http://dx.doi.org/10.5516/NET.08.2013.029

<Technical Note>

SPECTRUM WEIGHTED RESPONSES OF SEVERAL DETECTORS IN MIXED FIELDS OF FAST AND THERMAL NEUTRONS

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Received April 01, 2013
Accepted for Publication September 25, 2013

The spectrum weighted responses of various detectors were calculated to provide guidance on the proper selection and use of survey instruments on the basis of their energy response characteristics on the neutron fields. To yield the spectrum weighted response, the detector response functions of 17 neutron-measuring devices were numerically folded with each of the produced calibration neutron spectra through the in-house developed software 'K-SWR'. The detectors' response functions were taken from the IAEA Technical Reports Series No. 403 (TRS-403). The reference neutron fields of 21 kinds with 2 spectra groups with different proportions of thermal and fast neutrons have been produced using neutrons from the ^{241}Am-Be sources held in a graphite pile, a bare ^{241}Am-Be source, and a DT neutron generator. Fluence-average energy (E_{ave}) varied from 3.8 MeV to 16.9 MeV, and the ambient-dose-equivalent rate [$H^*(10)$/h] varied from 0.99 to 16.5 mSv/h.

KEYWORDS : Spectrum Weighted Response, Response of Neutron Survey meter, IAEA Technical Reports Series 403, Reference neutron Field, DT Neutron Generator, Bonner Sphere Spectrometer, Fast Neutron Field

1. INTRODUCTION

The number of neutron generating facilities and industrial applications of radiation with fast neutrons, has continued to increase for several decades. Such facilities and applications include particle accelerators, reactors, source storage facilities and neutron generators. These types and forms of facilities are becoming more varied owing to an expansion of the industrial and medical radiation. A need for a technology to measure and evaluate fast neutron fields has appeared because human beings are exposed to them more often than before. To evaluate the operational quantity of radiation in these various workplaces, an experimental method using proper detectors is generally used. For the use of a neutron detector depending heavily on the neutron energy distribution, it is very difficult to measure exactly the operational quantity of a neutron field, because most of the facilities to be monitored have wide neutron spectra from thermal neutrons to a few MeV neutrons. The best way to reduce this measurement uncertainty is to calibrate the neutron-measuring devices using a simulated workplace neutron field (SWNF), which is similar to a real neutron fields as described by ISO-12789 [1].

The International Organization for Standardization (ISO) recommends that neutrons fields that calibrate neutron devices such as the neutron survey meter and thermoluminescence dosimeters (TLDs) are obtained from radionuclide sources (including neutrons sources in a moderator), mono-energetic neutrons produced by nuclear reactions in charge particle accelerators, and neutrons with wide or quasi-mono-energetic spectra from reactors [2]. Reference neutron fields with various spectra shape and mean energy have been constructed using the several neutron sources mentioned above. If we know the responses of the neutron detector considering the neutron fields similar to a work-space, the neutron ambient dose in various positions with different neutron spectra can be evaluated easily and quickly. Such a response of the detector, considering the neutron field, is called the spectrum weighted response (SWR). The SWRs of several detectors were calculated to provide guidance on the proper selection and use of the neutron detector on the basis of their energy response characteristics on the neutron fields. International Atomic Energy Agency (IAEA) Technical Reports Series No. 403 (TRS-403) provides the aforementioned neutron detectors' SWRs on various SWNFs produced in many institutes [3].

In the present study, the SWRs concerning the mixed fields of thermal and fast neutrons produced at the Korea Atomic Energy Research Institute (KAERI) were obtained using the response function of the neutron detectors as given in the TRS-403 [3]. In our previous study [4], 5 kinds of reference neutron fields (group 'GB') had been constructed using the radionuclide sources (^{241}Am-Be) and the graphite pile (thermal neutron generator). In continuation with our previous study, 15 kinds of reference neutron fields (group 'GN') have been established using a DT (Deuteron-Tritium) neutron generator instead of the ^{241}Am-Be source in our previous study [4] at KAERI. In view of the increasing use of accelerators leading to the presence of fast neutrons at workplaces, it was decided to study the responses of neutron survey meters in the mixed fields of fast neutrons from a DT neutron generator and thermal neutrons.

