over time without the need for fans or pumps. Good design is important to the safe operation of SNF storage facilities because SNF must be received, handled, stored, and retrieved without excessive risk to health and safety, or to the public environment. There are various commercial dry storage system designs. With some designs, the steel cylinders containing the fuel are placed vertically in a concrete vault; other designs orient the cylinders horizontally. The concrete vaults provide the radiation shielding. Other cask designs orient the steel canister vertically on a concrete pad at a dry cask storage site and use both metal cask and concrete overpack for radiation shielding. Currently, there is no long term permanent storage facility; dry storage is designed as an interim safe solution. There have been many efforts on developing a dry storage system, however, there is no licensed or operating dry storage system for PWR SNF in Korea. This paper presents the basic design development of the SNF dry storage module for PWR, called KMODST, future application.

2. Basic Design Procedure

2.1 Design Basis

Technical design requirements were established by the regulation for SNF storage, as given in 10 CFR 72[3], Nuclear Safety Act., IAEA SSS No.SSG-15[4], NUREG-1536[5]/1567[6], and ASME Sec.III Div.3.[7] The design criteria for the KMODST have been formulated by assuring that public health and safety should be protected during dry storage. These design criteria cover both the normal storage conditions for a 50-year licensing approval period and postulated accidents that last a short time, such as a fire. The detailed design requirements were constructed with fuel specification, nuclear criticality, thermal safety, radiation shield, seismic performance, and handling crane mass design data as described in Table 1. The fuel assemblies loaded in the canister was set up to 24 relevant canister design for the PWR SNF.

2.2 Design Modeling

Fig. 1 shows a schematic diagram of the KMODST. The steel cylinders containing the fuel canister are placed vertically in a concrete module and the air inlet and outlet holes are located in the upper and lower part of the sidewall. The size of the KMODST is 20.5X10X7.8 (WXLXH) meters determined by critical, shielding, heat, and structural analysis.

Table 1: Design Requirement

	Parameter	Value
Fuel Specification	- Max. SNF burnup - Enrichment - Min. Cooling time - # of FAs in canister	- 45 GWd/MTU - 5wt.% - 10 yr - 24
Sub-criticality		- $k_{eff} < 0.95$
Thermal	fuel cladding temp - normal - abnormal	- 400°C - 570°C
Radiation shield	- Surface at module - Surface at pence	- 0.5 mSv/h - 0.01 mSv//h
Seismic		- 0.3g (SSE)
Mass	- Toal handling mass	- 113 ton

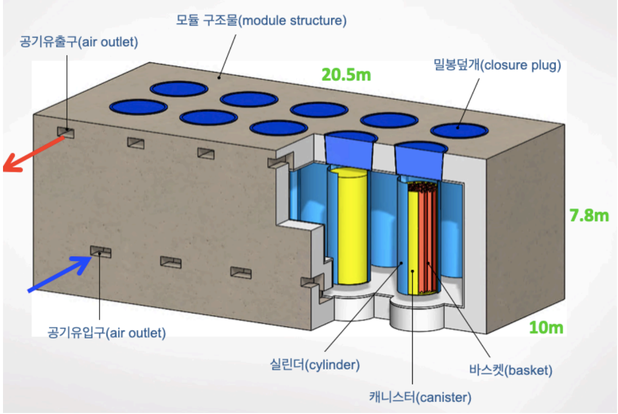

Fig. 1. Schematic Diagram of KMODST

3. Basic Design Analysis Results

3.1 Analysis Tools

The ORIGEN-S, SCALE 6.1, MCNP 6.1, FLUENT 19.2, and ANSYS19.2 codes were used for source term, nuclear criticality, radiation shielding, thermal, and structure layout analysis of the KMODST model.

3.2 Criticality Analysis Result

The design of fuel canisters intended for use with KMODST shall ensure that the fuel will remain in a configuration that has been predetermined to be subcritical during loading, storage, and retrieval. This criticality design should allow for any consequences likely to result from the redistribution or the intrusion of a moderator as a consequence of an internal or external event. The effective k-value from the criticality analysis was 0.93041 which is less than 0.9326 limiting value. Fig. 2 shows a criticality analysis model of the KMODST.

