ISSN: 0975-833X

Available online at http://www.journalcra.com

International Journal of Current Research
Vol. 11, Issue, 07, pp.5714-5720, July, 2019

DOI: https://doi.org/10.24941/ijcr.35431.07.2019

INTERNATIONAL JOURNAL OF CURRENT RESEARCH

RESEARCH ARTICLE

STANDARDIZATION OF ^{241}Am-Be NEUTRON RADIATION FIELD TO CHARACTERIZE THE MODERATED (9″) NEUTRON DETECTOR

[1]Shamsuzzaman, M., [1,*]Rahman, M. S., [1]Siddiqua, T., [1]Bhuiyan, M. M. H., [1]Paul, D., [2]Ferdous, J., [2]Chakraborty, S. R. and [2]Deb, A. K.

[1]Secondary Standard Dosimetry Laboratory, Health Physics and Radioactive Waste management Unit, Institute of Nuclear Science and Technology, Bangladesh Atomic Energy Commission, Dhaka, Bangladesh
[2]Department of Physics, Chittagong University, Chittagong, Bangladesh

ARTICLE INFO

Article History:
Received 12th April, 2019
Received in revised form
15th May, 2019
Accepted 20th June, 2019
Published online 31st July, 2019

Key Words:

Remmeter, Calibration, Neutron, Free field dose equivalent, Ambient dose equivalent.

Corresponding author:* **Rahman, M. S.

ABSTRACT

Neutron field of ^{241}Am-Be calibrator was standardized in terms of corrected free field dose equivalent (FFDE) by applying several correction factors. Subsequently, characterization of nine inch moderated neutron remmeters (BF_3 counter) were performed in terms of the standardized neutron field. Several correction factors were determined to standardize the neutron field. The geometrical correction factor, air scattering factor and room scatter factors lie in between 1.004 to 1.018, and 1.004 to 1.044 and 1.0004 to 1.005, respectively at the distances from 0.595 m to 2.0 m. The responses of the neutron remmeters were verified in terms of the corrected FFDE The average response of the neutron remmeters ASP2e/NRD and E600/NRD was found to be 1.0010.162 and 1.0130.164 which meets the ICRP recommendation for area monitoring detectors. The minimum and maximum estimated combined uncertainty for neutron dose measurement was 0.755% *(k=1)* and 2.495% *(k=1)*.

Copyright©2019, Shamsuzzaman et al. *This is an open access article distributed under the Creative Commons Attribution License, which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.*

***Citation: Shamsuzzaman, M., Rahman, M. S., Siddiqua, T., Bhuiyan, M. M. H., Paul, D., Ferdous, J., Chakraborty, S. R. and Deb, A. K.,* 2019.** "Standardization of ^{241}Am-Be neutron radiation field to characterize the moderated (9″) neutron detector", *International Journal of Current Research*, 11, (07), 5714-5720.