2. MATERIAL AND METHODS

The SWRs of five commercial neutron survey meters and two single-moerator-based detectors were calculated concerning the mixed neutron fields of fast and thermal neutrons constructed in this study. There were 'LEAKE' (Leake rem counter type, BF_3 tube) [5], 'A-B-2' (Andderson-Braun type, BF_3 tube) [6], 'NRD2' (Eberline NRD2, USA, BF_3 tube) [6], '2202D' (Studsvik 2202D, Sweden, BF_3 tube) [7], and 'LB6411' (Berthold LB6411, Germany, ^{3}He tube) [8] commercial neutron survey meters. Four single-moderator-based detectors were Bonner sphere (BS) consisting the spherical moderators of 20.3 and 25.4 cm diameter incorporated with a ^{6}LiI scintillator ('LiI-BS8' and 'LiI-BS10') [9] or ^{3}He proportional counter ('3He-BS8' and '3He-BS10') [10]. The SWRs of the aforementioned detectors concerning the constructed neutron calibration fields were obtained using the response functions of the detectors taken from the TRS-403 [3].

2.1 Construction of the Reference Neutron Fields

The calibration neutron fields constructed at KAERI [4] were suitably augmented to study the responses of several commercial neutron survey meters in the mixed field of thermal and fast neutrons of energy above 1 MeV. The thermal neutron field was obtained by using eight ^{241}Am-Be neutron sources in a graphite pile (1.5 m × 1.5 m × 1.5 m) in the neutron calibration room at KAERI. The neutron calibration room has dimensions of 8 m (L) × 6 m (W) × 6 m (H), and the graphite pile was placed in a corner of the room. The graphite blocks were stacked on a steel plate base held at 50 cm above the concrete floor. Eight ^{241}Am-Be sources (~37 GBq each) were loaded equidistantly in a source mounting channel in the graphite pile to create a broad thermal neutron beam at a reference point (Fig. 1) at 50 cm in front of the graphite pile. The ^{241}Am-Be sources formed an octagon circumscribed into a circle with a radius of 15 cm. The total neuron emission rate from these sources was 1.82×10^7 s^{-1}, and the total fluence rate at the reference point was ~1×10^7 cm^{-1} h^{-1}. The fast neutron field was obtained using 14 MeV neutrons from the DT neutron generator (EADS SODERN Genie 16C, France). The total neutron emission rate of the DT neutron generator was ~1×10^8 s^{-1} with the 80 kV applied voltage and 50 μA applied current. The shape of excitation signal was a pulsed shape, and the neutron pulse frequency was ~1 kHz.

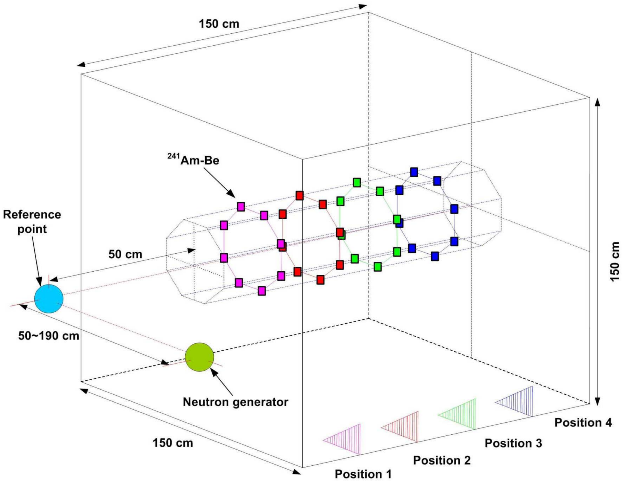

Fig. 1. Schematic Diagram of the Positioning of the Neutron Survey Meter, the Graphite Pile, and DT Neutron Generator. The Reference Point was at 50 cm in Front of the Graphite Pile (150 × 150 × 150 cm^3). The DT Neutron Generator Could be Held to have Distances of 50, 100, 150, and 190 cm between the Target of the DT Generator and Centre of the Survey Meter along the Front Face of the Graphite Pile. Eight ^{241}Am-Be Sources were Placed in 'Position 2' in this Study.

As a result, spectra group 'GB' refers to the thermal neutron field added to fast neutrons from an ^{241}Am-Be source (111 GBq) held at 50, 100, 150, and 200 cm from the reference point for the fields 'GB50', 'GB100', 'GB150', and 'GB200', respectively [4]. The field 'GB00' means that only thermal neutrons were used. Spectra group 'GN' refers to the thermal neutron field added with fast neutrons from the DT neutron generator with different applied current of the DT generator held at 50, 100, 150 and 190 cm from the reference point. The reference point of irradiation was 50 cm from the front-surface of the graphite pile. The Bonner sphere spectrometer (BSS) for the quantification of the reference neutron fields were placed in the reference point (Fig. 1).

