PRELIMINARY SHIELDING ANALYSIS TO SET OPTIMAL OPERATING CONDITIONS OF METAL CASK FOR SPENT NUCLEAR FUEL IN DRY STORAGE

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ABSTRACT*: A suitable shielding design for radiation protection must be in place for the dry storage facilities during normal, abnormal and accident conditions. The spent nuclear fuel storage casks differed from transport casks in that a precise safety code and standard for the radiation of single casks is not determined. Also, according to the single cask design standards, ensuring the safety of storage facilities is given priority over radiation safety in the design of spent fuel storage casks. When evaluating the metal storage cask in 2× 10 array condition, the results show that appropriate distance to the annual dose rate of 0.25mSv for ordinary person is approximately 280m. For a design basis accident involving metal storage casks, it was assumed that the casks were in the 2× 10 arrangement inside the storage facility and one additional storage cask was being transported when a fire accident took place, and the additional cask rollover, leading to a complete loss of neutron shielding material of the cask body. Dose rates of 1.5460 mSv and 0.0993 mSv were measured at 100 m and 280 m from the outermost cask in the 2× 10 arrangement. The actual value of yearly radiation dose rate should be smaller than 0.25mSv within 280m of the controlled area boundary. According to results of dose rate assessment under design accident, 3.1% of 50mSv which is personal dose rate in controlled area boundary were measured. Therefore, spent nuclear fuel metal cask and storage facilities maintain radiological safety if the distance to the appropriately assessed control area boundary is ensured.*

KEYWORDS: Spent Nuclear Fuel, Dry Storage, Metal Cask, Radiation Shielding Analysis.

I. INTRODUCTION

The Korea Radioactive Waste Agency (KORAD) has developed a dual-purpose metal cask for the dry storage of spent nuclear fuel that has been generated by domestic light-water reactors. The metal storage cask is an independent cylindrical and canister based storage cask, vertically stored on a storage pad, which stores spent nuclear fuel. The cask was designed to store up to 21 fuel assemblies of Westinghouse WH14×14/WH16×16/WH17×17 spent nuclear fuel assembly (hereafter "spent fuel") and Combustion Engineering CE16×16 spent fuel in a dry condition.

During long-term storage of spent nuclear fuel in metal casks kept in dry condition, the integrity of the storage cask and spent nuclear fuel must be maintained, also taking into consideration that the radiation dose rate does not surpass the storage facility's design standards. And, suitable shielding design for radiation protection must be in place for the dry storage facilities during normal, abnormal and accident conditions. Therefore, the controlled area boundary where spent fuel is handled and stored must be situated at least 100 meters away from the storage pad's casks. Also, in terms of the shielding analysis and radiation protection, the 'As Low As Reasonably Achievable (ALARA)' requirement must be considered for protecting radiation workers and the general public against unnecessary radiation exposure.

This paper describes the analysis and results of the dose rate limit requirement set by code and standard 10CFR72 and 10CFR20 from the United States' Codes of Federal Regulation, as well as the analysis method presented by the United States

NRC standard review plan, NUREG-1536, pertaining to the condition for single metal storage cask or 2×10 arrangement of metal storage casks. (Ref. 1, 2)

II. ANALSYS METHOD & ASSUMPTIONS

The spent nuclear fuel storage casks differed from transport casks in that a precise safety code and standard for the radiation of single casks is not determined. Also, according to the single cask design standards, ensuring the safety of storage facilities is given priority over radiation safety in the design of spent fuel storage casks. Therefore, it is prescribed to design the controlled area boundary under normal conditions, to conform to the annual dose limit of 0.25mSv.

In the case of a safety analysis on radiological protection for dry storage casks and facilities of spent nuclear fuel under the Standard Review Plan, the analysis design requirements are as follows.

a. Minimum 100m distance that should be kept from the Controlled Area Boundary to the spent fuel storage facility.
b. Never surpass a yearly dose rate of 0.25mSv in the Controlled Area Boundary.
c. In case of accident conditions, never surpass yearly personal dose rate of 50mSv in nearby Controlled Area Boundary.
d. In case of normal and off-normal conditions, yearly dose rate of ordinary citizens nearby the Controlled Area Boundary should not surpass 0.25mSv, 0.75mSv, 0.25mSv for each body, thyroid gland, body tissue, respectively.