INTRODUCTION

In Bangladesh, neutron sources are increasingly being used in various fields such as research, nuclear power development, industrial process, radiation biology and medicine. The assurance of radiation protection in a facility is a prerequisite for radiation safety. The concept of radiation protection is based on limiting the stochastic health effects (probability of cancer induction and genetic damage) and deterministic effects of ionizing radiation (Eric and Amato, 2006). From this view point, radiation protection instruments for area monitoring are important operational tools to optimize radiation dose. The radiation monitoring instruments have to be calibrated to ensure good operational performance and high reliability (Sharmin and Rahman, 2008). Calibration ensures that radiation protection measuring instruments are working properly thus suitable for their intended purpose. Radiation protection is based on the principle of dose optimization. In this regard, International commission on radiological protection (ICRP) has recommended dose limits for radiation workers as well as to the members of the public (ICRP, 1991 & 2007). For the traceability of authentic measurements, calibration facilities play an important role from primary standard to the radiation users through the national standards (IAEA, 2000a). In this regard IAEA supported calibration laboratories in the developing countries including Bangladesh to execute a key role in achieving the mandate of international basic safety standards. To ensure the protection of occupational worker, public and environment from hazard of ionizing radiation including neutron radiation, such facilities conduct a key role. The optimization of radiation protection is the main policy by establishing proper calibration of radiation field and to check the radiation protection devices under that condition. A complete calibration of such detectors is a prerequisite under the conditions for which the instrument was designed to ensure the user requirement. Calibration is a general procedure for establishing a relationship between the observed value of a measuring instrument and the conventionally measured true value of the quantity to be measured under well-defined reference conditions (IAEA, 2000a). This is a prerequisite to ensure that radiation protection monitoring instruments can measure radiation dose with accuracy needed for its intended purpose. To accomplish the calibration of dosimetric instruments of any radiation type the laboratory must have an appropriate structure and sufficient resources to carry out such activity. For the calibration of neutron measuring devices isotopic neutron sources have been approved by the international standard organization (ISO , 2000) as reference sources for the neutron radiological instruments calibration. In this perspective the ^{241}Am-Be neutron sources came to be most suitable for the calibration purpose (Jozefowicz *et al.,* 2004). In order to update the calibration process of the neutron detectors, secondary standard dosimetry laboratory (SSDL) of Bangladesh Atomic Energy Commission has acquired an OB 26/1 irradiation system manufactured by Buchler GmbH based on an ^{241}Am-Be source (Buchler, 1986). Ideally, this source should be free-in-air to comply with ISO-8529-1 (ISO, 2001) recommendations, requiring a well-known spectrum and fluence rates, so that the device response or calibration factor should be independent of the calibration facility or experimental techniques employed. For this reason, in the case of calibration procedures for instruments with neutron sources and gamma sources, if instruments are able to respond to scattered neutrons and gamma radiation and to the source used during the process, it is necessary to determine corrective environmental factors in the room in which the procedure is performed for the neutron (Eisenhauer *et al.,* 1987; Eisenhauer *et al.,* 1982; Vega-Carrillo *et al.,* 2007). According to ISO 8529-2, ISO 8529-3 and ISO 10647 (ISO, 1998 & 2000) a room for instrument calibration sources must submit a neutron scattering contribution as low as possible, but in no case may cause an increase in instrument reading more than 40%. For this purpose, there are three established methods for correcting the effect of scattering: semi-empirical, the cone of shadow and the polynomial fit. In the experiments semi-empirical method was used to estimate the expected changes in the primary neutron spectrum for scattering contribution compared with the free-in-air situation. Generally, the observed scattering factors in a radiation room are: own room scattering, attenuation of neutrons through the air, scattering due to air in the room, scattering due equipment with hydrogenated compounds and spectral effects. Among them, presently three influencing scattering factors such as Room scatter correction (F_{RS}), Air scatter correction (F_{AS}) and Geometrical correction factor (F_g) are estimated to characterize accurately the neutron beam resulting from the delivered set-up at different source to surface distances (SDDs), emphasizing on irradiation positions. In the present study, the characterization of the neutron field is performed based on the calculated FFDE and measured neutron dose equivalent using two neutron area dosimeters based on Boron Trifluoride (BF_3) detectors (ASP2e/NRD #9177/2628 and E600/NRD#9072/ 2616). The aim of this article is to present the results of neutron radiation field standardization performed in a comparative manner with the experimental and calculated FFDE at SSDL facility for characterizing the typical nine inch remmetrs using for radiation protection in neutron field.

MATERIALS AND METHODS

In the present study the neutron radiation field has been standardized by applying some neutron scatter factors in the measured neutron dose equivalent. Subsequently, a comparative analysis between the calculated FFDE and corrected measured neutron dose equivalent was performed from the instrumental reading of the typical 9 remmeter.

