Performance of a Spherical Neutron Counter for Spectroscopy and Dosimetry

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Abstract

A spherical neutron counter for spectroscopy and dosimetry has been developed. The counter consists of a spherical polyethylene moderator and three slender ^{3}He position-sensitive proportional counters. Rough measurements of neutron fluence spectra and ambient dose equivalents, H*(10), have been done in the moderated-neutron field of JAERI. Characteristics of the counter are examined and compared with those of a Bonner sphere neutron spectrometer.

I. INTRODUCTION

It is well known that a Bonner sphere neutron spectrometer (BSS) [1] has been playing an important role in neutron spectrometry and dosimetry in a wide energy range, typically from thermal energies to about 20 MeV, the important energy region for radiation protection dosimetry. Though the BSS is almost the only neutron spectrometer that gives spectral information on neutron fluence in a wide energy range, it takes a significantly long time and effort to obtain the above information. It is necessary to use an appropriate spectrum unfolding method with multisphere measurements from a set of Bonner spheres because the energy resolution of a single sphere is poor, *i.e.* the response function of each sphere overlaps in a wide energy range.

The Energy Sensitive Spherical Neutron Counter, ESPHENEC [2], presented here, can be used for neutron fluence spectrometry and dosimetry in a wide energy range at nuclear power reactors and nuclear reprocessing facilities. There is an advantage that the ESPHENEC is sensitive to neutrons with energies from thermal to about 20 MeV, because the ESPHENEC is based on neutron moderation, as the BSS is. Moreover, there is an outstanding advantage for the ESPHENEC over the BSS that there is no need for the multisphere measurements, because the detection position information obtained by the position-sensitive proportional counters (PSPCs), inserted into the moderator, gives a similar information as is obtained by the multisphere measurements using a set of the Bonner spheres [3].

II DESCRIPTION OF THE ESPHENEC

The ESPHENEC consists of a spherical polyethylene moderator with a diameter of 26 cm, and three PSPCs with outer diameters of 1 cm, which are filled with ^{3}He (101 kPa) and CF_4 (71 kPa) gases. A schematic view of the ESPHENEC is shown in fig. 1. The three PSPCs are called the X-, the Y-, and the Z-PSPC, because they are placed along the Cartesian coordinate system whose origin was set to the center of the sphere. Each PSPC gives one dimensional position profile of detected neutrons which are thermalized in the moderator. The position resolution is fairly good (FWHM 0.6 cm) at an applied voltage of 1500 V.

III ENERGY RESPONSE FUNCTION

Figure 2 shows the traces of the scattered neutrons in the ESPHENEC, calculated with a Monte Carlo simulation code. The Monte Carlo code is based on the modification of the O5S code [4]. The incident neutrons are from a point source, which isotropically emits 2 MeV monoenergetic neutrons, that is located on the line of which direction cosine, (u, v, w) in the Cartesian coordinate system is (1,0,0). The distance between the source and the center of the moderator is 200 cm. Figure 3 shows the three position profiles of the thermalized neutrons which are detected with each PSPC when the total number of the incident neutrons is 1x10^7.

Figure 4 shows the radial distributions of the detected neutrons with the three PSPCs calculated for various monoenergetic neutrons with the energies from 1 eV to 15 MeV. As the energy increases, the fraction of the neutrons detected around the central region of the moderator

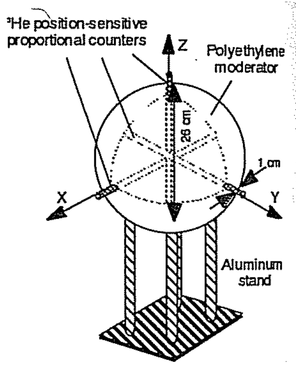

Fig. 1 A schematic view of the ESPHENEC.