The MCNP5 code was used in the shielding analysis of metal storage casks. The code is general purposed transportation code for electrons, photons, and neutrons. And, metal density and chemical compositions of ASME 2010 apply to the metallic material for calculation of dose rate

II.A. Single and 2×10 Array Cask(s) Under Normal Condition (Ref. 3)

The analysis model of metal storage cask is based on the conditions of normal operation of storing 21 assemblies of spent fuel vertically on the storage pad.

II.A.1. Single Cask

The total height of the metal storage cask is 5,335 mm, and the carbon steel body and the resin used as neutron shielding at the side are 215 mm and 110 mm thick, respectively. Moreover, for calculating the heat radiation of the storage cask, a heat transfer pin in the shape of an oblique type assembly in the circumferential direction, and the top and bottom trunnions for recovery and rotation of the cask, were included in the analytical model.

The analysis of the radiation dose rate of a single storage cask under normal conditions found that an excessive amount of radiation was emitted at the cask's lower side, indicating the need to install a supplementary shield in order to reduce over-exposure among workers performing routine tasks (visual inspection, monitoring and maintenance, etc.). It was decided that 90 mm-thick stainless steel would be used as the supplementary shield after a sensitivity analysis of the radiation dose rate against thickness, and a detailed analytical model for this is shown in Fig. 1(a).

II.A.2. 2×10 Array Casks

The array condition shielding analysis model of the interval between casks was set to 1.2m based on the analysis results of the current situation of international spent fuel storage facilities and the metal storage casks' shielding analysis model under the array conditions is represented in Fig 1(b).

II.B. Under Design Basis Accident

Accident conditions, excluding a fire accident involving storage casks, may affect multiple storage casks or a single storage cask. However, because limited and local damage occurs to the cask's exterior surface at the time of an accident, it was determined that there is little radiation impact for a single storage cask. In addition, since a substantial distance (over 100 m minimum) is maintained between the storage facility where the storage cask is located and the controlled area boundary, the impact of radiation on the design basis of the storage facility is insignificant and negligible when it occurs under accident conditions other than a fire accident with a storage cask. (Ref. 4, 5)

To determine the design basis accident condition involving metal storage casks, a situation was assumed where different accidents took place successively, involving the various types of accidents that can have an impact on shielding characteristics, during the process in which the fuel is taken out of the receiving facility and then stored at a desired location of the storage facility. For example, a fire broke out on the storage cask and then the cask rollover. From a conservative perspective, it was considered that the shielding of the storage cask consists only of the cask body and the lid, assuming that the neutron shielding material at the side of the cask body exterior and the cask bottom was destroyed and lost in its entirety after the fire accident. The configuration of this metal storage cask is shown in Fig. 2. An analysis was performed to see if the accumulated radiation dose rate exceeded 50 mSv and if radioactive safety was secured for the duration of the accidents (30 days) at the controlled area boundary. These are the technical criteria for when fire and rollover accidents occur at the same time.