2.2 Quantification of the Reference Neutron Fields

The neutron spectra were measured by a ^{6}LiI(Eu) scintillator (Ludlum 42-5, USA) in combination with the BSS which consists of six polyethylene spheres having different diameters (5.1, 7.6, 12.7, 20.3, 25.4, and 30.5 cm).

The energy range of the LiI(Eu) scintillator was thermal to ~12 MeV, and the size of the LiI(Eu) was 4 mm (Ø)×4 mm (H). The Count-rate; net area under a peak of pulse-height spectrum resulting from either the (n, α) reaction in the LiI(Eu) scintillator or the (n, p) reaction in the ^{3}He proportional counter, was acquired from the KAERI's BSS. The statistical uncertainty of the 'Count-rate' in this study was below 1.0% in each measurement. This BSS' data was input into the 'few channel' unfolding program MXD_FC31 (a modification of MAXED) [11-13], which uses the maximum entropy method for a deconvolution of the multi-sphere neutron spectrometer data. The Monte Carlo code MCNPX (ver. 2.5.0) [14] was used for a derivation of priori information for the unfolding in the present work.

The dosimetric properties of the produced neutron spectra are summarized in Table 2. The quantities of the ambient-dose-equivalent conversion coefficient to the neutron fluence [$h^*(10)$], ambient-dose-equivalent rate [$H^*(10)$/h], and fluence-average energy (E_{ave}) were calculated using the ambient-dose-equivalent conversion coefficients [$H^*(10)/\phi$] of ICRU-57 [15]. The fluence-average energy (E_{ave}) varied from 0.09 MeV to 11.0 MeV. Eave is defined as follows: the neutron energy averaged over the spectral neutron fluence,

$$E_{ave} = \frac{1}{\phi}\int_0^\infty E \cdot \phi_E(E)\, dE$$

where ϕ and $\phi_E(E)$ are the total and spectral neutron fluences (energy distribution of the neutron fluence) [16]. While the ambient-dose-equivalent rates [$H^*(10)$/h] varied from 26.1 mSv/h to 7290 mSv/h, and the fluence-to-ambient-dose-equivalent conversion coefficient [$h^*(10)$] varied from 23.5 pSv.cm^2 to 418 pSv.cm^2. $H^*(10)$/h and $h^*(10)$ are defined as follows:

$$H^*(10)/h = \frac{1}{\Delta t}\int_0^\infty h_\phi(E) \cdot \phi_E(E)\, dE\,,$$

$$h^*(10) = \frac{1}{\phi}\int_0^\infty h_\phi(E) \cdot \phi_E(E)\, dE$$

where Δt and $h_\phi(E)$ are the elapsed time and ambient-dose-equivalent conversion coefficient per unit neutron fluence in unit of Sv.cm^2 for monoenergetic neutrons incident on the ICRU sphere [15].

2.3 Calculation of the Spectrum Weighted Response (SWR)

The 'K-SWR' program written in FORTRAN language was developed to calculate the SWRs of the neutron measurement devices concerning the constructed reference neutron fields in our previous study [17]. The 'K-SWR' calculated the detector's SWRs on the reconstructed neutron spectra. The detector's SWRs were taken by the superposition of the response function and neutron spectra, which were obtained from the TRS-403 and BSS, respectively. Also, the 'K-SWR' reconstructed the energy intervals of the neutron spectra. The neutron spectra of the reference neutron fields obtained from the BSS had 281 energy intervals from 1 meV to 100 GeV. The response functions of the TRS-403 had 61 energy intervals from 1 meV to 630 MeV [3]. Two data sets could not be used coincidently because those energy intervals were different from each other. For this purpose, the measured neutron spectra with 281 energy intervals were reconstructed to correspond with 61 energy intervals of the TRS-403.

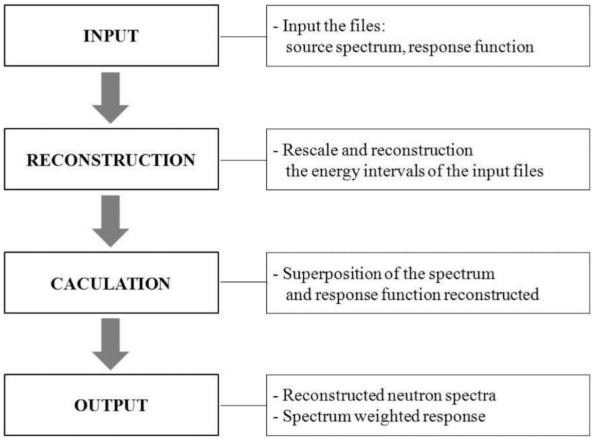

Fig. 2. Flow Chart of the Program 'K-SWR' to Calculate the Spectrum Weighted Response (SWR) of the Detector and to Reconstruct the Energy Intervals of the Neutron Spectra.