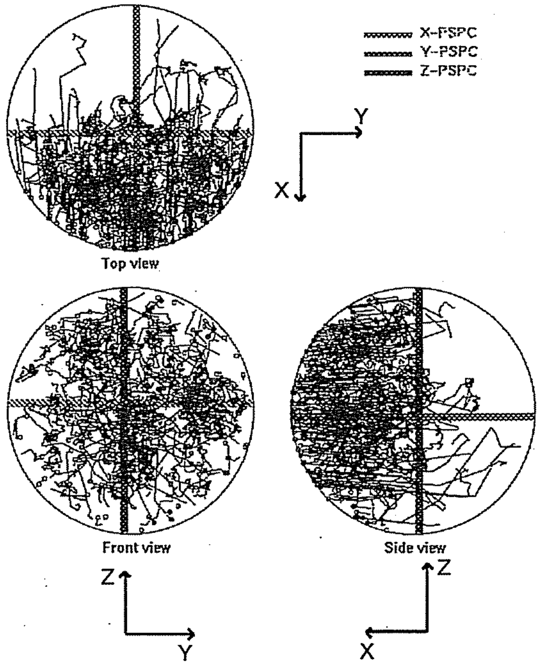

Fig. 2 Traces of the path of the incident neutrons on the ESPHENEC, from the top (top left), front (bottom left) and side (bottom right) view.

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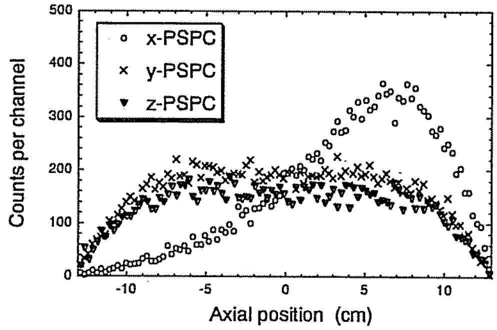

Fig. 3 Detection position profiles obtained with the X-, Y-, and Z-PSPCs for 2 MeV monoenergetic neutrons.

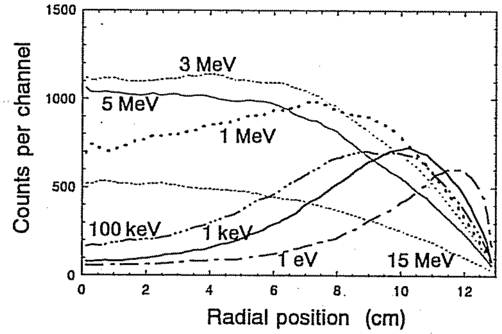

Fig. 4 Radial view of the detection position profiles for the monoenergetic neutrons.

increases. Therefore, the deep region of the sphere is sensitive to high energy neutrons, and the shallow region is sensitive to low energy neutrons [3].

The position of the neutron detection can be divided into several bins, so we need not to change the thickness of the moderator, but to find the relation between the counts in any position bins and the neutron energy. With the position information obtained by the PSPCs, only a single measurement, which is equivalent to the multisphere measurements using a set of the Bonner spheres, is required [3]. The spherical moderator was imaginary divided into five spherical shells with the same thickness of 2.6 cm, in this study. The total counts of the thermalized neutrons in the whole sphere brings us information on the integrated neutron fluence, and the ratio of the counts in each spherical shell region brings us a spectral information.

IV EXPERIMENT AT JAERI NEUTRON FIELD

A performance test of the ESPHENEC was done at the moderated-neutron field of Japan Atomic Energy Research Institute (JAERI). A schematic view of the experimental room is shown in Fig. 5. The wall, the floor, and the ceiling of the room are made of concrete, except a, b, c, and d shown in fig. 5. An Am-Be neutron source (a) with the neutron emission rate of 2.40 x 10^6 s^{-1} (± 2%) was placed between the back board (c), made of heavy concrete, and the neutron counter (b). The source was placed at 10 cm from the back board. The center of the counter was 53 cm from the floor, and 110 cm from the neutron source. The integral fluence rate of the neutrons that directly pass through the center of the counters was15.8 cm^{-2} s^{-1} when the counters were removed. Measurements with the same experimental conditions using the BSS were also done to check the performance of the ESPHENEC.