Determination of free field dose equivalent (FFDE): Free field dose equivalent (FFDE) is dose equivalent, which is air, and room scattering free. In the present experiments, neutron remmeter meter was used to measure the radiation level in terms of FFDE which includes the ambiance effect of the scattered neutron radiation. With a view to estimate the free-in-air FFDE, the contribution of the scattered neutron radiation need to be excluded. In this regard, some correction factors that presents the ambiance effect was determined, and applied in the experimental FFDE to get the corrected FFDE that correspond to the free-in-air. In this process, the measured free-in-air FFDE in the neutron fields of a ^{241}Am-Be neutron calibrator (OB-26/1) at the SSDL facility were corrected to standardize the neutron field. Subsequently, characterization of nine inch moderated neutron detector was performed using this corrected experimental free-in-air FFDE in a comparative manner with the calculated FFDE. Characterization of nine inch moderated neutron detectors (ASP2e/NRD and E600/NRD) was performed by estimating the ambient neutron dose equivalent at different distances. The responses of the neutron remmeters were verified with a series of experiments in terms of distance and ambient dose equivalent. The correction factors, such as geometrical, air scattering, room scatter correction factors were determined based on the source to detector distance, detector geometry and room size.

Calculation of free field dose equivalent (FFDE): The calculated FFDE reasonably simulates the FFDE free-in-air that excludes the ambiance scattering effect on the neutron field. The calculation of the FFDE free-in-air is a prerequisite to estimate the ambiance contribution on the neutron field due to the scattering effect. To calculate FFDE the following equation was used which does not include the contribution of air scattering, room scattering and geometrical factors, and thus present the FFED without any ambiance effects. This equation only includes anisotropic factor of the ^{241}Am-Be source. However, in the conventional laboratory measurements, instrument reading includes the influence of all the above mention factors which should be excluded, so as to get the FFDE that correspond to the free-in-air to avoid the ambiance effect. In this regard, firstly we calculated the FFDE using the following equation

$$\text{FFDE} = \frac{B*F(\theta)*h(10)*3600*10^{-6}}{4\pi d^2} \quad (1)$$

Where B = neutron emission rate (n/sec), F (θ) = Anisotropic factor, h(10) = dose conversion coefficient and d = source to detector distance (cm)

The calculated FFDE was then compared with the corrected experimental FFDE to perform a comparative analysis, and to estimate the contribution of the scattered neutron.

Standardization of neutron field for calibration of neutron survey meter: In a calibration facility of neutron survey meter, neutrons are scattered by air on floor, walls, support structures and neutron sources enclosure that may contribute significantly to the neutron radiation field and have an influence on the instrument reading during its calibration. As per the recommendation of international organization for standardization, the neutron scattering in a room of instrument calibration must ensure such a low contribution which does not increase the instrument reading more than 40%. Therefore, environmental corrective factors of scattering effect need to be estimated. In this regard, among several scattering factors, the main factors of scattering effects that change the neutron spectrum and the fluence rate at the instruments are air scatter and room scatter, which was determined, and discussed in following section.

Determination of correction factors

Air scatter correction factor F_{AS}: The air scattering factor commonly observed in a radiation room is caused by the attenuation of neutron through air and neutron scattering due to air in the room. The air scatter correction factor was determined by using the equation as mentioned bellow.

F_{AS}= 1+ [AS (%/m)]*d (2)

Where, 'd' is the source to detector distance in meter, and AS (%/m) is the air scatter per meter. The air scatter fraction per meter AS (%/m) signifies that air in-scatter component is scattered neutrons, which could reasonably strike the instrument and contribute to its reading. The air out-scatter component is the air attenuated neutrons in the facility. Air in scatter is approximately two times of air-out-scatter. The value of AS(%/m) was used 1.01 as recommended by ISO for typical 9 remmeter with ^{241}Am-Be source.