As shown in Fig. 2, the 'K-SWR' consists of four parts: 'INPUT', 'RECONSTRUCTION', 'CALCULATION', and 'OUTPUT'. In the 'INPUT' part, the 'K-SWR' reads the spectrum and detector response functions, and names the output file name. In the 'RECONSTRUCTION' part, the energy bins of the neutron spectrum are rescaled to match the interval, owing to the fact that two data sets (BSS and TRS-403 data) could not be used coincidently because their energy intervals were different from each other; the measured neutron spectra (BSS data) and response functions (TRS-403 data) had 281 and 61 energy intervals, respectively. The 'CALCULATION' part calculates the SWRs by the superposition of the reconstructed neutron spectra and response functions imported from the TRS-403. The group fluence (ϕ_g) and SWR ($\bar{R}$) in an energy interval (E_i–E_{i+1}) were defined as follows [16]:

$$\phi_g = \int_{E_i}^{E_{i+1}} \phi_E(E)\, dE \;\;,\;\; \bar{R} = \frac{1}{\phi}\sum_g R_g \phi_g\,,$$

where ϕ and ϕ_g are the total neutron fluence and group fluence in an energy interval (E_i–E_{i+1}). R_g is the group response functions of the detector [3].

The validity of the energy interval reconstruction was proven using the SWRs of the BSS of ten kinds incorporated with a LiI(Eu) scintillator or ^{3}He proportional counter in a previous study [17]. The SWRs of the BSS on the bare ^{252}Cf source were obtained using the response functions taken by the MCNPX calculation. The original SWRs ('KAERI-A' in Table 1) were calculated using the response functions (281 energy intervals), and the modified SWRs ('KAERI-B' in Table 1) were calculated using the response functions (61 energy intervals) reconstructed through the 'K-SWR' program. The 'TRS403' in Table 1 were calculated using the response functions of the TRS-403 [3]. The SWRs obtained from the original data ('KAERI-A', 281 energy intervals) and reconstructed data ('KAERI-B', 61 energy intervals) were in good agreement within 0.1% (0.999 < 'KAERI-A' / 'KAERI-B' < 1.001) as shown in Table 1.

3. RESULTS AND DISCUSSION

The reference neutron fields were constructed by changing the position of the DT neutron generator and the ^{241}Am-Be neutron source at KAERI (Table 2). In spectra group 'GB' (Fig. 3), the numeric values (50, 100, 150, and 200) of the notations indicate the distance (cm) between the additional ^{241}Am-Be source and the reference point, and spectrum 'GB00' means the thermal neutron field only [4]. In spectra group 'GN' (Figs. 4 and 5), the first numeric values (50, 100, 150, and 190) of the notations represent the distance (cm) between the target of the DT neutron generator and the reference point, and the second numeric values (5, 10, and 50) indicate the applied current (μA) of the DT generator. For example, 'GN190_5' means a 190 cm target distance and 5 μA applied current. The applied voltage of the DT generator for spectra group

Table 1. Comparison of the SWRs of the BSS Obtained Using Three Response Functions, MCNPX Data (A), Reconstructed MCNPX Data (B), and TRS-403 Data (C)

Detector [a]	Spectrum weighted response, SWR (cm^2)			Ratio	
	KAERI-A (A)	KAERI-B (B)	TRS403 (C)	A/B	B/C
LiI + BS 3˝	6.211	6.213	5.379	1.000	1.155
LiI + BS 5˝	1.985	1.985	1.843	1.000	1.077
LiI + BS 8˝	2.436	2.436	2.200	1.000	1.107
LiI + BS 10˝	1.614	1.615	1.723	0.999	0.937
LiI + BS 12˝	1.043	1.043	1.206	1.000	0.865
3He + BS 3˝	3.227	3.228	3.089	1.000	1.045
3He + BS 5˝	1.776	1.777	1.661	0.999	1.070
3He + BS 8˝	2.466	2.466	2.298	1.000	1.073
3He + BS 10˝	2.039	2.039	1.861	1.000	1.096
3He + BS 12˝	1.443	1.442	1.315	1.001	1.097

[a] The numeric values (2˝, 3˝, 5˝, 8˝, 10˝, and 12˝) represent the diameter (inch) of the Bonner sphers.

