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Establishment of neutron dose calibration fields based on a ^{252}Cf source by Monte-Carlo method

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Abstract: This paper presents calculation results based on Monte-Carlo method to select an appropriate neutron moderator and design four configurations for a ^{252}Cf irradiation system. These configurations provide six neutron spectra with the various average energies (1.04 MeV, 1.38 MeV, 1.69 MeV, 2.05 MeV, 2.46 MeV and 2.93 MeV) suitable for the calibration of neutron survey meters and personal dosimeters.

Keywords: *^{252}Cf irradiation system, Monte-Carlo method, neutron moderator, neutron spectrum, neutron dose calibration.*

I. INTRODUCTION

A neutron dose calibration system with various neutron energy spectra and different dose rates is necessary for every radiation dose calibration laboratory. During 1995 in Vietnam, some researchers tried to make the personal neutron albedo dosimeter, but the result was limited due to the lack of the necessary dose calibration irradiation system [7]. By the 2006, several neutron dose calibration fields based on a neutron source $^{241}Am/Be$ were established at the Nuclear Research Institute and they met in part of the needs for calibrating neutron survey meters and neutron personal dosimeters [8]. In this study, we try to establish different neutron fields based on a ^{252}Cf irradiation system at the Nuclear Research Institute by using Monte – Carlo method.

II. METHOD

A. Technical requirements for a neutron calibration system

Usually, neutron isotopic sources are used for neutron dose calibration. They must meet the following main technical criteria:

- Average energies are in the range from some hundreds of keV to 5 MeV [1,2,4];
- An ambient dose rate equivalent or personal dose rate equivalent is more than some µSv/h for calibration of survey meters and more than tens µSv/h for calibration of personal dosimeters;
- Radiation beam must cover whole detector volume (for the case of survey meter calibration) or whole phantom (in the case of personal dosimeter calibration).

B. ^{252}Cf Irradiation System

The irradiation system consists of a protective container containing 01 ^{252}Cf source inside, an irradiation table and an electromechanical system for opening or closing the source. The system is made by the Vietnam Atomic Energy Institute and placed at the Nuclear Research Institute for educational and researching purposes.

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The source has a diameter of 3.4 mm and height of 3 mm. On January 5th, 2014, it had an activity of 215 MBq and produced neutron intensity of 2.5×10^7 (s^{-1}).

C. Scientific contents to be solved, research methods and necessary means

To achieve the above goals, the following scientific contents are in place to deal with:

- Choice of an appropriate neutron moderator;

- Choice of appropriate calibration positions;

- Choice of moderator positions and its configurations;

- Calculating neutron spectra, neutron average energies, ambient neutron dose equivalents and their uniformity at selected positions with correlative configurations of moderators.

In this work, a MCNP5 simulation code [9] was used. The file INPUT was established on the base of irradiation system parameters and laboratory dimensions.

III. RESULTS AND DISCUSSION

A. Choice of an appropriate neutron moderator

Using suitable moderators can create several neutron spectra with different average energies from a neutron source. Usually, materials like D_2O, C and H_2O are used for slowing down the fast neutrons [2,3,4,6].

In this study, four materials, including D_2O, H_2O, Paraffin and PMMA (Poly Methyl Methacrylate) were chosen as moderator. In the file INPUT, irradiation system parameters and laboratory configurations were considered. The origin of coordinates is set at the source center. Moreover, it is supposed that the rectangular shaped moderator with a cross section of 30×30 cm^2 is set at a distance of 27.5 cm from the source center and is perpendicular with neutron beam axis. The number of histories is 10^7 and the relative error is less than 2%. The surveyed position is on the neutron beam axis and at a distance of 100 cm from the source center. The neutron fluences crossing a 5 cm radius sphere at this position were calculated.

By running MCNP5, we gave neutron fluence spectra and total neutron fluence rate, φ. Then average neutron energies, E_{tb}, were calculated according to the following expression:

$$E_{tb} = \sum_i E_i \times \rho_i \qquad (1)$$

where: E_i and p_i are neutron energy and probability at energy E_i .

Calculation results of φ and E_{tb} are represented in Fig. 1 and Fig. 2. From the calculated results, it can be seen: Neutron slowing down ability of PMMA is similar to the H_2O. With the thickness of more than 20 cm, Paraffin has slowing down ability better than PMMA and H_2O, but it reduces neutron fluence more than other materials. D_2O has the best slowing down ability, but this material is very expensive.

Based on the calculated results and the actual situation, the PMMA was chosen as the moderator for next calculations.

B. Calculation results for the neutron dose calibration system configuration

Calculation results for change of φ and E_{tb} with moderator thickness and its position at a distance of 100 cm (from the neutron source center) are listed in Table I. Results in Table I show that the φ increases with increasing distance from moderator block to the source and φ decreases with increasing moderator thickness. The E_{tb} decreases with increasing distance from moderator block to the source or when the moderator thickness increases. To reduce errors and lower costs in manufacturing the dose calibration system, the PMMA block position is fixed at 27.5 cm (from the neutron source center) and the value is used for next calculations.