Room scatter correction factor F_{RS}: The room scattering factor commonly observed in a radiation room is the scattering from room's own wall and scattering due to equipment. Room scatter correction factor F_{RS} was calculated from an equation which is given below (Lim *et al.,* 2005).

F_{RS} = 1+ [S (%/m^2)] d^2 (3)

Where, d is the source to detector distance, S (%/m^2) is the fractional room scatter contribution per meter^2 at unit source-detector distance, which gives the fractional room scatter contribution at unit source-detector distance. To calculate [S (%/m^2)] we used a semi-empirical method with using the following equation:

$R_{c1}= R_0/d^2 +R_s$

$R_{c1}*d^2 =R_0 (1+S.d^2)$ here, $S = R_s /R_0$ (4)

Where, R_{c1} = detector response (corrected for air scatter and geometrical effect between source and detector), R_0 = calculated detector response due to direct neutron only, R_s = response to room scattered neutron. S= fractional room scatter contribution at unit source-detector distance.

Plotting $R_{c1}*d^2$ vs d^2 should result in a straight line with intercept R_0 and slope R_0S. From this plotted graphs (discussed in results part), we found two fitted equations, $R_{c1}*d^2$ = 12.01521+0.1329*d^2 and $R_{c1}*d^2$ = 11.90486+0.24841*d^2, respective to two neutron detectors, ASP2e/NRD and E600/NRD. Thus, the room scatter correction coefficient 'S' can be determined by using these two fitted equations. The calculated value of [S (%/m^2)] for neutron survey meters are 0.0111 and 0.0209 respectively. Applying the values of [S (%/m^2)] in equation (3), the room scattering factors were determined for different distances as presented in Table 1.

Geometrical correction factor F_g: For a spherical detector and a point isotropic neutron source, the response of the device is increased by a factor of $1+\delta*(r/2d)^2$. The term $r^2/4d^2$ is the additional fractional number of neutrons entering the detector volume, and the parameter δ attempts to account for the relative effectiveness of these extra neutrons in producing a response in the detector. The above factors are expressed in terms of a correction factor, known as geometrical correction factor. The geometrical correction factor is represented in a form of equation, given as below

$F_g = 1+\delta*(r/2d)^2$

$= 1+\delta*(a^2+b^2)/(2d)^2$ (5)

Where 'r' is the distance between the source center and the effective point of the detector, δ is the neutron effectiveness parameter (δ= 0.5 for 9" remmeter), 'd' (cm) is the source to detector distance, 'a' is the radius of the detector (a = 11.43 cm), b is the radius of the source (b = 1.5 cm). This factor is useful to calculate the deviation from inverse square law. This expression of geometrical factor is termed as Axton's formula which is applicable for a point source irradiating a spherical detector.

Anisotropic factor F_I (θ): Commercially manufactured radioactive neutron sources are generally cylindrical and doubly encapsulated in order to prevent leakage, so the emission varies with the effective path length through the encapsulation, and hence is not isotropic. Thus, a factor of anisotropic emission needs to be used. A fixed value of F_I (θ) is used (Lim and Chang, 2005) in the present study for ^{241}Am-Be source which is given as

$F_I (\theta) = 1.036$ (6)

Determination of corrected FFDE (R_c): The corrected FFDE was determined by dividing the instrument reading (R) with all the correction factors (i.e., F_g, F_{AS}, F_{RS}) to determine the scatter-corrected delivered dose for a passive detector.