Table 2. Details of the Reference Neutron Fields for the Measurement of the SWR of a Neutron Detectors

Group	Neutron field	Neutron source	Location and features
GB	GB00	Thermal neutrons	- Thermal neutrons + fast neutrons (^{241}Am-Be) - Position of ^{241}Am-Be: 50, 100, 150, and 200 cm from the graphite pile face.
	GB50, GB100, GB150, GB200	Thermal neutrons + ^{241}Am-Be	
GN	GN50_5, GN100_5 GN150_5, GN190_5	Thermal neutrons + 14 MeV neutrons (DT generator)	- DT tube's applied current: 5, 10, and 50 μA - DT tube's position : 50, 100, 150, and 190 cm from the reference point
	GN50_10, GN100_10 GN150_10, N190_10		
	GN50_50, GN100_50 GN150_50, N190_50		

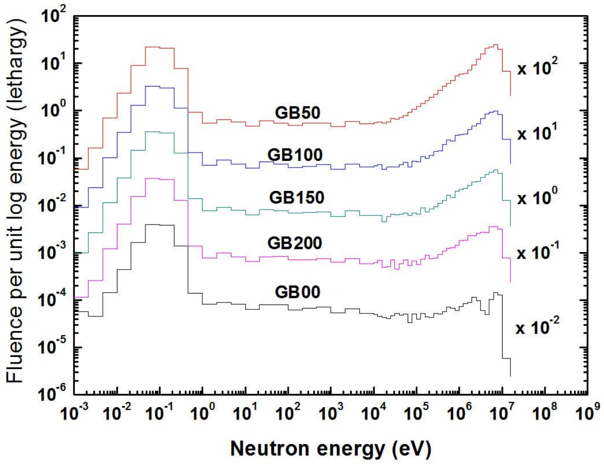

Fig. 3. Neutron Fluence Spectra Produced by Eight ^{241}Am-Be Sources Held in Graphite Pile and Additional ^{241}Am-Be Source at KAERI. The Numeric Values ('50', '100', '150', and '200') in the Notations of Spectrum Name Mean the Distance (cm) between the Additional ^{241}Am-Be Source and Reference Point. 'GB00' Means the Thermal Neutron Field Only.

'GN' was 80 kV, and the applied current was changed by 5, 10, and 50 μA. As shown in Fig. 5, the fluence of fast neutrons (> 100 keV) was in proportion to the applied current of the DT generator. The neutron spectra in the 10 and 50 μA applied current were omitted because it was similar with the spectra of the 5 μA applied current.

Table 3 gives the spectral characteristics (percentage to total fluence rate in different energy ranges) of the reference neutron fields, which were obtained by the unfolding process for neutron energy ranges: < 0.1 MeV, 0.1 MeV–10 MeV, and > 10MeV. For the same spectra group (Table 3), the percentage of the fluence for thermal and intermediate neutrons (< 0.1 MeV) increased with a decrease in the fluence-average energy (E_{ave}); in contrast, the percentage of the fluence for fast neutrons (> 0.1 MeV) decreased. E_{ave} varied from ~90 KeV to 11.0 MeV. The ambient-dose-equivalent rates [$H^{*}(10)/h$], and fluence-to-ambient-dose-equivalent conversion coefficient [$h^{*}(10)$] obtained using the conversion coefficients of ICRU-57 [15]. $h^{*}(10)$ varied from 24 to 418 pSv.cm^{2}, and $H^{*}(10)/h$ varied from 26 to 7290 mSv/h.