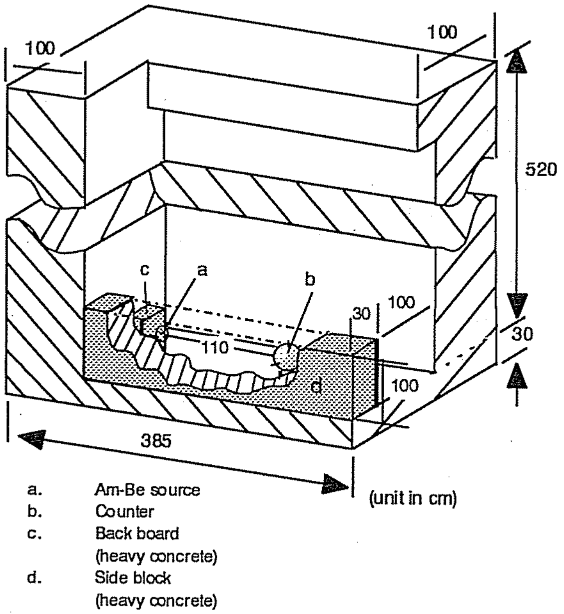

Fig. 5 A schematic view of the moderated-neutron field of JAERI.

A. Experiment with the ESPHENEC

The ESPHENEC was set so that the neutron source was on the line whose direction cosine was (1,0,0). The PSPCs were operated with an applied voltage of 1500 V. The data from each PSPC were processed with a 6-parameter data acquisition system (SEIKO EG&G 1910). The position calculation was done after the storage of the LIST mode data on a MO disk. The measurement time was about 1600 sec.

Figure 6 shows the detection position profiles obtained with each PSPC. The contribution of the scattered neutrons from the floor (floor-returned neutrons) is seen as the large bump at the negative portion of the position profile for the Z-PSPC. The decrease in the counts of the detected neutrons at the positive portion of the position profile for the Z-PSPC is due to the decrease in neutron flux of the upper side. We can see from fig. 5 that there is a large space (417 cm) on the upper side of the ESPHENEC, compared to the bottom side (53 cm). Then the neutron flux of the upper side became lower than that of the bottom side, because of the escape of the neutrons.

The radial position profile of the detected neutrons is shown in fig. 7. The numbers in the figure indicate the position bins, or the spherical shell regions.

B Experiment with the BSS

The Bonner sphere systems used for the measurement consists of a BF_3 filled (26.6 kPa) proportional counter (LND Ltd., type 2708) and eight polyethylene spheres with the moderator thickness of 1 cm, 2 cm, 3 cm, 4 cm, 6 cm, 8 cm, 10 cm, and 14 cm [6]. Table 1 summarizes the list of the Bonner sphere set and

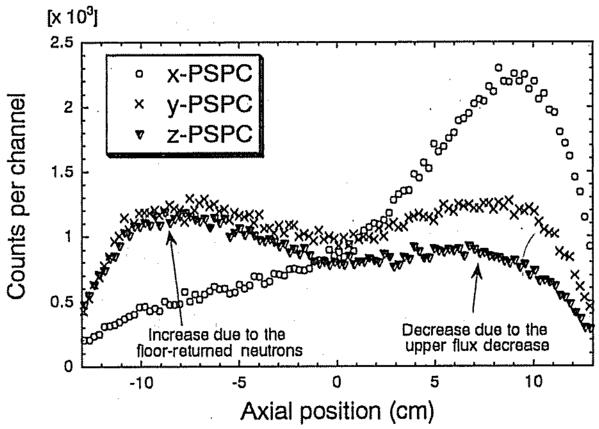

Fig. 6 Detection position profiles with the X-, Y-, and Z-PSPCs for the neutrons from the Am-Be source in the moderated-neutron field of JAERI.

