Development of a Neutron Calibration Field with Radioactive Neutron Sources

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Introduction

The neutron dosemeters for routine monitoring are usually calibrated with ^{252}Cf and ^{241}Am-Be neutron sources, whose average energies are 2.3 MeV and 4.5 MeV, respectively. But in the environmental neutron field surrounding nuclear facilities, the neutron spectra are in general much softer. We therefore developed a neutron calibration field having softer spectra by using a ^{241}Am-Li neutron source and an iron-moderated ^{252}Cf source in the Center. Figure 1 shows the schematic view of the calibration field.

A 1.2 mCi ^{252}Cf source (neutron emission rate of 3.84×10^6 n/s on July 9, 1987) and a 1.0 Ci ^{241}Am-Li source (neutron emission rate of 3.3×10^4 n/s on Dec. 2, 1986) were used, and the ^{252}Cf source was inserted at the center of 20-cm-diam iron sphere. The neutron spectra of ^{241}Am-Li, ^{252}Cf and iron-moderated ^{252}Cf source in the calibration field were measured with three types of neutron spectrometers, 1) multi-sphere spectrometer, i.e. 10 atm ^{3}He counter covered with 0-, 1.5-, 3-, 5- or 9-cm thick polyethylene moderator, 2) proton-recoil proportional counters of 5 atm (4.5 atm H_2 and 0.5 atm CH_4) and 1.2 atm (1.08 atm H_2 and 0.12 atm CH_4), and 3) 2"-diam×2" NE-213 scintillator.

Response function of neutron detector

The response functions of the multi-sphere spectrometer and the NE-213 have already been well established in Refs. (1) and (2). The response functions of the proportional counters were calculated by the SNIDOW subroutine in the SPEC-4 code[3)] and their accuracy was checked by the experiment with monoenergetic neutrons of 133 keV, 560 keV, 994 keV and 4.99 MeV. In the original SNIDOW program, the recoil proton range in the mixed gas of hydrogen and methane, R(E) is defined as

$$\frac{1}{R(E)} = \frac{p_H}{R_H(E)} + \frac{p_C}{R_C(E)}, \qquad (1)$$

where R_H, R_C: recoil proton range in hydrogen and methane, respectively, p_H, p_C: partial pressure of hydrogen and methane, respectively. But, the calculated response functions based on Eq. (1) show some discrepancy especially in high energy region with the measured results. According to the Bragg-Kleeman rule, the recoil proton range depends on gas pressure and also its atomic mass, that is,

$$\frac{\rho_1 R_1}{\rho_2 R_2} = \sqrt{\frac{A_1}{A_2}}, \qquad (2)$$

where R_i: recoil proton range in ith material, ρ_i: density of ith material, A_i: atomic mass of ith material. By using Eq. (2), the new formula to calculate the recoil proton range is given by

$$R(E) = \frac{RT}{2p_H + (\sqrt{12}+4)p_C} \left\{ \frac{1}{\sqrt{2}} \rho_H R_H(E) + \frac{1}{\sqrt{16}} \rho_C R_C(E) \right\}, \qquad (3)$$

where R: gas constant, T: gas temperature.

Figures 2 and 3 show the comparison of our experimental response functions and those calculated by using Eq. (3) for 1.2 atm and 5 atm proportional counters, respectively. The agreement between experiment and calculation is very good.

Neutron spectra

The neutron spectra were obtained by unfolding the measured data of the multi-sphere spectrometer with the SAND-2 code[4)], the proportional counter with the FERDOR code[5)], and the NE-213 with the FERDOU code.[6)].

Figure 4 shows the ^{241}Am-Li neutron spectrum with errors obtained by 1.2 atm and 5.0 atm proportional counters. The dotted curve below about 150 keV is the extrapolated estimate. Our experimental result is compared with the calculation by Geiger[7)] and the measurement by Weaver et al.[8)] Our spectrum agrees with Geiger's calculation above about 0.8 MeV and with Weaver's experiment below about 0.5 MeV. The average neutron energy of ^{241}Am-Li was about 240 keV.

