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A Preliminary Study on the Criticality Control Ability Evaluation of Potential Neutron Absorption Materials to Develop the New Neutron Absorber

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1. Introduction

The storage and disposal of the spent nuclear fuel (SNF), which is a type of the high level radioactive wastes, have been concerned continuously. In Korean nuclear power plant, SNFs generated are about 15,000 tons (standard 2012). It is expected that storage spaces of all nuclear power plants such as Kori and Wolsong will be fully loaded by SNF until 2026 [1]. Because of Korean policy and technology, however, construction of independent SNF storage installation has been delayed. Also, generation of more lots spent fuels will be anticipated in the future. Therefore, storage problems of SNF will be steeply increased.

For design of spent fuel storages, major four conditions (criticality control, radiation protection, heat removal, and structural integrity) must be considered. The criticality control is the most important condition among them. To increase storage efficiency and to maintain subcritical condition with any circumstances, neutron absorber is mandatorily required.

The neutron absorber is made from neutron absorption materials and the rest materials. The existing neutron absorbers are mostly produced by using metal composite such as aluminum alloy or stainless steel with boron or boron compound (B_4C). Boron, which is common neutron absorption material, leads to increase neutron absorption performance and to have good mechanical properties of neutron absorber. However, existing neutron absorbers are quite expensive. Also, if content of boron is over the certain percent, it can result in degradation problems of various properties such as machinability, strength, absorption ability, and so on. It leads to difficulty to increase of boron quantity more than necessary. Therefore, development of improved neutron absorber with more superb criticality control ability and reasonable cost is needed.

In this study, some neutron absorbers containing potential material are selected. And then, preferentially, applicability of some neutron absorbers is verified in terms of criticality control ability.

2. Methods and Results

Potential materials as neutron absorption material should satisfy the following conditions.

- Maintaining subcritical with any conditions
- Low cost
- Good mechanical properties
- Low solubility in water
- Machinability as neutron absorber

In this section, three steps were progressed. First, potential neutron absorption materials were suggested. Second, criticality calculation of spent fuel rack with inserting the suggested neutron absorber was performed for the evaluation of criticality control ability. Finally, by comparison of existing material with suggested materials, applicability of suggested neutron absorption materials was estimated.

2.1 Selection of potential neutron absorption material

The maintaining subcritical with any condition is one of the most important requirements of the neutron absorber. As mentioned earlier, boron is a typical useful material for the criticality control. It is well known that boron is already used as criticality control material in nuclear reactor. Actually, almost all existing neutron absorbers contain boron or boron compound for criticality control; thus, composites made with boron or boron compound were considered as potential materials in this study.

From the research, four materials (borosilicate glass or PYREX, boron nitride, calcium borate, and colemanite) as the potential materials were selected. The reasons are as follows. First, these materials have boron contents similar to existing neutron absorber. Second, these materials are commonly utilized as neutron absorption material in other field such as burnable absorber or radiation shielding material. The composition and properties of each material are shown in Table I.

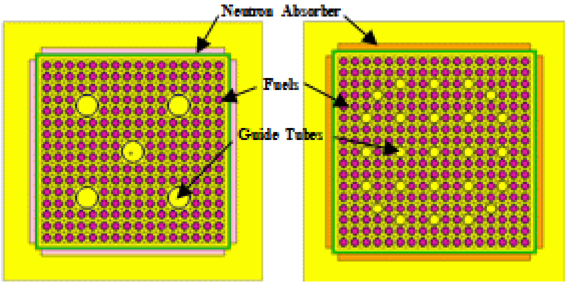
Table I: Composition and Density of Potential Materials

	BORAL (w/o)	Glass (w/o)	Boron Nitride (w/o)	Calcium Borate (w/o)	Colemanite (w/o)
Density (g/cm^3)	2.66	2.23	2.2	2.95	2.95
Si	-	37.9	-	-	-
B	29.0	4.0	50	17.2	15.8
C	8.0	-	-	-	-
Ca	-	-	-	31.9	19.5
Al	63.0	1.1	-	-	-
Na	-	3.0	-	-	-
N	-	-	50	-	-
H	-	-	-	-	2.5
O	-	54.1	-	50.9	62.3
Total	100	100	100	100	100

Each material has some pros and cons to be used by neutron absorber. That is as follows. The colemanite is a type of mineral. This material has low solubility in water. But, this has breakable characteristic. The boron nitride is one of the radiation shielding materials [2]. This material has good neutron absorption performance. But, this has low machinability. Borosilicate glass, which has good thermal resistance, has been used as burnable poison rod in nuclear power plant. This can be broken due to a type of glass. Finally, the calcium borate is a sort of ceramic. It has good machinability. But, because this material has bad thermal transfer, it can lead to thermal problem.