Where, total correction (T_c) = F_g.*F_{AS}.*F_{RS}

Determination of calibration factor (CF): To calibrate a remmeter using a neutron field, it is required to verify its response in a reference irradiation position of a calibrator facility. In the present experiments, remmeter was placed at a distance of 59.5 cm, i.e., a shortest distance, where solid angle fully covers the detector which positioned at a certain vertical height, along the central beam line. Then, the remmeter turns on by setting the measurement option at rate mode. The camera focus was adjusted to visualize the remmeter scale for accurately record the detector reading while exposed. The background reading was recorded prior to commence the exposure. Then the control panel of neutron source (^{241}Am-Be) was switched on to operate the source in exposure position. Subsequently, remmeter reading of FFDE was monitored through CCTV to observe the meter response, and the calibration factor (CF) of the remmeter for the moderated neutron was determined. The calibration factors of the neutron remmeters were determined in terms of the calculated FFDE and the corrected FFDE (R_c) by using the following relation. Based on the estimated CFs, the corresponding response factors of each remmeter were determined that compiles the ICRP recommendation for a neutron detector to be used for area monitoring.

$$CF = \frac{\text{Calculated Free Field Dose Equivelent (FFDE)}}{\text{Corrected Free Field Dose Equivelent } (R_c)}$$

Uncertainty assessment for neutron dose measurement with typical 9" remmeter: The measurement uncertainty in the neutron field dosimetry was estimated by following the conventional statistical method (IAEA, 2008). The measurement uncertainty for the neutron dosimetry was estimated in terms of Type A uncertainty, and systematic uncertainty (i.e instrumental) was estimated in terms of Type B uncertainty for the current experimental setup. Then Type A and Type B uncertainties are combined by using the statistical rules to estimate the combined uncertainty as given bellow.

$$u_c = ({}_A^2 + u_B^2) \quad (7)$$

Description of the neutron calibration facility of SSDL

Characteristics of the ^{241}Am-Be neutron source of OB 26/1 Calibrator: The schematic view of the neutron calibrator or system at SSDL is shown in Fig. 1.It provides biological protection against the radiation produced by the ^{241}Am-Be neutron source. It consists mainly of a cylindrical polyethylene (ρ_{PE}= 0.92 gm^{-3}) container enveloped with thin layers of lead (ρ_{Pb}= 11.3 gm^{-3}), cadmium (ρ_{Cd} = 8.8 gm^{-3}) and stainless steel ($_{SS}$ = 7.9 gm^{-3}), successively. The neutron source is radially positioned along the beam channel. The channel of 15.5 cm diameter is closed with a polyethylene stopper which has to be removed before starting calibration. An Amersham capsule with its three pellet-source of ^{241}Am-Be (, *n*) of 185 GBq global activity (5 Ci), is mounted within the irradiator. The cylindrical source is doubly encapsulated in welded stainless steel of 1.2 mm thickness. The outer dimensions of the capsule are 60 mm long and 30 mm in diameter. The radioactive source is placed in a vertically positioned channel and is lifted into the irradiation position by means of a motor drive. The source irradiation position is0.504 m above the floor.

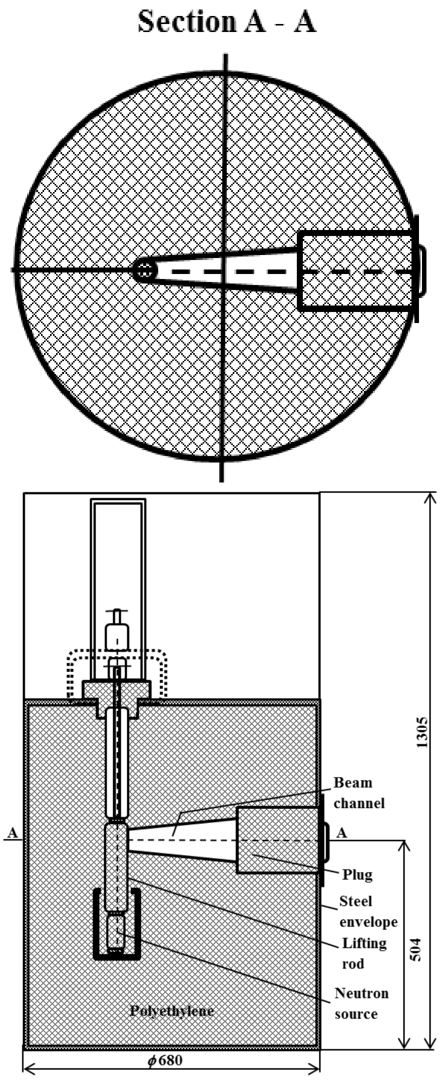

Figure 1. Schematic view of ^{241}Am-Be neutron calibrator OB 26/1 (dimensions are in mm)