Table 3. Spectral Characteristics (Percentage to Total Fluence) and Dosimetric Quantities of the Reference Neutron Fields Measured by Using the Bonner Sphere System

Neutron Field	Percentage to total fluence rate (%)			E_{ave} [a] (MeV)	$h^{*}(10)$ [b] (pSv.cm^{2})	$H^{*}(10)/h$ [c] (μSv.h^{-1})
	< 0.1 MeV	0.1 MeV –10 MeV	> 10 MeV			
GB50	57	40	3.0	2.04	184	417
GB100	80	18	1.5	0.99	94	143
GB150	88	11	0.7	0.49	63	84
GB200	91	8.2	0.5	0.33	49	63
GB00	97	3.3	0.0	0.09	24	26
GN50_5	45	12	42	7.18	279	707
GN100_5	72	9.4	18	3.34	148	218
GN150_5	83	7.0	9.6	1.78	94	130
GN190_5	88	6.1	6.4	1.28	73	94
GN50_10	31	15	53	8.87	340	1370
GN100_10	59	13	28	4.91	206	400
GN150_10	74	9.5	16	2.66	131	226
GN190_10	81	8.2	11	1.89	103	159
GN50_50	20	18	62	11.0	418	7290
GN100_50	42	17	51	8.14	328	2080
GN150_50	59	14	28	6.16	257	990
GN190_50	67	12	21	4.80	213	656

[a] E_{ave}: fluence-average energy.

[b] $h^{*}(10)$: fluence-to-ambient-dose-equivalent conversion coefficient.

[c] $H^{*}(10)/h$: ambient-dose-equivalent rate.

Most of the spectra had almost the same spectrum shape under a neutron energy of 1 keV, because of the same thermal neutron source (graphite pile with ^{241}Am-Be sources), but over 1 keV, had different spectrum shapes because of the different fast neutron sources (^{241}Am-Be and DT neutron generator with different tube current). There were some fast neutrons even in the 'GB00' configuration (Table 3 and Fig. 3) owing to neutrons from the ^{241}Am-Be sources, which have not been fully moderated and contributed to the fast neutron component. In the spectra group 'GN' (Figs. 4 and 5), the fluence of fast neutron (> 0.1 MeV) increased with an increase of the applied current of the DT neutron generator. The overlapped peaks at 14 MeV in the neutron spectra were due to un-attenuated 14 MeV neutrons from the DT neutron generator (Figs. 4 and 5).

The 'K-SWR' program calculated the SWRs from the 9 kinds of detectors on the constructed reference neutron fields of 17 kinds (Table 3). The type of detectors was Bonner sphere and commercial survey meter type. The Bonner sphere types ('LiI-BS8', 'LiI-BS10', '3He-BS8', and '3He-BS10') consisted of a polyethylene moderator (diameter of 8 and 10 inches) and detecting element (LiI(Eu) scintillator and ^{3}He proportional counter). The commercial neutron survey meters, which were generally

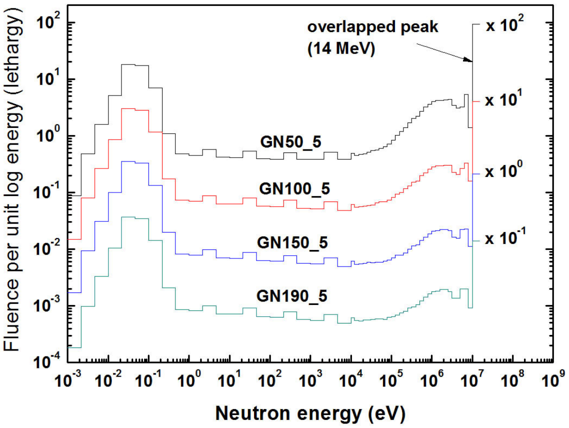

Fig. 4. Neutron Fluence Spectra 'GB**_5' Produced by Eight ^{241}Am-Be Sources Held in Graphite Pile and the DT Neutron Generator. The First Numeric Values (**) in the Notations Represent the Distance (50, 100, 150, and 190 cm) between the Target of the DT Neutron Generator and Reference Point, and the Second Numeric Value '5' Indicate the Applied Current (5 μA) of the DT Generator.

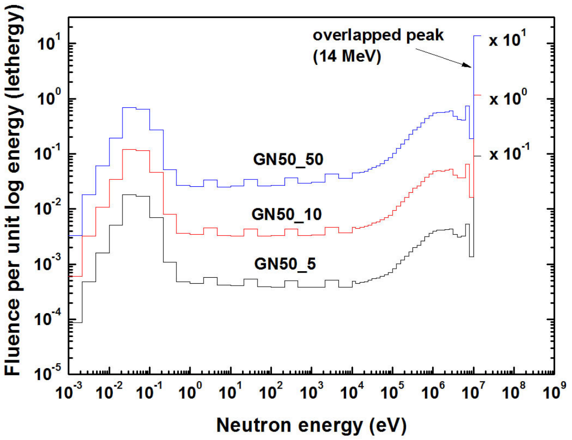

Fig. 5. Neutron Fluence Spectra 'GB50_**' Produced by Eight ^{241}Am-Be Sources Held in Graphite Pile and the DT Neutron Generator. The Second Numeric Values (**) in the Notations Represent the Applied Current (5, 10, and 50 μA) of the DT Neutron Generator, and the First Numeric Value '50' Indicate the Distance (50 cm) between the Target of the DT Neutron Generator and Reference Point

