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# A Study on Shielding Performance Evaluation to Discern Suitability of New Shielding Material in Korean Dual Purpose Cask

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## 1. Introduction

Many Spent Nuclear Fuels (SNF) and radioactive wastes are generated by fission reaction in Nuclear Power Plant (NPP) every year, and the amount of SNFs have been increased continuously. These have high radioactivity and heat. If they are exposed outside, it can cause fatal environmental problems. Therefore, these days, management and disposal of these harmful materials has been considered one of the most important issues in nuclear fields.

In Korea, all of SNFs are temporarily stored in the pool of reactor site during about 10~50 years. After Fukushima accident, however, unsafety of temporary storage has been consistently indicated, and a shortage of storage capacity is expected in 2024. Thus, for storage efficiency and long term storage, interim dry storage facility using cask has been considered. For the safe design of cask, four requirements should be satisfied; criticality control, radiation protection, heat removal, structural integrity. Neutron shielding material is required to protect radiation of cask. However, Korea depends fully on the shielding material techniques developed from foreign companies. Furthermore, in the international nuclear market, it is known that shielding performance and functional shielding materials of metal cask occupy about 80% of the dry storage facility market [1]. Therefore, for improvement of economic independence and stable supply-demand of the cask, development of new neutron shielding material as a strategic material is essentially required.

In this study, new neutron shielding material was suggested. Also, to discern suitability of the suggested shielding material, shielding performance evaluation was conducted. The performance evaluation of suggested material was conducted with the Korean cask developed by Korea Radioactive Waste Agency (KORAD) recently.

## 2. Methods and Results

In generally, neutron shielding material for cask shielding is designed to minimize radiation dose rates by neutron and gamma. To reduce dose rate, shielding material should contain elements with high scattering cross section. As part of it, the resin is used as neutron shielding materials in Korean DPC. In this study, Epoxy Resin based shielding material (ER) as the new shielding material was suggested. For the shielding performance evaluation, existing shielding materials, which are resin and possible other shielding materials, used to calculation are as follows; Resin (Reference material), Pure-polyethylene (Pure-PE), Borated Lead Polyethylene (B-Pb-PE), Bismuth based Polyethylene (Bi-PE), 5% Borated Polyethylene (5%-B-PE), and Lithium based Polyethylene (Li-PE). The composition of shielding material is described in Table I [2].

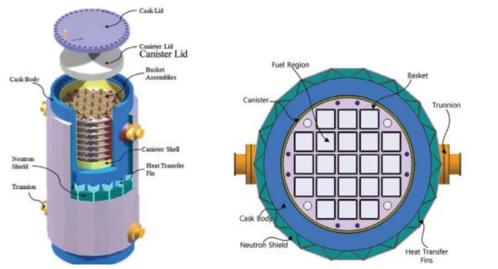
Table I. Composition of Shielding Material for Evaluation

| Items | Density ($g/cm^3$) | Material Composition | Weight Fraction (wt.%) |
|---|---|---|---|
| ER (suggested) | 1.65 | Epoxy Resin | 37.0 |
| | | $Al(OH)_3$ | 47.0 |
| | | $B_4C$ | 3.6 |
| | | W | 12.4 |
| Resin (Reference) | 1.68 | H | 6.00 |
| | | C | 27.70 |
| | | O | 42.80 |
| | | N | 2.00 |
| | | Al | 21.50 |
| Pure-PE | 0.92 | H | 14.37 |
| | | C | 85.63 |
| Li-PE | 1.06 | H | 7.90 |
| | | C | 58.21 |
| | | O | 26.33 |
| | | Li | 7.56 |
| Bi-PE | 2.92 | H | 3.09 |
| | | C | 18.40 |
| | | Bi | 78.51 |
| B-Pb-PE | 3.80 | H | 1.71 |
| | | C | 10.21 |
| | | O | 4.02 |
| | | B | 5.84 |
| | | Si | 0.45 |
| | | Ca | 1.17 |
| | | Pb | 76.60 |
| 5%-B-PE | 0.95 | H | 11.70 |
| | | C | 83.30 |
| | | B | 5.00 |

In this study, two methods were suggested to evaluate shielding performance of suggested shielding material. One is a method to conduct shielding analysis of cask with shielding material suggested is performed from comparison with existing shielding materials. Another is to perform sensitivity evaluation of thickness of cask body with suggested shielding material. It can be definite comparison of suggested shielding material.

### *2.1 Cask Modeling for Performance Evaluation*

In this study, Westinghouse 17x17 OFA (Optimized Fuel Assembly) was determined base assembly for evaluation because it is one of the conservative assemblies. Spent fuel cask used for the evaluation was selected Korean DPC. It can hold 21 fuel assemblies and store both Westinghouse and CE type. The detail of cask properties is described in Fig. 1and Table II [3].



