Integrity evaluation of neutron absorber for spent nuclear fuel racks using Boron-10 areal density analysis method

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1. Introduction

Neutron absorbers are mainly used for criticality control in the storage racks of spent fuel pool and transport cask for storing or transporting spent nuclear fuel at high density. In general, commercially available neutron absorption materials include BORAL, a composite of aluminum and boron carbide (B_4C), Boraflex, a composite of a silicon polymer organic compound and boron carbon, Bored Aluminum, prepared by mixing fine aluminum grains with boron carbide powder, and stainless steel. Since the neutron absorbing material cannot be used as a structure due to low mechanical strength, the neutron absorbing material is generally attached to a wall surface of a stainless steel-based steel structure cell. In this study, to analyze changes in properties caused by deterioration of neutron absorber exposed to high radiation environments in spent nuclear fuel wet storage, thermal neutron radiographic test were performed on monitoring specimens installed in the spent nuclear fuel wet storage of domestic nuclear power plants. The neutron absorbing material to be tested was performed on the BORAL monitoring standard specimens of domestic power plants.

2. Methods and Results

Neutron irradiation test equipment [1] (Thermal neutron standard field) is used to measure sensitivity of thermal neutron detectors used in neutron dosimeters. It consists of a neutron generating source, a moderator and a detector that decelerates the generated neutron. The test apparatus emits about 55 thermal neutrons per second.

2.1 Detector Model

As shown in Figure 1, thermal neutron radiographic test equipment consists of a neutron source generating neutrons, graphite forming a thermal magnetic field by decelerating the generated neutrons, and a detector measuring neutron flux. As a neutron detector, a 3He proportional counter is used and fixed to one side of the graphite. The specimen to be inspected is fixed between the hexahedral graphite and the neutron detector.
Neutrons generated from the source were measured by the detector through the specimen to be inspected.

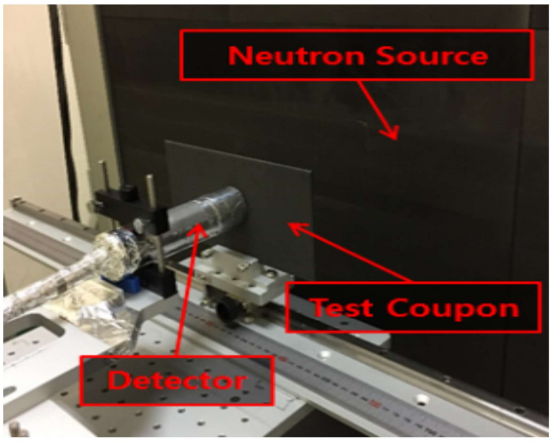

Fig 1. Thermal neutron radiographic test equipment

Neutrons generated by the test equipment include some epithermal neutrons as well as thermal neutrons, as shown in Figure 2. Fluence for Air.
Therefore, after shielding the detector with cadmium (Cd), by measuring the epithermal neutrons (Fluence for air in Cd filter) excluding epithermal neutrons from all neutrons, calculate thermal neutron flux.
Finally, the thermal neutron energy distribution applied to thermal neutron radiographic test has a Maxwell-Boltzman distribution at a temperature of 311K.

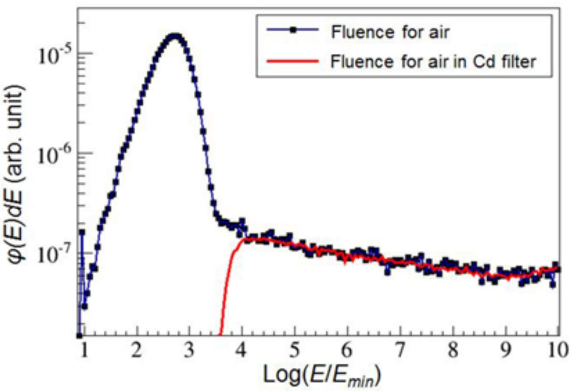

Fig 2. Neutron spectrum of neutron irradiation test facility

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2.2 Test procedure

For the thermal neutron radiographic test for the neutron absorbent monitoring specimen, a thermal neutron radiographic test of at least 80,000 counts or more was performed on 5 points(central and 4 corners of specimen location) per specimen. Fig. 3 shows the location of the neutron irradiation test transmittance measurement. Tests were performed on five locations for the neutron absorbent monitoring specimen as shown in the specimen below.