2.2 The criticality control ability evaluation of potential materials

The aim of this section is as following: 1) obtaining criticality evaluation data of potential neutron absorption materials, 2) applicability judgment in terms of criticality control by result comparison existing neutron absorber with neutron absorber using potential materials. The evaluation of criticality control ability was conducted with the absorber which is shown in Table II. The PLUS7 and WH17x17 spent fuel storages are used for criticality calculations, and Fig 1 shows that the storage racks with neutron absorbers [3, 4]. MCNP5 code [5] with ENDF/B-VI and SAB2002 thermal cross section library is used for criticality calculation.



(a) Rack for PLUS7 (b) Rack for WH 17x17

Fig. 1. Unit Storage for the PLUS7 and WH 17x17

Table II: Properties of the neutron absorber for evaluation

	Value
Type	Plate
Height	Effective Height of Nuclear Fuel
Width	19 cm
Thickness	0.2 cm

The criticality safety guidelines refer that the multiplication factor should be not exceeded 0.95 containing the lots of uncertainties [6]. For conservative evaluation, following conditions are assumed. First, SNF used calculation is fresh fuel. Second, moderator is fresh water. Third, reflective boundary of assemble is set-up to assume infinite arrangement of SNF. Finally, two cases were considered. Case 1 is that density of neutron absorber is original. Case 2 is that density of neutron absorber is 75% of original. Fig. 2, 3, Table III, and IV show that K_{eff} calculation results of PLUS7 and WH17x17 storage with neutron absorber.

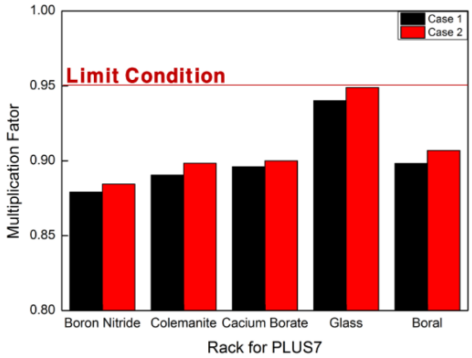


Fig. 2. K_{eff} with each material for the PLUS7 storage

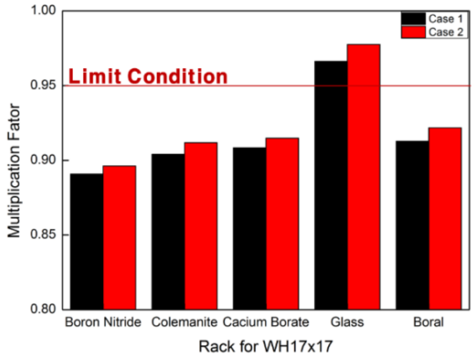


Fig. 3. K_{eff} with each material for the WH17x17 storage

Table III: K_{eff} with each material for the PLUS7 storage

	Case 1	Case 2
BORAL	0.89824(±0.00083)	0.90686(±0.00082)
Borosilicate Glass	0.94010(±0.00083)	0.94894(±0.00080)
Boron Nitride	0.87896(±0.00083)	0.89624(±0.00080)
Calcium Borate	0.89605(±0.00082)	0.91486(±0.00082)
Colemanite	0.89037(±0.00081)	0.89833(±0.00079)

Table IV: K_{eff} with each material for the WH17x17 storage

	Case 1	Case 2
BORAL	0.91275(±0.00080)	0.92181(±0.00083)
Borosilicate Glass	0.96623(±0.00080)	0.97760(±0.00080)
Boron Nitride	0.89092(±0.00080)	0.89624(±0.00080)
Calcium Borate	0.90846(±0.00079)	0.91486(±0.00082)
Colemanite	0.90404(±0.00080)	0.91186(±0.00082)

The results of calculation show that multiplication factors in using each potential material were increased as decreasing quantity of boron. For borosilicate glass, it has least quantity of boron. Also, multiplication factor of borosilicate glass exceeds limit condition; therefore, the criticality control performance of borosilicate glass is lower than others. Also, results show that ability of each potential neutron absorption material except borosilicate glass is not fewer than ability of existing material.

3. Conclusions

In this study, to develop new neutron absorber, four potential neutron absorption materials were selected. From a criticality control ability evaluation of suggested neutron absorber, results show that potential materials in terms of criticality control were well satisfied with criticality limit condition except borosilicate glass. In the future, this result can be utilized as some reference data to develop a new neutron absorber.

4. Acknowledgments

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