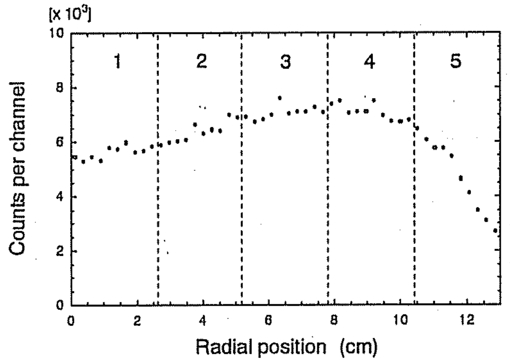

Fig. 7 Radial position profile calculated from the axial position profiles shown in fig. 6. The numbers in the figure indicate the position bins.

the mean count rate for each of the spheres obtained with the measurement.

V Results and Discussion

Figure 8 shows the measured spectra of the neutron fluence obtained by an unfolding process with the ESPHENEC and the BSS. Both spectra were calculated with the SAND-II using the same initial guess spectrum. The initial guess spectrum was a calculated one with the MCNP-4A. The fluence spectra were divided into 20 energy bins whose energy structure was shown in Table 2. The upper and the lower end of the energy range were 15 MeV and 10^{-4} eV, respectively. Figure 9 shows the same spectra in the energy range from 10 keV to 15 MeV and the fluence spectrum of the neutrons directly incident from the Am-Be neutron source. The spectrum was given by ISO Standards 8529. The integral fluence rate, the fraction of thermal neutrons (~ 0.5 eV) and the ambient dose equivalents, H*(10), measured at the position where the counters were placed are summarized in Table 3.

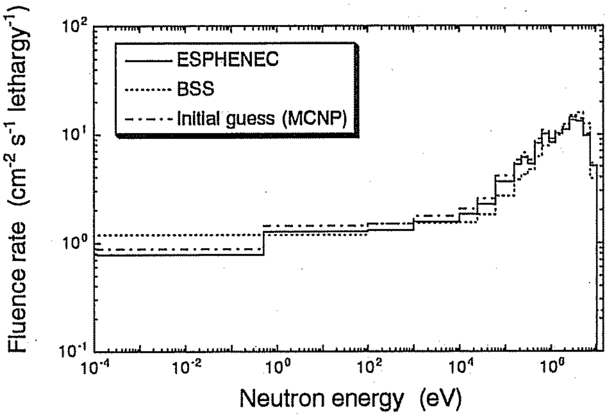

Fig. 8 Neutron fluence spectra obtained with the ESPHENEC (solid line) and the BSS (dotted line) measured for the moderated-neutron field of JAERI. The chain line shows the initial guess spectrum calculated with the MCNP-4A.

It is considered that the energies of the incident neutrons from (1,0,0) direction are high, on an average, while those of the room-scattered neutrons from other directions are relatively low. Such a directional dependency of the fluence spectra would make the unfolded spectrum with the ESPHENEC a little bit different from that of the true spectrum, because the response function is slightly directional [3].

In this experiment, the set of the response functions of the ESPHENEC used for the spectrum unfolding was calculated for the point source geometry whose direction cosine is (1,0,0). The source geometry does not match the experimental conditions, completely, because it is difficult to obtain the directional information on the fluence spectrum of the incident neutrons. If the information was obtained, an appropriate response functions

Table 1

Response of the Bonner spheres.

Thickness (cm)	Count rate (s^{-1})
0 (bare)	13.69 ± 0.08
1	11.59 ± 0.07
2	33.22 ± 0.19
3	53.85 ± 0.30
4	67.06 ± 0.33
6	71.84 ± 0.42
8	62.77 ± 0.37
10	51.40 ± 0.25
14	30.35 ± 0.18

Table 2

The energy structure for the energy spectra.

