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Characteristic Investigation of Unfolded Neutron Spectra with Different Priori Information and Gamma Radiation Interference

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1. Introduction

Neutron field spectrometry using multi spheres such as Bonner Spheres (BS) has been almost essential in radiation protection dosimetry for a long time at workplace[1] in spite of poor energy resolution because it is not asking the fine energy resolution but requiring easy operation and measurement performance over a wide range of energy interested.

KAERI has developed and used extended BS system based on a LiI(Eu) scintillator as the representative neutron spectrometry system[2,3] for workplace monitoring as well as for the quantification of neutron calibration fields such as those recommended by ISO 8529. Major topics in using BS are how close the unfolded spectra is the real one and to minimize the interference of gamma radiation in neutron/gamma mixed fields in case of active instrument such as a BS with a LiI(Eu) scintillator. The former is related with choosing a priori information when unfolding the measured data and the latter is depend on how to discriminate it in intense gamma radiation fields.

Influence of a priori information in unfolding and effect of counting loss due to pile-up of signals for the KAERI BS system were investigated analyzing the spectral measurement results of Scattered Neutron Calibration Fields (SNCF).[3]

2. Methods and Results

2.1 Design of Analysis Tools

Among four kinds of KAERI's BS system an active BS based a LiI(Eu) scintillator was implemented in this investigation using the simulated priori information for unfolding and the effect of counting loss due to intense gamma/neutron mixed radiation fields which were constructed using AmBe neutron source of 3 Ci and ^{137}Cs gamma source of 100 Ci at the irradiation room of KAERI.

Three kinds of different spectra as a priori information for the neutron field to be measured were made using the continuous function that consists of thermal neutron peak, intermediate neutron and fission neutron peak of ^{252}Cf source. The magnitudes of two peaks in the default spectrum were fit to three kinds of the ratio of the thermal to the fission peak as 1 to 3, 1 to 1 and 3 to 1. The measurement data of five SNCFs and three kinds of simulated spectra were input for unfolding separately. Followings are the analytic functions of three kinds of neutron sources and finally summed together to get simulated input spectra for unfolding.

$$\textit{Thermal peak} : const \cdot \left(\frac{E}{b}\right)^2 \cdot \exp\left(-\frac{E}{b}\right)$$

$$\textit{Fission peak} : const \cdot \frac{1}{b}(E)^{3/2} \cdot \exp\left(-\frac{3E}{2b}\right), \textit{ and Intermediate neutron} :$$

$$const \cdot \left[a + b \cdot (9 + \log E) \cdot \left(1 - \tanh\left(f \cdot \log\frac{E}{d}\right)\right) \cdot \left(1 + \tanh\left(e \cdot \log\frac{E}{c}\right)\right)\right]$$

The gamma radiation with the exposure rate of 1, 10, 15 Rh^{-1} was delivered to each BS, the conventional BSs and new extended BSs, with AmBe neutron source. The change in total counts with and without AmBe source was monitored to calculate the fractional counting loss with the gamma exposure rate and plotted in Fig. 1. According to the fractional counting loss, the measurement data of BS consisting of the PE spheres only to the five kinds of SNCFs were corrected and input to the unfolding code.

The unfolded spectra for all cases above were compared with the reference results obtained from the original extended BS (captioned as normal hereinafter) and all unfolding of measurement data were performed using the MXD_FC31 code developed at EML.[4]

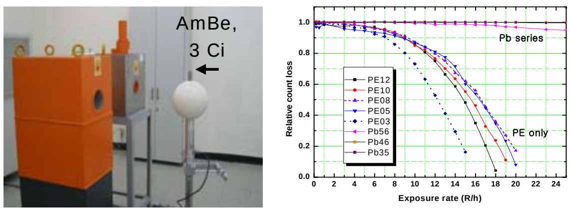

Fig.1 Normal BS irradiated in gamma/neutron mixed field (left) and relative counting loss with the gamma exposure rate (right).

2.2 Influence of a priori information in unfolding

According to Table 1 the biggest difference between the use of input spectra (for normal case) calculated using the MCNPX code[5] and the simulated one was found in case of [C] and [E], which contain more neutrons of low energy relative to the high energy of fission neutron source due to the heavy shielding, to be 35 % in the fluence average energy (E_{ave}), 19 % in the neutron fluence to dose equivalent conversion factor (h^*) and 20 % in the dose equivalent (DE) rate respectively. It comes mainly from the relatively small quantity of intermediate neutron in the default spectra when the simulated default spectrum was used in case of measurement [C]. Except for the extreme case of [C] the integral quantity of dose equivalent was not changed within 5 % but E_{ave} and h^* had big difference in the maximum of 20 % and 27 % respectively.