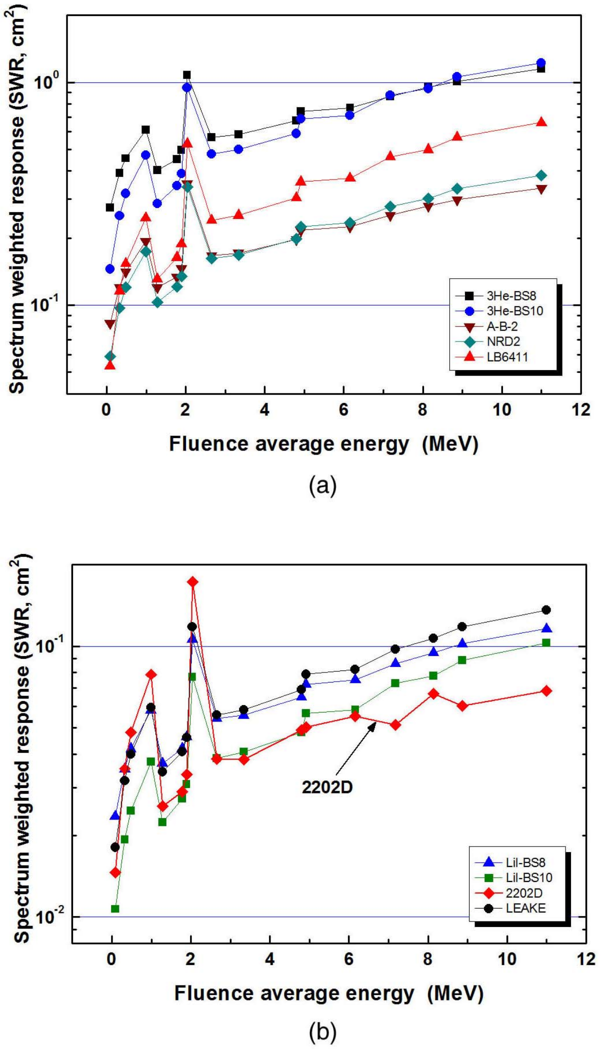

Fig. 6. (a) Spectrum Weighted Response (SWR, cm^2) of Several Neutron Detectors ('3He-BS8', '3He-BS10', 'A-B-2', 'NRD2', and 'LB6411'), and (b) the SWR of Several Neutron Detectors ('LiI-BS8', 'LiI-BS10', '2202D', and 'LEAKE') Corresponding to the Neutron Fluence-average Energy of the Reference Neutron Fields.

used in neutron measurement, were ‘LEAKE’, ‘A-B-2’, ‘NRD2’, ‘2202D’, and ‘LB6411’. As shown in Table 4 and Fig. 6, most detectors had an under-response (SWR < 1) on mixed neutron fields of fast and thermal neutrons. There was also an increase of the SWR with the increasing fluence-average energy of the reference neutron field. This means that those detectors are more suitable for high neutron energy ranges (> 0.1 MeV) than for low energy ranges (< 0.1 MeV). The SWRs had a big difference, up to more than 17 fold (between ‘3He-BS10’ and ‘2202D’ in ‘GN50_50’ field in Table 4). As shown in Fig. 6, ‘3He-BS8’ and ‘‘3He-BS10’ exhibited the highest SWRs (0.1-1 cm^2) for the constructed neutron fields; in contrast, ‘LiI-BS8’, ‘LiI-BS10’, and ‘LEAKE’ exhibited the SWRs under ~0.1 cm^2. The response (SWR) of the detectors with a ^{3}He counter was relatively high, and the detector with the BF_3 counter showed a relative low response (SWR). Fig. 7 showed the percentage to total neutron fluence rate for the fast neutron energy ranges (> 100 keV and 100 keV –10 MeV) corresponding to the neutron fluence-average energy of the reference neutron fields. When comparing Fig. 6 and Fig. 7, the SWRs of most detectors had a similar trend of the percentage of fast neutrons (> 100 keV) to the total fluence, and that of ‘2202D’ was similar to the percentage of fast neutrons (100 keV-10 MeV).