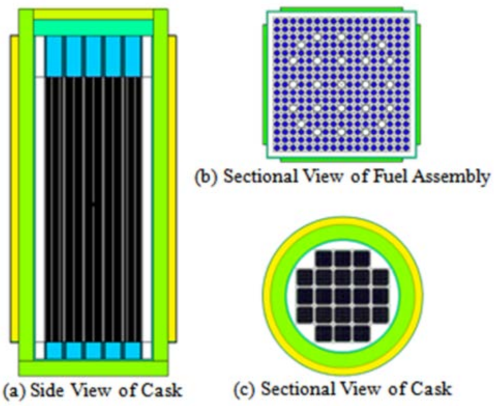

(a) Side View of Cask (b) Sectional View of Cask

Fig.1. Outline of the Dual Purpose Metal Cask

Table II. Specifications of Dual purpose metal cask

| Items | Description |
|---|---|
| Capacity | 21 PWR F/A (WH 17x17 OFA) |
| Reference Fuel | Maximum Burn-up : 45,000 MWD/MTU<br>Maximum Initial Enrichment : 4.5 wt%<br>Minimum Cooling Time : 10 years |
| Canister | Dimensions : (O.D.)1.7m x (L) 5.0m<br>Material : Stainless Steel, Boral($B_4C$+Al) |
| Dimensions | (O.D.)2.4m x (L)5.3m |
| Material | Forged Carbon Steel |

The cask body in the DPC is made of forged carbon steel with thickness 21.5 cm and the shielding material of thickness 11 cm is located in cask body surrounding. The canister lid is 24 cm thick with considering radiation exposure in the air about workers or ordinary people. Equipment which has a less effect on radiation dose rate such as trunnion, heat transfer fins, etc. was excluded in the calculations. MCNP modeling considering above conditions is showed in Fig. 2.

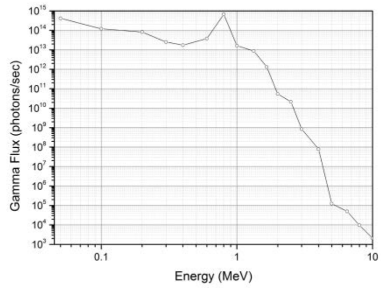


(a) Side View of Cask (b) Sectional View of Fuel Assembly (c) Sectional View of Cask

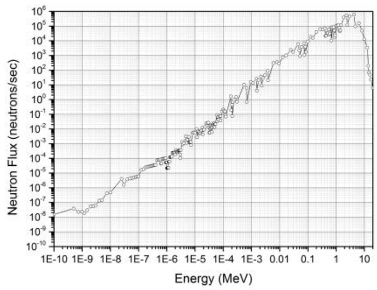
Fig. 2. Modeling for Shielding Calculation by MCNP

### *2.2 Radiation Source Term and Calculation Conditions*

To calculate dose rates emitted in the DPC, two type of source term, neutron and gamma sources, were determined. The source term calculations were performed using ORIGEN-ARP module of SCALE 6.1 system [4]. Also, calculations considering conservative conditions were carried out applying maximum burn-up 45,000 MWD/MTU and 10 years cooling time. Also, energy spectrums were set 18 group gamma fluxes and 238 group neutron fluxes. In consequence, the source terms were derived as shown Fig 3.




(a) Gamma Ray Spectrums of the Spent Fuel




(b) Neutron Spectrums of the Spent Fuel

Fig. 3. Gamma Ray and Neutron Spectrums of the Spent Fuel

### *2.3 Shielding Performance Analysis*

In this study, MCNP5 1.6 with ENDF/B-VI and SAB2002 cross section library was used in this analysis [5]. Radiation dose rates were evaluated at the cask external surface, 1m, and 2m away from the cask surface. The particle history was determined that all of the relative errors of the results were satisfied within 5%. Also, the flux to dose conversion factor in ICRP-116 was used [6].

The results with radiation dose rates were given in Table III, IV and Fig. 4. The result of Fig. 4 means that sum value of the dose rates by neutron and gamma sources. First of all, as shown in Table III, the calculated dose rate by using ER is lower than others except Pure-PE. Also, when comparing with the result of the resin which is the reference material, result of dose rate by using ER was decreased about 2.5%. On the other hand, Table IV indicates results of dose rates by gamma source. The results show that ER is the lowest dose rate except for Li-Poly and Bi-Poly, and ER is about 8.4% superior material than using resin. When overall result, therefore, in terms of radiation protection, it means that ER can have enough to the performance of shielding.