Figure 5 shows the iron-moderated ^{252}Cf neutron spectrum obtained by 1.2 atm and 5.0 atm proportional counters, multi-sphere spectrometers and NE-213. The spectra measured with three different detectors are close each other. Our measured spectra also agree with the spectrum calculated by the ANISN-W code[9)], where the neutron transport through a 20-cm-diam iron sphere was calculated by using the ^{252}Cf fission spectrum. The average neutron energy of this source was 1.12 MeV.

These two neutron sources are used for detector calibration.

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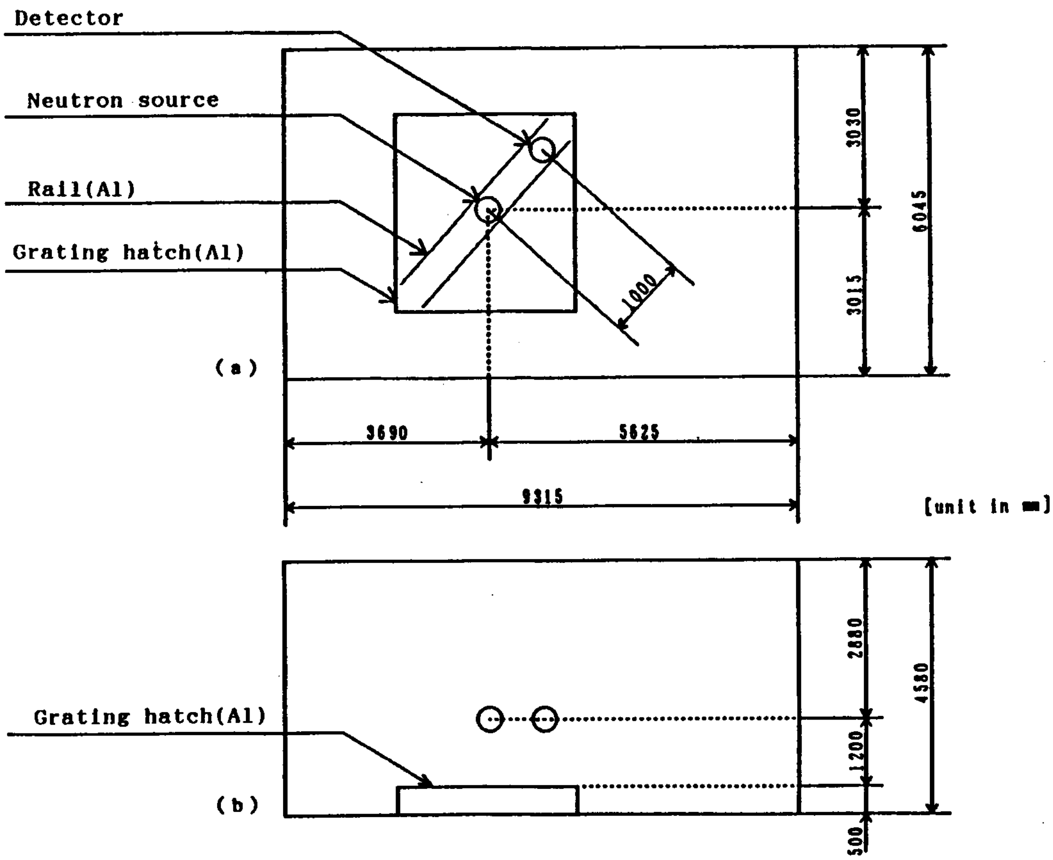

Fig. 1. Schematic view of neutron calibration field: (a) plan view, (b) cross sectional view.