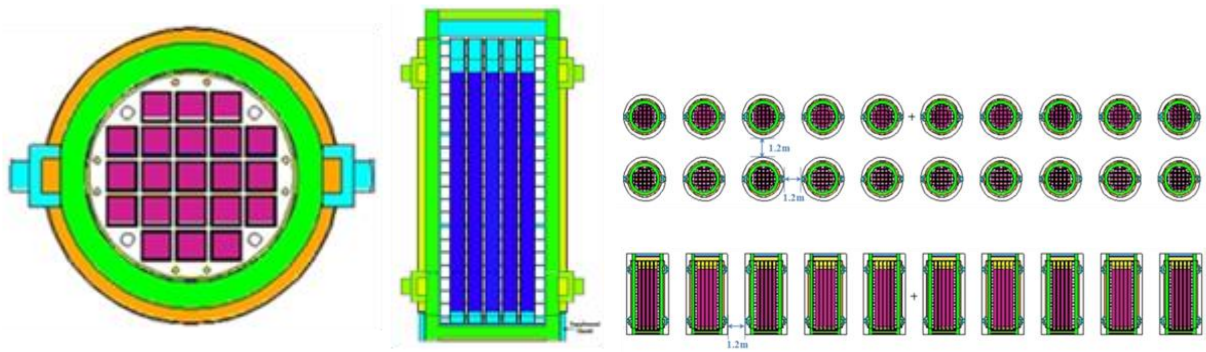
III. RESULT & CONCLUSIONS

Because the code and standard of radiation safety of spent fuel storage conditions are not quantitatively clear, the radiation dose rate was assessed taking into account the normal work environment of workers (installation and transportation of metal storage casks, visual inspection, radiation monitoring and maintenance/repair, etc.) and the casks' surface, 1m and 2m from the separation site. The radiation worker's normal work requirements regarding single metal storage casks are reflected on the cask's surface (side, upper parts) the maximum dose rate results of the separation site 1m from the surface and 2m are shown in Table I. The radiation safety analysis of a single storage cask under spent nuclear fuel storage conditions found that The average surface dose rate on the sides of a storage cask was calculated to be $0.4132 mSv \cdot hr^{-1}$. The dose rate at the bottom of the storage cask (cask base – side neutron shielding material bottom) was calculated as $0.4847 mSv \cdot hr^{-1}$, and it was confirmed that the performance of the supplementary shield was effective.

The shielding analysis for storage casks of spent nuclear fuel under the 2×10 arrangement conditions found that the dose rate at the center point of longitudinal arrangements was higher in all regions (up to the controlled area boundary) than at the center point of the transverse arrangements. Thus, the distance to the controlled area boundary under the single storage cask condition and the 2×10 arrangement condition was determined using the transverse arrangement as the basis, and the distance to the controlled area boundary for the two conditions was found to be about 155 m and 280 m, respectively (Fig.3). This indicates the annual (8,760 hours) dose rate of an ordinary person located at the controlled area can be assumed by using the center point of the outermost 20 cask arrangement and the center part (about 2.5m high from the bottom) of the axial direction of the storage cask as the basis.

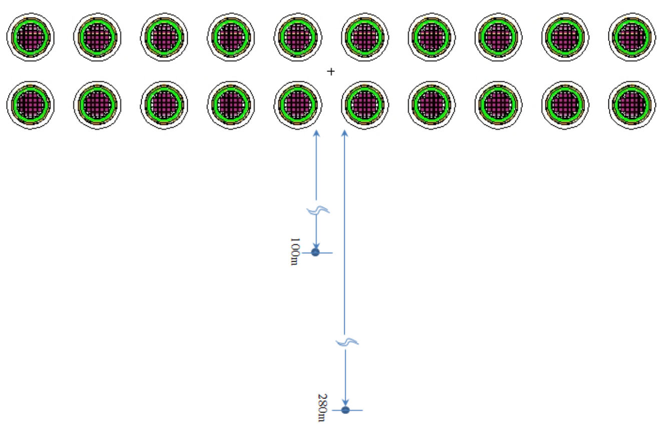
The analysis of radiation dose rate was performed by assuming that this metal storage cask rollovered following a fire accident and that the base surface of the cask faced the controlled area boundary. The dose rates at the surface of a single cask and at 1 to 2 m apart points are shown in Table II. The accumulated dose in the controlled area boundary for the 30-day period was 0.8796 mSv and 0.0787 mSv at 100 m and 280 m respectively. Since this does not exceed the upper limit of 50 mSv, the design basis accident can be regarded as having secured radioactive safety. (Table III)

Source specifications of metal storage cask for spent fuel shall not surpass the limit of predesigned standard fuel amount. The actual value of yearly radiation dose rate should be smaller than 0.25mSv within 280m of the controlled area boundary. According to results of dose rate assessment under design accident, 3.1% of 50mSv which is personal dose rate in controlled area boundary were measured. Therefore, a metal cask and storage facilities maintain radiological safety if the distance to the appropriately assessed control area boundary is ensured.