Calibration room: The calibrator has been installed at the south-east corner of the SSDL calibration room depicted in Fig. 2.This room is 845 cm long, 630 cm wide and 333.5 cm high. The concrete shielding walls of this room is 65.5 cm thick with 24 cm thick ceiling and floor. The room has a single iron door with 210 cm high and 148 cm wide. This door consists of a lead slab of 2 cm thickness sandwiched between two sheets of stainless steel of 1.6 cm thickness. The stand which is presently used for positioning of the device to be calibrated is a wooden desk.

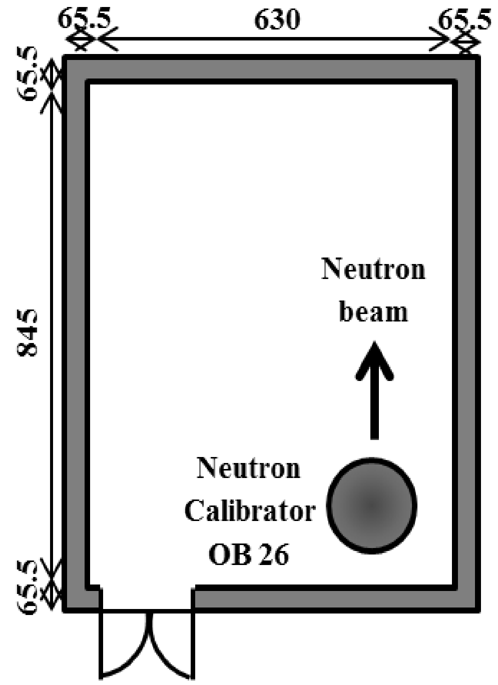

Figure 2. Structural geometry of the SSDL calibration room (Dimensions are in cm)

RESULTS AND DISCUSSION

The neutron fields of a ^{241}Am-Be neutron calibrator (OB-26/1) were characterized in terms of calculated FFDE and measured FFDE (i.e., ambient dose equivalent) at different distances. In this regard several correction factors such as geometrical, air scattering, room scatter correction factors were determined and found varying with source to detector distance, detector geometry and room size. The air scattering factor and room scatter factors lie in between 1.004 to 1.018, and 1.004 to 1.044 at a distance from 0.595 m to 2.0 m respectively whereas, the geometrical correction factor was found in between 1.0004 to 1.005, as shown in Table 1. The room scatter factors presented in Table 1 were determined based on the estimation of the room scatter per m^2 [i.e., S (%/m^2)] from the fitted equation of Fig. 3 (a) and (b). From this fitted equations, the S (%/m^2) values of 0.0111 and 0.0209 were calculated for the two remmeters (ASP2e/NRD and E600/NRD), respectively. Then, room scattering factors were determined for different distances by applying the values of S (%/m^2) in equation (3), and presented in Table 1. The average response of the neutron rate meter ASP2e/NRD and E600/NRD was found to be 1.0010.162 and 1.0130.164, which meets an excellent agreement of a neutron detector to be used for area monitoring according to ICRP recommendation. The average responses of the neutron remmeters are estimated based on the calibration factors as presented in Table 1 of the subsequent section.