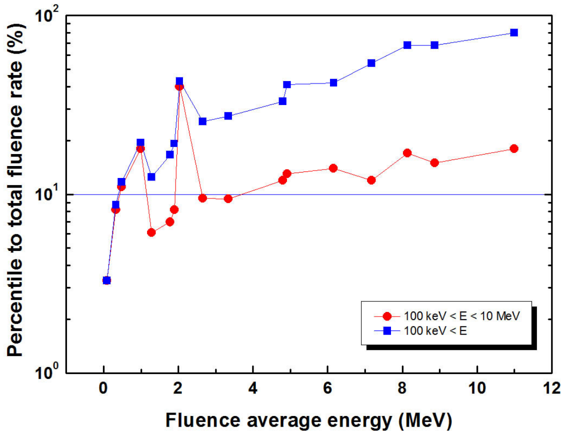

Fig. 7. Percentage of the Neutron Fluence to Total Fluence Rate for the Fast Neutron Energy Ranges (> 100 keV and 100 keV–10 MeV) Corresponding to the Neutron Fluence-average Energy of the Reference Neutron Fields.

Table 4. Spectrum Weighted Responses (SWR) of the Neutron Detectors to the Reference Neutron Fields

Neutron Field	Spectrum weighted response (SWR, ×10^{-2} cm^2)								
	LiI-BS8	LiI-BS10	3He-BS8	3He-BS10	A-B-2	NRD2	2202D	LB6411	LEAKE
GB50	10.6	7.69	108	94.6	35.1	33.9	17.3	53.0	11.8
GB100	5.81	3.75	61.3	47.2	19.3	17.4	7.87	24.7	5.93
GB150	4.19	2.47	45.6	31.7	14.1	12.0	4.81	15.4	3.99
GB200	3.52	1.93	39.1	25.2	12.0	9.71	3.52	11.6	3.18
GB00	2.36	1.07	27.4	14.5	8.30	5.88	1.46	5.32	1.81
GN50_5	8.64	7.29	86.5	87.3	25.3	27.7	5.12	46.3	9.74
GN100_5	5.57	4.08	58.2	50.1	17.1	16.8	3.81	25.3	5.81
GN150_5	4.19	2.73	45.2	34.3	13.4	12.1	2.90	16.4	4.08
GN190_5	3.69	2.24	40.4	28.5	12.0	10.3	2.57	13.1	3.44
GN50_10	10.2	8.88	101	106	29.7	33.3	6.03	56.8	11.8
GN100_10	7.23	5.65	74.0	68.6	21.7	22.5	5.03	35.8	7.88
GN150_10	5.41	3.86	56.8	47.7	16.7	16.2	3.84	24.0	5.58
GN190_10	4.64	3.10	49.6	38.8	14.6	13.5	3.36	18.9	4.61
GN50_50	11.6	10.3	115	122	33.5	38.2	6.86	66.1	13.6
GN100_50	9.47	7.78	95.3	93.7	27.8	30.2	6.67	50.0	10.7
GN150_50	7.52	5.83	77.0	71.0	22.5	23.4	5.50	37.2	8.21
GN190_50	6.49	4.80	67.4	58.9	19.7	19.8	4.90	30.3	6.90

4. CONCLUSIONS

The reference neutron fields were constructed using a thermal neutron generator (graphite pile with ^{241}Am-Be sources) and a DT neutron generator at KAERI. The neutron spectra quantities and dosimetric properties of these neutron fields were measured using a BSS. The SWRs of several neutron detectors were calculated using the 'K-SWR' programmed by KAERI and the response functions of detectors presented by IAEA's 'TRS-403'. As a result, a general type of neutron detector (e.g. '3He-BS8', '3He-BS10', 'LiI-BS8', and 'LiI-BS10') and a commercial neutron survey meter (e.g. 'LB6411', 'A-B-2', 'NRD2', and '2202D') have different responses (SWR) on the several mixed neutron fields of fast and thermal neutrons. Most BS detectors and commercial neutron survey meters had an under-response (SWR < 1 cm2) in the fast neutron fields (> 100 keV). The BS detectors ('3He-BS8' and '3He-BS10') and commercial detector ('LB6411') incorporated with a ^{3}He proportional counter had a high (fast) response (SWR) in the fast neutron fields. Finally, the SWRs presented in the current study could be used to estimate the response of the neutron detectors and to choose a suitable detector in a workplace field of fast neutrons to be monitored.

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