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Development of Boron Meter Model with MCNPX

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1. Introduction

A boron meter has been used to monitor the boron concentration of coolant continuously in a pressurized water reactor. The uncertainty of currently used boron meter is at least 2%, and the practical boron meters are supposed to show much bigger than 2%. In 2011, P. Pirat presented a new boron meter called Boronline which showed improved accuracy [1], however it is required to develop more accurate boron meter for safety. For that purpose, the boron meter model was developed and evaluated with Monte Carlo code MCNPX [2].

2. Mechanism of Boron Meter

The boron meter is composed of two parts: source and detector. The principle is that a constant amount of neutrons are emitted from source and the detector counts the neutrons. The counting rate is determined by the concentration of boron. The concentration can be calculated with a fitting curve. Generally, an Am-Be source is used to generate constant neutrons, and a BF_3 detector is used to count the neutrons.

The Boronline uses a three term rational equation to estimate boron concentration as shown in Eq. (1):

$$Cr = \frac{1}{a \times Cb^2 + b \times Cb + c}, \quad (1)$$

where *Cb* is the boron concentration and *Cr* is the counting rate of the detector, and *a*, *b*, and *c* are coefficient.

3. Boron Meter Modeling

3.1 Am-Be Neutron Source

Constant neutron source can be obtained from the alpha decay of americium and (α, n) reaction of beryllium.

$$^{241}_{95}\mathrm{Am} \rightarrow {}^{237}_{93}\mathrm{Np} + {}^{4}_{2}\mathrm{He}, \quad (2)$$

$$^{9}_{4}\mathrm{Be} + {}^{4}_{2}\mathrm{He} \rightarrow {}^{12}_{6}\mathrm{C} + {}^{1}_{0}\mathrm{n}. \quad (3)$$

The americium emits roughly 5.5 MeV alpha particles and a neutron is emitted by (α, n) reaction of beryllium [3-5]. The neutron energy spectrum can be achieved by the TRITON and ORIGEN code [6]. The ratio of Am-Be compound is 1:10. Fig. 1 shows neutron spectrum after 1 day depletion.

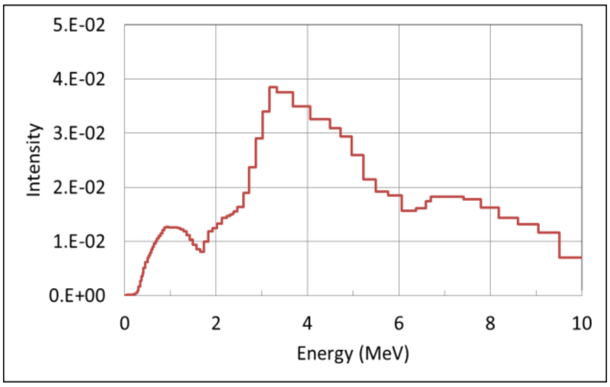

Fig. 1. Am-Be neutron source spectrum by ORIGEN.

3.2 BF_3 Detector

BF_3 detector is filled with BF_3 gas. Charged particles are released as a result of the absorption reaction of boron 10 as follow:

$$^{10}_{5}\mathrm{B} + {}^{1}_{0}\mathrm{n} \rightarrow {}^{7}_{3}\mathrm{Li} + {}^{4}_{2}\mathrm{He}. \quad (4)$$

This charged particle will produce ion pairs, and the ion pairs will be counted. MCNPX can simulate (n, α) reaction, and the number of absorbed neutron which is proportional to detector signal can be tallied with 'pulse height' tally option. Counting rate can be calculated by the number of absorbed neutrons times the efficiency. In our case, 100% efficiency is assumed. Tallied result is normalized by the number of source neutrons.

3.3 Test Model

The Am-Be source is positioned at the center of the cylinder, and 4 detectors are installed. Detectors and source are covered with stainless steel 304.

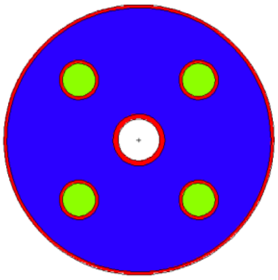

Fig. 2. Top view of boron meter.

Table I: Density of Test Model

Region	Density (g/cm^3)
BF_3 gas	0.002567
Stainless steel 304	8.03
Water	0.69

4. Results

The coefficients, *a*, *b*, and *c*, in Eq. (1) were determined by least square fitting. The 6 tallied points (10, 500, 750, 1000, 3000, and 6000 ppm) are used to determine the variables of the fitting equation. The counting rate and boron concentrations are calculated with the fitting equation, and these are compared in 18 points (10, 50, 100, 250, 500, 750, 1000, 1250, 1500, 1750, 2000, 2250, 2500, 2750, 3000, 4000, 5000, and 6000 ppm) which were tallied. Fig. 3 shows the count rate depending on boron concentration, while Fig. 4 shows the errors between estimated concentration and input concentration.

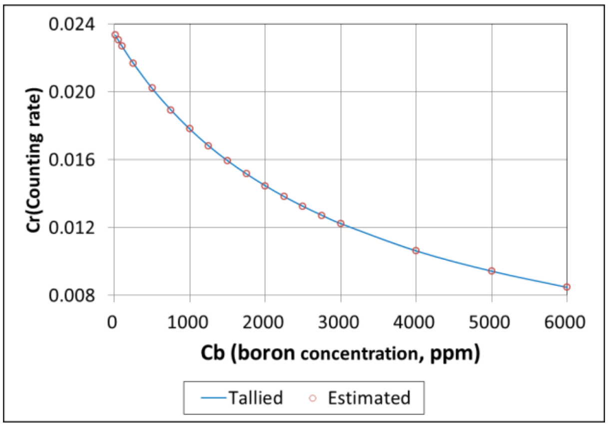

Fig. 3. Count rate depending on *Cb*.

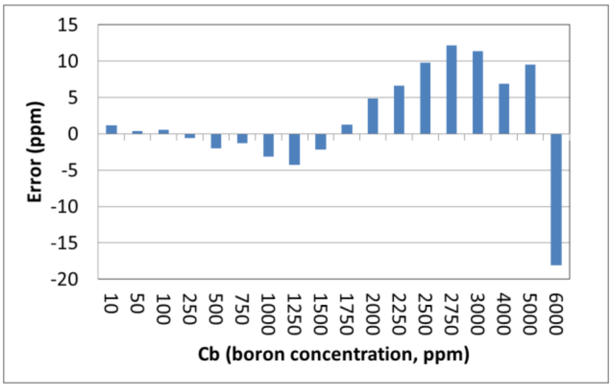

Fig. 4. Errors of estimated *Cb*.

5. Conclusions

A new boron meter model was developed and evaluated. The result shows better accuracy (0.1-0.8%) in comparison with current boron meters (2%). The accuracy can be more improved by using mix set of detectors which have different sensitivity or by using additional moderator outside of the detectors. Further study will be performed with those ideas.

ACKNOWLEDGMENTS

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