Results for the dependence of φ and E_{tb} at the distance of 100 cm (from the neutron source center) on PMMA block thicknesses are presented in Table II. Data in Table II show that there are four appropriate PMMA blocks with thickness of 0 cm, 4 cm, 25 cm and 30 cm. Corresponding to these thicknesses there are four neutron spectra with E_{tb}: 2.46 MeV, 2.93 MeV, 2.05 MeV and 1.69 MeV respectively.

The next studies were performed to determine the dependence of φ, E_{tb} and ambient dose rate equivalent H*(10) on PMMA thickness, irradiated sample position and the uniformity of neutron spectrum. The INPUT file has a similar structure and considers to additional assumptions: PMMA thicknesses are 0, 4, 25 and 30 cm; interested points are on the neutron beam axis at distance 100 and 200 cm; detector material is air and its radius, r, varies in the range from 2 to 12 cm. In all calculations, the number of histories is 10^7, therefore the relative error is less than 2%. Results are presented in Table III - Table V.

The Figure 3 describes the changes in neutron energy spectra with PMMA thicknesses at the positions 100 cm and 200 cm. Calculation results show that:

(1) The total neutron fluence φ and average energy E_{tb} are varied with detector position and PMMA thickness;

(2) The φ is nearly constant in the range of detector radius from 2 cm to 12 cm;

(3) The values E_{tb} in six of eight obtained neutron spectra are separated to each other: 1.04 MeV; 1.38 MeV; 1.69 MeV; 2.05 MeV; 2.46 MeV and 2.93 MeV (see Table 4);

(4) At the positions of interest (100 and 200 cm) and with selected PMMA thickness, the E_{tb}varies a little (no more than 3%) despite of detector radius varies from 2 cm to 12 cm;

(5) Without moderators, the E_{tb} is almost constant in the region of 200 cm from source center (along the neutron beam axis);

(6) The E_{tb} decreases with increasing PMMA thickness and the distance from the source center;

(7) The magnitude of neutron dose rate fluctuates from a few µSv/h to several hundred µSv/h.

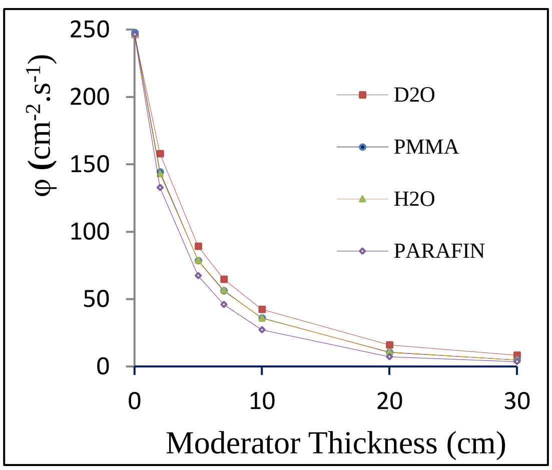

Fig.1. The change of φ vs. Moderator thickness

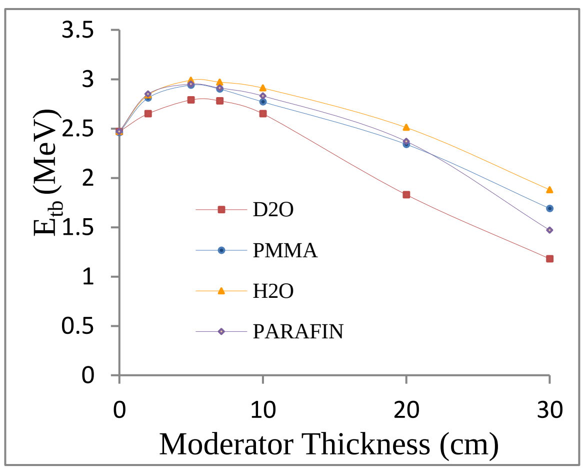

Fig.2. The change of E_{tb} vs. Moderator thickness

Table I. Dependence of φ and E_{tb} on the moderator position and its thickness

Moderator thickness (cm)	PMMA at 27.5 cm		PMMA at 50 cm	
	φ ($cm^{-2}.s^{-1}$)	E_{tb} (MeV)	φ ($cm^{-2}.s^{-1}$)	E_{tb} (MeV)
10	35.00	2.77	47.84	2.42
20	10.50	2.34	16.19	2.00
30	4.79	1.69	7.11	1.53

Table II. Dependence of φ and E_{tb} on the PMMA thickness

PMMA thickness (cm)	φ($cm^{-2}.s^{-1}$)	E_{tb} (MeV)	PMMA thickness (cm)	φ($cm^{-2}.s^{-1}$)	E_{tb} (MeV)
0	247.83	2.46	7	56.20	2.90
1	185.35	2.67	8	47.99	2.87
2	144.37	2.81	10	35.89	2.77
3	115.47	2.89	15	18.35	2.59
4	94.37	2.93	20	10.50	2.34
5	78.48	2.94	25	6.76	2.05
6	66.12	2.92	30	4.78	1.69

Table III. Total neutron fluence rate φat the positions 100 cm and 200 cm.