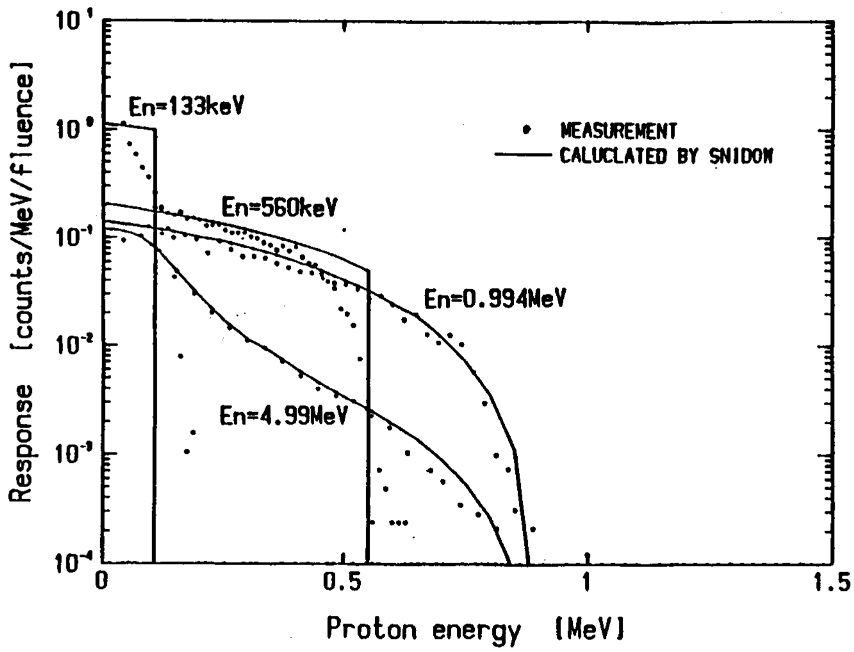

Fig. 2. Response functions of 1.2 atm proportional counter to monoenergetic neutrons.

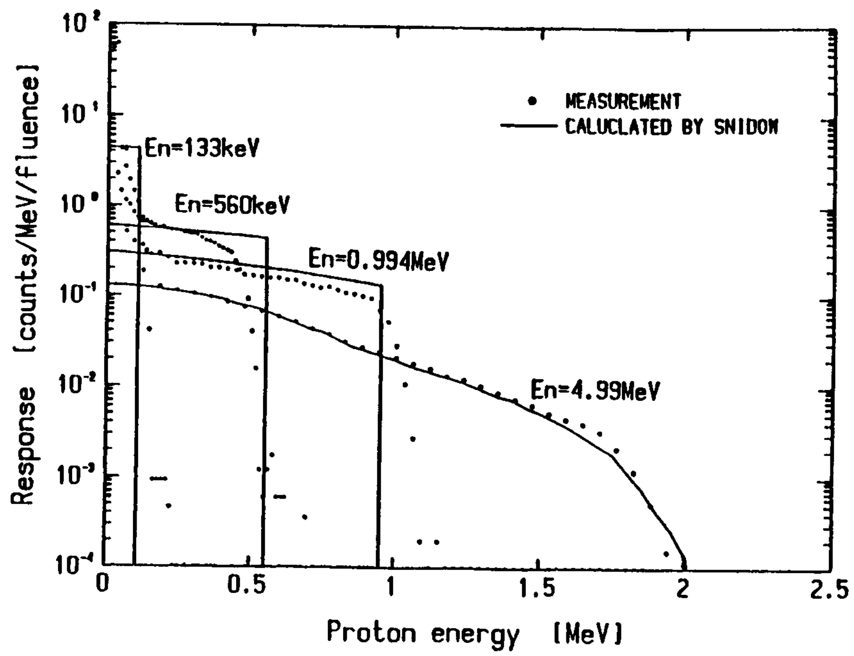

Fig. 3. Response functions of 5 atm proportional counter to monoenergetic neutrons.