Bin	Upper energy (eV)	Bin	Upper energy (eV)
1	1.500e+07	11	4.458e+05
2	1.055e+07	12	3.136e+05
3	7.425e+06	13	2.207e+05
4	5.224e+06	14	1.553e+05
5	3.675e+06	15	6.223e+04
6	2.586e+06	16	2.495e+04
7	1.819e+06	17	1.000e+04
8	1.280e+06	18	1.000e+03
9	9.006e+05	19	1.000e+02
10	6.331e+05	20	5.000e-01

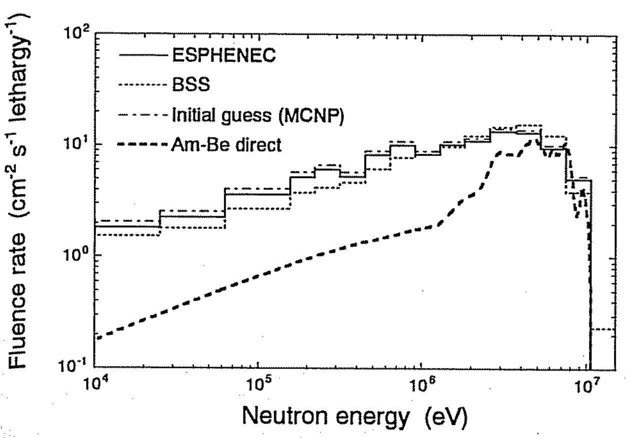

Fig. 9 The same spectra shown in fig. 8, and the energy spectrum for the Am-Be neutron source (thick broken line).

Table 3

Experimental results with the ESPHENEC and BSS.

Measured system	Total fluence rate (cm^{-2} s^{-1})	Below 0.5 eV (%)	Dose equivalent H*(10) (μSv h^{-1})
ESPHENEC	64.1	11.2	45.9
BSS	66.4	15.3	47.9
Calculation [a]	70.3	11.5	49.0

(a. calculated with the MCNP-4A)

used for an unfolding process with which the fluence spectrum that is close to the true spectrum would be obtained. One of the methods to obtain the directional information is a Monte Carlo calculation of the relation between the energy and the direction of the incident neutrons. The method seems impractical, however, for the use of the ESPHENEC in various neutron fields even if the source geometry is known, because it requires a long time to evaluate the fluence spectrum. It is still under consideration to seek a general way of deciding the response functions used for spectrum unfolding processes in various source geometries, in relation to the directional characteristics of the ESPHENEC.

The ESPHENEC gave an overestimation of the neutron fluence in the energy range from about 10 keV to 1 MeV, and an underestimation in the thermal energy region, compared to the BSS. The integral fluence rate measured with the ESPHENEC was 91.2 % and 96.4 % of the calculated one with the MCNP-4A [7] and the experimental one with the BSS, respectively. The difference of the measured energy spectrum obtained with the ESPHENEC and that with the BSS, and the discrepancy of the integral fluence rate of the ESPHENEC are due to the directional dependency of the response functions of the ESPHENEC. The experimental results would somewhat change, if we use the other source geometries, energy structures, and the position binnings for the response calculation of the ESPHENEC. It is necessary to further improve the response functions of the ESPHENEC.

VI. CONCLUSIONS

The performance of the ESPHENEC was examined at the moderated-neutron field of JAERI. The neutron fluence spectrum measured with the ESPHENEC was compared with that obtained with the BSS. The ESPHENEC gave an overestimation of the neutron fluence in the energy range from about 10 keV to 1 MeV, and an underestimation in the thermal energy region (~ 0.5 eV), compared to the BSS. The integral fluence rate measured with the ESPHENEC was 91.2 % and 96.4 % of the calculated one with the MCNP-4A and the experimental one with the BSS, respectively. The difference of the measured energy spectrum obtained with the ESPHENEC and that with the BSS, and the discrepancy of the integral fluence rate of the ESPHENEC are mainly due to the directional dependency of the response functions of the ESPHENEC. It is necessary to further improve the response functions of the ESPHENEC for the practical use in various neutron fields. The optimization of the energy structure and the position binning to give the best energy resolution must be done, together with a study of the directional dependency of the counter performance that affects the measured energy spectra.

VII. ACKNOWLEDGMENT

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