d (cm)	φ at 100 cm ($cm^{-2}.s^{-1}$)				φ at 200 cm ($cm^{-2}.s^{-1}$)			
	r = 2 cm	r = 5 cm	r = 9 cm	r = 12 cm	r = 2 cm	r = 5 cm	r = 9 cm	r = 12 cm
0	247.98	247.80	248.08	248.08	63.18	63.17	63.20	63.26
4	94.45	94.37	94.49	94.46	24.11	24.10	24.11	24.12
25	6.75	6.76	6.75	6.78	2.64	2.64	2.64	2.65
30	4.79	4.79	4.81	4.82	2.28	2.32	2.28	2.29

Table IV. Average neutron energy E_{tb} at the positions 100 cm and 200 cm.

d (cm)	E_{tb} at 100 cm (MeV)				E_{tb} at 200 cm (MeV)			
	r = 2 cm	r = 5 cm	r = 9 cm	r = 12 cm	r = 2 cm	r = 5 cm	r = 9 cm	r = 12 cm
0	2.46	2.46	2.46	2.46	2.41	2.40	2.41	2.41
4	2.93	2.93	2.93	2.93	2.83	2.83	2.83	2.83
25	2.05	2.05	2.05	2.04	1.38	1.38	1.38	1.37
30	1.68	1.69	1.68	1.68	1.06	1.04	1.06	1.05

Table V. Ambient neutron dose rate equivalent H*(10) at the positions 100 cm and 200 cm.

d (cm)	H*(10) at 100 cm (μSv/h)				H*(10) at 200 cm (μSv/h)			
	r = 2 cm	r = 5 cm	r = 9 cm	r = 12 cm	r = 2 cm	r = 5 cm	r = 9 cm	r = 12 cm
0	333.00	333	333.07	333.11	83.72	84.93	83.76	83.83
4	125.30	125.30	125.30	125.29	31.23	31.23	31.23	31.26
25	5.42	5.42	5.42	5.43	1.82	1.82	1.82	1.82
30	3.46	3.46	3.46	3.47	1.43	1.45	1.43	1.43

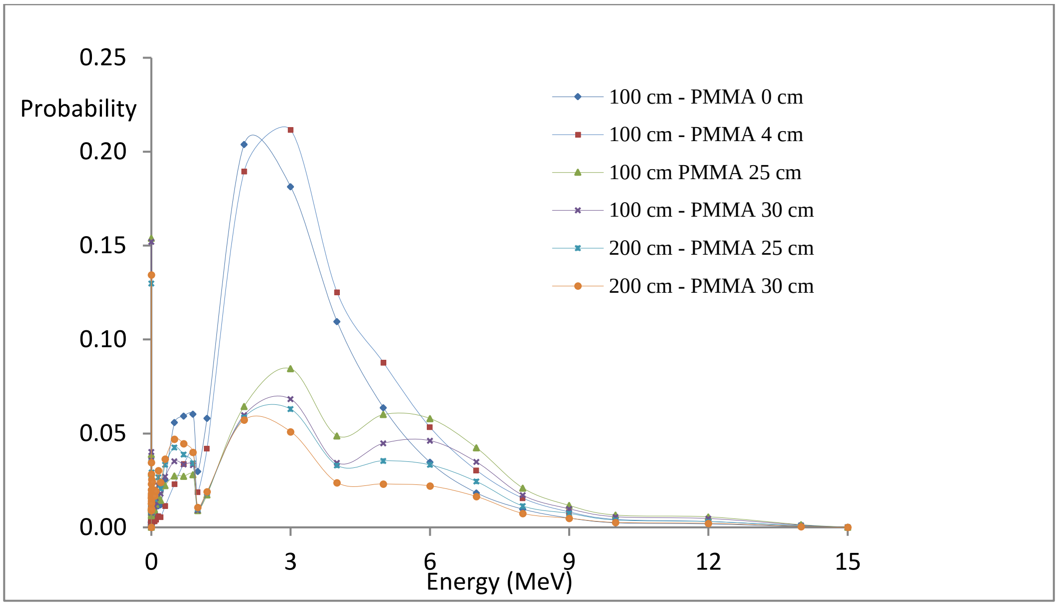

Fig.3. Neutron spectra at positions 100 cm and 200 cm from the source with different thicknesses of the PMMA

IV. CONCLUSION

Research results calculated by using the MCNP5 code show:

(1) The PMMA (Poly Methyl Methacrylate) is a suitable moderator for creating neutron spectra with different energies from a ^{252}Cf original source.

(2) Using PMMA blocks with thicknesses of 0, 4, 25 and 30 cm located on the neutron beam axis at distance of 100 cm and 200 cm from the source center, we can obtain six neutron spectra having separate E_{tb} (1.04 MeV, 1.38 MeV, 1.69 MeV, 2.05 MeV, 2.46 MeV and 2.93 MeV) with equivalent dose rates from 1.5 μSv/h to 333 μSv/h.

(3) The ^{252}Cf irradiation system based on the above configurations is suitable for calibration of neutron survey meters and neutron personal dosimeters.

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