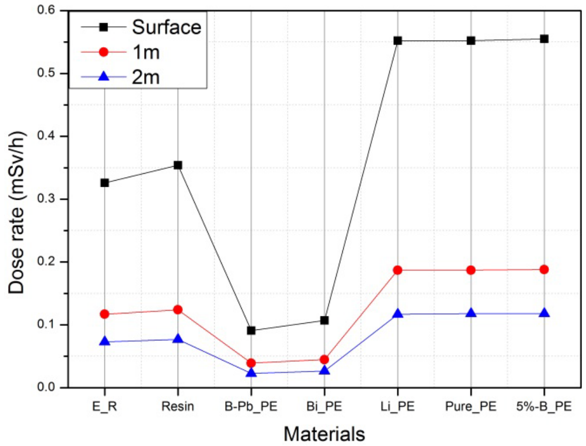



Fig. 4. Result of Total Dose Rates by two sources

Table III. Dose rate parameters by neutron sources

| Items | Surface (mSv/h) | 1m (mSv/h) | 2m (mSv/h) |
|---|---|---|---|
| ER (suggested) | 2.77E-02 | 1.33E-02 | 7.52E-03 |
| Resin | 2.84E-02 | 1.37E-02 | 7.65E-03 |
| Pure-PE | 2.24E-02 | 1.19E-02 | 6.64E-03 |
| Li-PE | 4.75E-02 | 1.92E-02 | 1.11E-02 |
| Bi-PE | 5.21E-02 | 2.04E-02 | 1.19E-02 |
| B-Pb-PE | 6.11E-02 | 2.30E-02 | 1.34E-02 |
| 5%-B-PE | 2.89E-02 | 1.39E-02 | 7.85E-03 |

Table IV. Dose rate parameters by gamma sources

| Items | Surface (mSv/h) | 1m (mSv/h) | 2m (mSv/h) |
|---|---|---|---|
| ER (suggested) | 2.98E-01 | 1.04E-01 | 6.53E-02 |
| Resin | 3.26E-01 | 1.10E-01 | 6.92E-02 |
| Pure-PE | 5.30E-01 | 1.76E-01 | 1.11E-01 |
| Li-PE | 5.04E-01 | 1.67E-01 | 1.06E-01 |
| Bi-PE | 5.45E-02 | 2.42E-02 | 1.47E-02 |
| B-Pb-PE | 2.99E-02 | 1.61E-02 | 9.46E-03 |
| 5%-B-PE | 5.26E-01 | 1.74E-01 | 1.10E-01 |

### *2.4 Sensitivity Evaluation of cask body thickness depending on shielding material*

The previous chapter described that shielding performance analysis of the DPC depending on the away distance from cask surface using each shielding material. In this chapter, for more definite comparison of shielding performance of shielding materials, a sensitivity analysis was conducted by below steps; at first step, a reference shielding material was set. At the second step, with decreasing cask body thickness using suggested shielding material, it evaluated reduction degree of cask body thickness satisfying with radiation dose rate of reference shielding material.

As mentioned earlier, shielding material using in Korean DPC for radiation protection of cask is resin. Therefore, the resin was determined as reference material for sensitivity evaluation. Also, evaluation targets were material suggested in this study and the shielding materials of more outstanding performance than resin evaluated in the section 2.3.

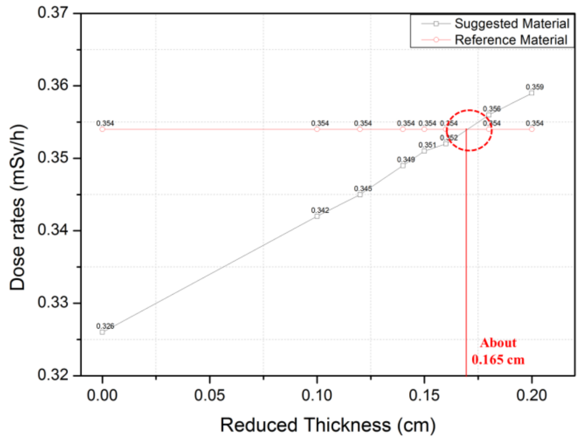



Fig. 5. Dose Rates Result Depending on Reduction Thickness

Fig. 5 describes results of the decrease degree depending on the thickness of cask body. The result shows that thickness was reduced about 0.165 cm when using the ER. If using ER, it means that dose rate of cask can be satisfied although body thickness was decreased about 0.8%. Therefore, use of the ER as shielding material of cask can also be expected economic benefit due to the reduction of using carbon steel.

## 3. Conclusions

In this study, new shielding material of the cask was suggested for the improvement of economic independence and stable supply-demand of the cask. To discern suitability of the new shielding material from the perspective of radiation protection, shielding performance evaluation was carried out. The result shows that ER is the sufficient shielding material able to use as substituting existing shielding material of DPC although ER is not the best performance of material among evaluation materials. Also, thickness reduction of cask body was shown through sensitivity evaluation. The thickness reduction can lead reduction of manufacturing cost, cask weight, and volume. Consequently, it is a little amount, but, it can be expected economic profit if ER is used as shielding material. In the future, to develop new shielding material of DPC, evaluation result will be utilized as base evaluation data.

## Acknowledgments

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