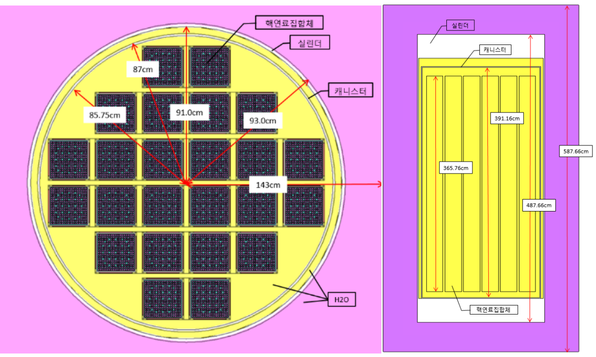

Fig. 2. Criticality Analysis Model of KMODST

3.3 Radiation Shield Analysis Result

The design of the KMODST shall be such that the external radiation fields do not exceed the criteria or limits when they are loaded with fuel. The design of the concrete module shall incorporate containment barriers acceptable to the Regulatory Body. Loading and unloading of SNF into the canister in a storage configuration shall be carried out using equipment and methods designed to limit sky-shine and the reflection of radiation towards uncontrolled areas, following the ALARA principle. The canister as a containment barrier shall prevent the release of radionuclides. The minimum thickness of the concrete module was estimated to 60 cm and the radiation shield modeling done by the MCNP code is shown in Fig. 3.

3.4 Thermal Analysis Result

The design of the KMODST shall ensure the transfer of residual heat to the surroundings in order to meet specified design requirements for controlling fuel storage temperatures and maintaining the integrity of structural materials. The concrete module shall be designed to permit adequate heat dissipation. Design features might be the maximum practical extent, systems for cooling spent fuel stored in KMODST should be passive and require minimal maintenance. The KMODST system is that relies on natural convection, conduction and radiant heat transfer. The thermal analysis results for the KMODST showed good performance to meet the thermal design requirement as illustrated in Fig. 4.

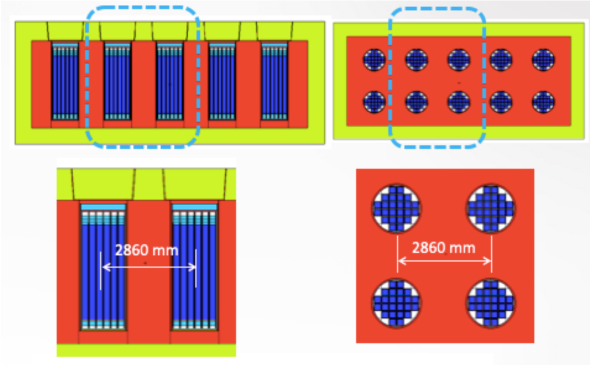

Fig. 3. Radiation Shielding Model of KMODST

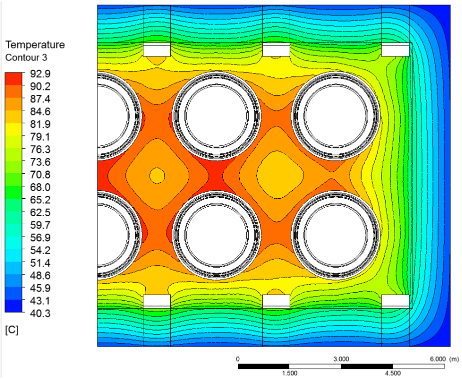

Fig. 4. Thermal Performance Model of KMODST

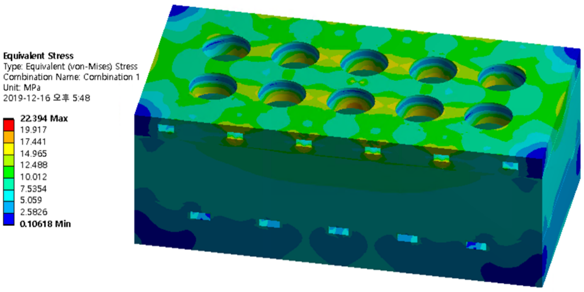

Fig. 5. Mechanical Structure Model of KMODST

3.5 Structure Analysis Result

The mechanical structure of the KMODST shall be designed to support, without structural deformity leading to handling problems, the mass of other fully loaded canisters which may be placed upon it if stacking is proposed. Static, impact and seismic loads shall be considered. Ease of access is required for transfers of spent fuel to module storage positions during normal operations, or during recovery operations after anticipated operational occurrences or accident conditions. The structure analysis results for the KMODST showed good performance to meet the structure design criteria as illustrated in Fig. 5.

4. Conclusions

The basic design of SNF dry storage module for PWR, KMODST, was developed for future application. The detail design requirements were constructed associated with fuel specification, criticality, thermal safety, radiation shield, seismic performance, and handling crane mass design data based on the domestic and international regulations. Nuclear criticality, radiation shield, thermal and structural analysis were performed to confirm the layout of the KMODST system. The detailed design for the KMODST will be carried out with a future study.

REFERENCES

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