As expected already the best result of within 2 % difference was in the case of [A] using the spectra DS_01 similar to that calculated using the MCNPX code. It means that it needs to prepare good input spectrum as a priori information and it is possible to make and to use an appropriate input spectrum considering the characteristics of neutron field and the result of similar measurement by a reliable method without any calculation. The unfolding using input spectra consisting of several analogous functions as done in this paper can be performed reasonably if a little discrepancy in the results would be acceptable instead of having the calculation difficulties.

Table 1. Comparison of the dosimetric quantities of unfolded spectra using the different default spectra as a priori information for unfolding.

SNCF	Classifi -cation	Default spectrum	Eave (MeV)	h*(10) ($pSv.cm^2$)	DE rate (mSv/h)
[A]	^{252}Cf	Normal DS_01 DS_02 DS_03	1.84 1.87 1.65 1.51	308 304 285 283	1.22 1.20 1.16 1.16
[B]	^{252}Cf + PMMA	Normal DS_01 DS_02 DS_03	0.55 0.70 0.62 0.52	123 147 128 117	0.22 0.22 0.22 0.22
[C]	D_2O modera ted ^{252}Cf	Normal DS_01 DS_02 DS_03	0.49 0.48 0.38 0.32	91 108 93 79	0.30 0.36 0.36 0.35
[D]	AmBe	Normal DS_01 DS_02 DS_03	4.23 3.05 2.97 2.87	366 374 370 370	0.37 0.35 0.35 0.35
[E]	^{252}Cf (behind wall)	Normal DS_01 DS_02 DS_03	0.25 0.33 0.29 0.23	79 100 85 76	0.03 0.03 0.03 0.03

2.3 Effect of gamma radiation on the unfolded spectra

According to Table 2 the effects of gamma interference in measurement do not appear severe below 10 Rh^{-1}, but there is unrealistic behavior and severe oscillation in the unfolded spectra at the exposure rate of 15 Rh^{-1}. If an extended BS is used to measure the neutron fluence spectra in the intense gamma radiation field, at least, of the exposure rate of 15 Rh^{-1}, which is based on this measurement, there is no changes and loss both in the spectral information and the integral quantities of E_{ave}, $h^*(10)$ and DE rate. This is one of the advantages in use of an extended BS especially the LiI(Eu) based BSs with a lead shell.

The examples of spectral changes mentioned above are shown in Fig. 2.

3. Conclusion

Unfolding is a process of inference to get to the best solution because there can be many solutions to fit the finite numbers of measurement data like as in case of the BS spectrometry. It means that the BS measurement data and a prior information are very important as well as the unfolding code. The relatively big uncertainty and ambiguity in the unfolded spectra can not be avoided but fortunately the integral quantities such as the dose equivalent or fluence mean energy is not changed so much, within 5 to 10 % on the whole region of interest of neutron energy.

The extended BS of KAERI with a lead shell only can be an alternative instrument without any distortion in lieu of the conventional BS with PE spheres in the intense photon fields at the exposure rate of about 25 Rh^{-1} according to the experimental results in this work. An extended BS set can be implemented to measure neutrons selectively according to the amount of gamma radiation in the workplace.

Table 2. Changes of dosimetric quantities due to the counting loss of the BS with PE spheres only.

SNCF	Classifi -cation	Exposure rate	Eave (MeV)	h*(10) ($pSv.cm^2$)	DE rate (mSv/h)
[A]	^{252}Cf	Normal 1 R/h 10 R/h 15 R/h	1.84 1.80 1.71 1.97	308 307 320 421	1.22 1.21 1.05 1.03
[B]	^{252}Cf + PMMA	Normal 1 R/h 10 R/h 15 R/h	0.55 0.52 0.58 0.79	123 119 137 279	0.22 0.21 0.20 0.15
[C]	D_2O modera ted ^{252}Cf	Normal 1 R/h 10 R/h 15 R/h	0.49 0.47 0.47 0.55	91 92 106 262	0.30 0.31 0.30 0.34
[D]	AmBe	Normal 1 R/h 10 R/h 15 R/h	4.23 4.22 4.28 2.53	366 368 379 418	0.37 0.37 0.33 0.17
[E]	^{252}Cf (behind wall)	Normal 1 R/h 10 R/h 15 R/h	0.25 0.26 0.28 0.43	77 69 84 168	3.2×10^{-3} 3.0×10^{-3} 2.7×10^{-3} 2.0×10^{-3}

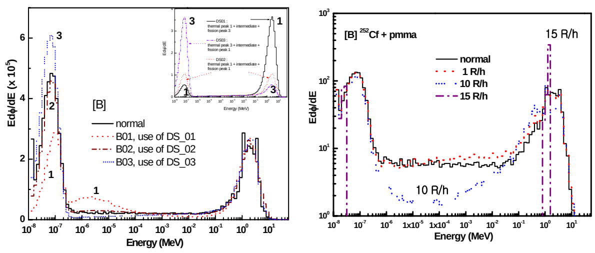

Fig. 2. Unfolded spectra with different input spectra (extended and conventional BS, left) and with gamma exposure rate (conventional BS, right)

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