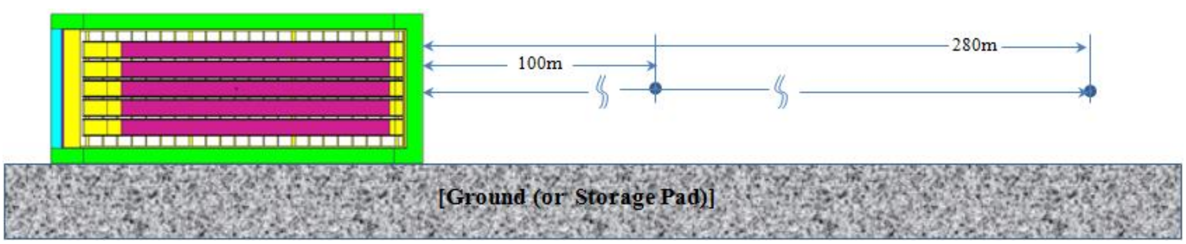


(a) Cross Section of Metal Cask (b) Cross Section of 2×10 Array Casks(Facility)

Fig. 1. Shielding Analysis Models for Metal Cask and Facility under Normal Condition



(a) The Horizontal Cross Section of 2×10 Array Casks



(b) The Cross Section of Cask for Rollover and Burned

Fig. 2. Shielding Analysis Models for Fire and Rollover of Metal Cask

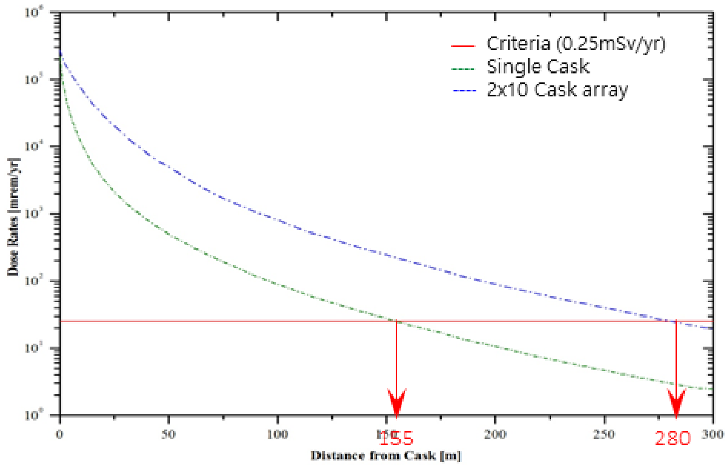


Fig. 3. Annual Dose Rate Results Versus Distance for Single Cask and 2×10 Array

TABLE I. Results of Shielding Evaluation for the Metal Cask under Normal Operation

[Unit : $mSv \cdot hr^{-1}$]

Position		Surface	1m	2m
Top of the Cask		0.2609	0.0761	0.0290
Cask Side	Upper	0.9554	0.1658	0.0806
	Middle	0.4982	0.1449	0.0917
	Lower	0.4847	0.3214	0.1424

TABLE II. Results of Shielding Evaluation for the Metal Cask under Design Basis Accident

[$mSv \cdot hr^{-1}$]

Position		Surface	1m	2m
Top of the Cask		0.2523	0.0957	0.0465
Cask Side	Upper	4.4303	1.5535	1.1619
	Middle	6.8968	2.9291	1.5352
	Lower	6.6063	2.1697	1.4038
Bottom of the Cask		2.6930	0.8276	0.3742

TABLE III. Dose Result for Design Basis Accident by Cask Fire and Rollover

[Unit : mSv/30day]

Item	Dose Results (Cask Bottom)	
	100 [m]	280 [m]
Design Basis Accident	0.8796	0.0787
Criteria		50.0

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