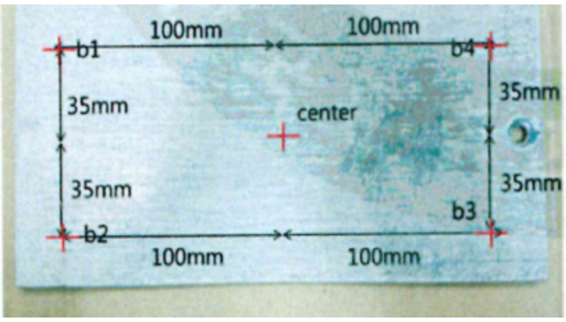

Fig 3. Test measurement location

① Install the 3He proportional counter in the thermal neutron standard field. In this case, the detector is shielded with a thickness of 0.6 mm except for the front surface. Measure the counting rate of the detector. This value is the detector coefficient (Rt) for neutrons. ② Block the front of the detector with a Cd cover and measure the detector's counting rate. This value is the detector coefficient (Re) for the extrapolated neutron. (En> 0.6 eV) ③ The thermal neutron coefficient Rth is determined using the difference between Rt and Re. : Rth = Rt–Re ④ Install the sample to be tested on the front of the 3He proportional counter. Measure the counting rate. This value is the detector's coefficient (St) for all neutrons passing through the specimen ⑤ Install a Cd cover between the sample to be tested and the detector. Measure the counting rate. This value is the coefficient (Se) of the detector for the extrapolated neutron (En> 0.6 eV) passing through the specimen.⑥ The coefficient Sth of the thermal element passing through the specimen is determined using the difference between St and Se . : Sth=St-Se ⑦ The transmittance rate P of the specimen to be inspected is determined. : P = Sth/Rth = (St-Se) / (Rt–Re)

2.3 Neutron transmittance test results

Thermal transmittance test results, relatively high content of B-10 in the specimen means that there are many thermal molecules absorbed. Conversely, a large thermal transmission rate means that the content of B-10 of the specimen is low, so that there are few thermal electrons absorbed. In the results of this thermal neutron radiographic test, it was analyzed that all specimens were less than 5%.

Table I: Thermal neutron transmittance rate

Sample	location	R_t a)	$u(R_t)$ b)	S_t(1/s) c)	$u(S_t)$ d)	P(10^{-2}) e)	u(P)/P f)
 sample#1	center	39.40	0.37	1.43	0.02	2.0	3%
	p1			1.59	0.02	2.3	3%
	p2			1.52	0.02	2.1	3%
	p3			1.55	0.02	2.2	3%
	p4			1.52	0.02	2.1	3%
 sample#2	center	39.16	0.35	0.77	0.01	3.5	12%
	p1			0.84	0.02	4.2	12%
	p2			0.82	0.02	3.9	12%
	p3			0.87	0.02	5.2	10%
	p4			0.85	0.02	4.6	11%
 sample#3	center	39.16	0.35	0.80	0.02	3.6	12%
	p1			0.82	0.01	3.5	15%
	p2			0.83	0.02	3.7	15%
	p3			0.81	0.02	3.3	16%
	p4			0.79	0.01	2.8	19%

a) Rt(1/s) : Detector coefficient for neutrons per second.
b) u(Rt) : Error in detector coefficient for neutrons
c) St(1/s) : The rate at which the detector counts for all neutrons passing through the specimen per second.
d) u(St) : Error in the detector count rate for all neutrons passing through the specimen per second.
e) P(10-2) : The transmittance rate of the specimen to be irradiated P = (St-Se) / (Rt-Re)
f) u(P)/P : Error in transmittance of specimen to be irradiated

2.4 Areal density conversion of monitoring specimens

The thermal neutron transmittance test is a test in which thermal neutrons are irradiated to the monitored specimen to be tested to calculate thermal neutron transmittance of each specimen. The calculated transmittance may be converted into B-10 areal density. To this end, a B-10 areal density conversion table according to thermal neutron transmittance was derived using MCNP6 computational code.

2.4.1 Evaluation computer code and modeling

The evaluation code used the Monte Carlo method MCNP6 computational code, which is a statistical method. For the nuclear reaction cross-sectional area library, the latest ENDF/B- Cont Continuous library was applied. In order to calculate the thermal neutron transmission rate according to the B-10 areal density of the monitoring specimen, Figure 4. Perform modeling as shown in Figure 4. Since the thickness of the specimen varies from the three specimens, the thickness that can represent each specimen was selected. Specimens with representative thickness were divided into six groups as shown in Table II.

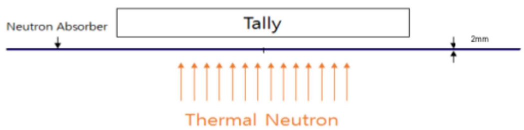

Fig 4. Areal density conversion modeling of irradiated specimens

Table II: Representative specimen thickness [mm]

Sample thickness [mm]	Representative thickness [mm]
1.91, 1.93, 1.96, 1.98, 2.01, 2.04, 2.06	2.00
2.13, 2.15, 2.31, 2.32	2.25
2.53, 2.54, 2.55, 2.56, 2.58, 2.59, 2.60, 2.61	2.57
2.74, 2.75, 2.79, 2.82	2.76
4.02, 3.98,	4.00
4.60	4.60

To evaluate the transmittance of neutron absorber monitoring specimens, while increasing the B_4C concentration by 1% from 9% to 49%, the corresponding B-10 areal density was calculated and reflected in the modeling and evaluation input data.