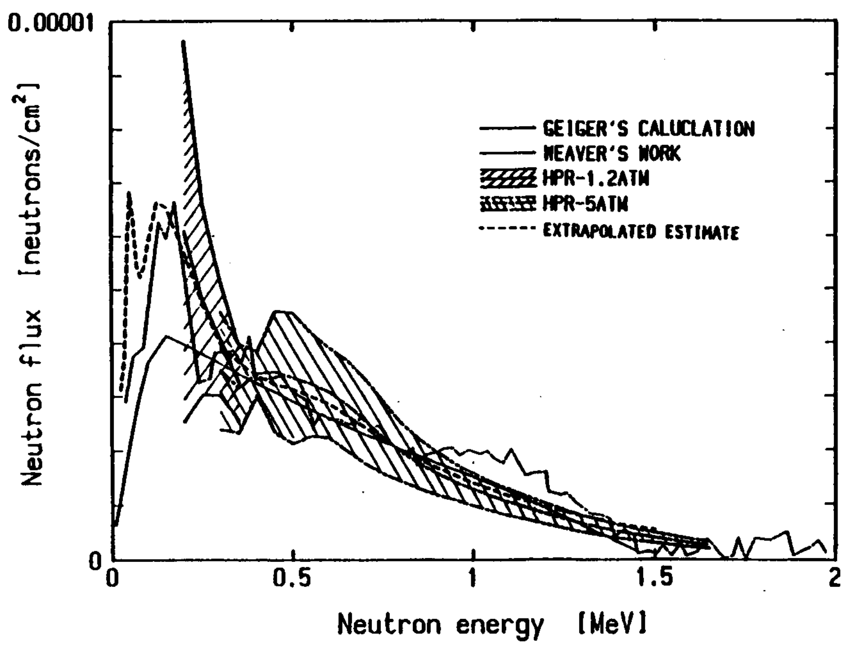

Fig. 4. Neutron spectrum of ^{241}Am-Li neutron source measured with 1.2 atm and 5 atm proportional counters.

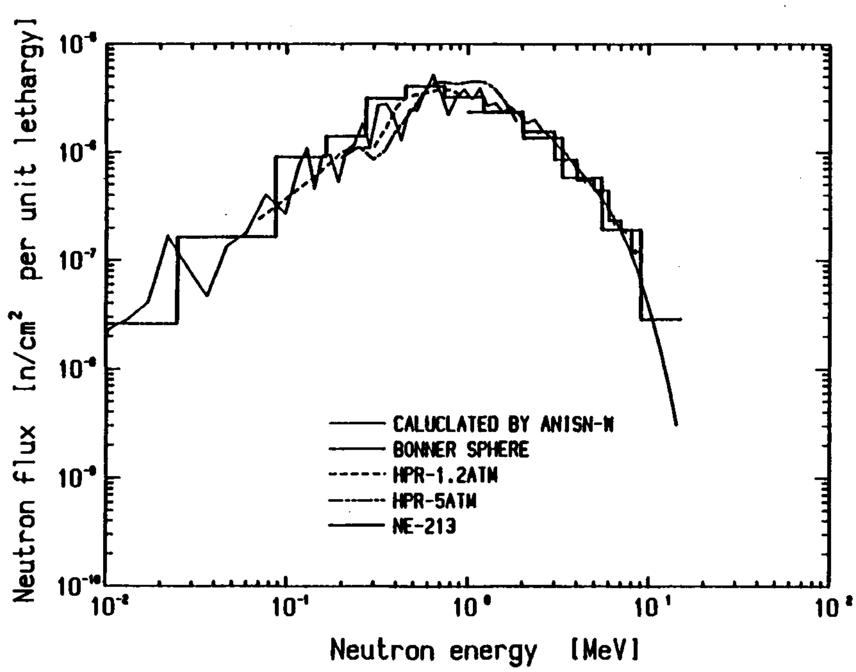

Fig. 5. Neutron spectrum of 20-cm-diam iron-moderated ^{252}Cr source measured with proportional counters, NE-213 and multi-sphere spectrometer (Bonner sphere).