When calculating the transmittance, the thermal neutron source was irradiated from the bottom to the top of the neutron absorber by applying the same conditions as the test environment with Maxwell-Boltzman distribution at 311K temperature. For the calculation of the transmittance of the neutron absorber monitoring specimen, 180 cases were calculated with 6 representative thicknesses and 30 B_4C concentrations, and the thermal electron transmittance according to the B-10 areal density by specimen thickness is shown in Table III and Figure 5.

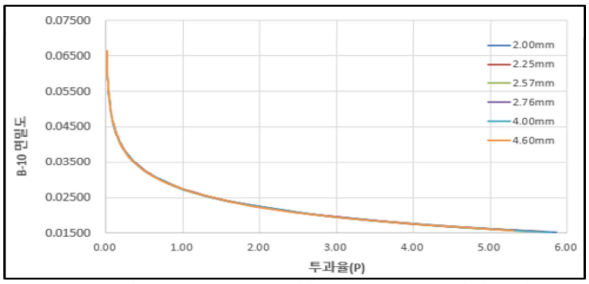

Fig 5. Transmittance rate according to B-10 areal density

Table III: Example of transmittance evaluation results

Model thickness : 2.57 mm			Model thickness : 2.76 mm		
B_4C (w/o)	Transmittance (%)	Areal density (g/cm^2)	B_4C (w/o)	Transmittance (%)	Areal density (g/cm^2)
16%	5.46	0.01560	15%	5.37	0.01571
17%	4.70	0.01657	16%	4.57	0.01675
18%	4.06	0.01755	17%	3.90	0.01780
19%	3.50	0.01852	18%	3.34	0.01885
20%	3.03	0.01950	19%	2.86	0.01989
21%	2.63	0.02047	20%	2.45	0.02094
22%	2.28	0.02145	21%	2.11	0.02199
23%	1.99	0.02242	22%	1.82	0.02304
24%	1.73	0.02340	23%	1.57	0.02408
25%	1.51	0.02437	24%	1.36	0.02513
26%	1.32	0.02535	25%	1.18	0.02618
27%	1.15	0.02632	26%	1.02	0.02722
28%	1.01	0.02730	27%	0.88	0.02827
29%	0.89	0.02827	28%	0.77	0.02932

The thermal neutron transmittance rate for the neutron irradiation specimen in Table I was applied to the result of converting the B-10 areal density, and the difference between the initial areal density provided by the manufacturer and the converted areal density was analyzed.

2.5 Test result(Converted areal density)

Table IV: B-10 areal density conversion result

Samlple	Sample thickness [mm]	Initial areal density [g/cm^2]	Converted areal density [g/cm^2]	Density deviation [%]
sample#1	1.98	0.02180	0.02194	0.6
sample#2	2.55	0.03417	0.03382	-1.0
sample#3	2.75	0.03590	0.03564	-0.7

Table IV shows the conversion result of the B-10 areal density calculated by applying the thermal neutron transmittance rate measured through the irradiation test to the B-10 areal density conversion table of the neutron absorber in Table III. As a result of the analysis, in the case of sample #1, it was evaluated that the B-10 areal density provided by the initial manufacturer was higher, and the remaining specimens were measured that the B-10 areal density was partially reduced. Compared to the initial areal density, it was evaluated within about -1%.

For reference, it may be seen that as the thickness of the neutron absorbent specimen increases, the deviation in areal density increases. This is judged to be due to the increase in the thickness of the specimen, which reduced the transmittance of the thermal neutron, and increased the measurement error of the detector.

3. Conclusions

Thermal neutron transmittance test was conducted on a BORAL-type neutron absorber monitoring specimen installed in an spent nuclear fuel wet storage at a domestic nuclear power plant, and the change in neutron absorption capacity due to long-term storage was analyzed by comparing the B-10 areal density.

As a result of comparing the initial areal density with the B-10 test results, it was evaluated that the B-10 content decreased by up to 1%, and it was evaluated that the operation standard criteria was satisfied because it was within -5% of the design standard suggested by the neutron absorbent supplier. However, in the case of specimen #1, it is judged that there may be a transmittance rate and conversion areal density error in accordance with the test that the measured areal density was higher than the areal density provided by the initial manufacturer. In addition, the accuracy of the initial areal density test results of the manufacturer provided when the initial storage stand was introduced is also an important factor influencing the test results.

REFERENCES

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