Table 1. Neutron field standardization data for typical 9 remmeter

Distance (cm)	FFDE (mR/h)	Detector Reading (mR/h) R_u	Geometrical correction factor F_g	Air scatter fraction F_{AS}	Room scatter fraction F_{RS}	Reading corrected $R_c=R_u/F_g*F_{AS}*F_{RS}$	Calibration factor $CF=FFDE/R_c$
Remmeter-1: ASP2e/NRD #9177/2628							
59.5	34.919	34.040	1.005	1.005	1.004	33.594	1.007
69.4	25.667	25.627	1.003	1.006	1.005	25.261	1.026
79.4	19.609	19.532	1.003	1.007	1.007	19.217	1.002
89.4	15.468	15.330	1.002	1.077	1.009	15.048	1.004
99.4	12.512	12.371	1.002	1.009	1.011	12.111	1.009
109.4	10.329	10.265	1.001	1.010	1.013	10.019	1.011
119.4	8.671	8.645	1.001	1.011	1.016	8.411	1.006
129.4	7.383	7.385	1.001	1.012	1.019	7.159	1.003
140.0	6.307	6.271	1.001	1.013	1.022	6.055	0.999
150.0	5.494	5.540	1.007	1.014	1.025	5.328	1.006
160.0	4.829	4.768	1.001	1.015	1.028	4.566	0.992
170.0	4.277	4.450	1.001	1.016	1.032	4.199	1.013
180.0	3.816	3.913	1.001	1.017	1.036	3.713	0.971
190.0	3.424	3.528	1.001	1.018	1.040	3.301	0.971
200.0	3.091	3.194	1.000	1.019	1.044	3.001	0.968
Remmeter-2: E600/NRD #9072/2616							
59.5	34.919	34.416	1.005	1.005	1.007	33.848	1.015
69.4	25.667	25.483	1.003	1.006	1.010	25.001	1.007
79.4	19.609	19.621	1.003	1.007	1.013	19.187	0.999
89.4	15.468	14.271	1.002	1.077	1.017	13.900	1.084
99.4	12.512	12.441	1.002	1.009	1.021	12.064	1.006
109.4	10.329	10.452	1.001	1.010	1.025	10.085	0.988
119.4	8.671	8.739	1.001	1.011	1.030	8.386	0.992
129.4	7.383	7.418	1.001	1.012	1.035	7.135	0.987
140.0	6.307	6.450	1.001	1.013	1.041	6.113	0.978
150.0	5.494	5.620	1.007	1.014	1.047	5.290	0.978
160.0	4.829	4.997	1.001	1.015	1.054	4.671	0.966
170.0	4.277	4.500	1.001	1.016	1.060	4.175	0.951
180.0	3.816	4.000	1.001	1.017	1.068	3.682	0.954
190.0	3.424	3.567	1.000	1.018	1.075	3.257	0.960
200.0	3.091	3.270	1.000	1.019	1.084	2.961	0.945

Table 2. Uncertainty assessment for neutron field measurement with typical 9 remmeters

Uncertainty	Field of uncertainty	Uncertainty (%)		Combined uncertainty (%)			
		Remmeter-1 (S/N: 9177/2628)	Remmeter-2 (S/N: 9072/2616)	Remmeter-1 Min	Remmeter-1 Max	Remmeter-2 Min	Remmeter-2 Max
Type A	Geometrical correction, F_g	0.12	0.12				
Type A	Air scatter correction, F_{AS}	0.45	0.45				
Type A	Room scatter correction, F_{RS}	1.28	1.28				
Type A	Detector response	0.58 (Min) 1.44 (Max)	0.61 (Min) 1.56 (Max)				
Type A	Half life	0.16	0.16	0.755	2.123	0.775	2.495
Type B	Conversion coefficient	0.40	0.40				
Type B	Neutron emission rate, B	0.10	0.10				
Type B	Anisotropy factor, F_I (θ)	0.90	0.90				
Type B	Distance, d	0.20 (Min) 0.30 (Max)	0.20 (Min) 0.30 (Max)				
Type B	Detector positioning	0.20 (Min) 0.30 (Max)	0.20 (Min) 0.30 (Max)				

Min: minimum; Max: Maximum

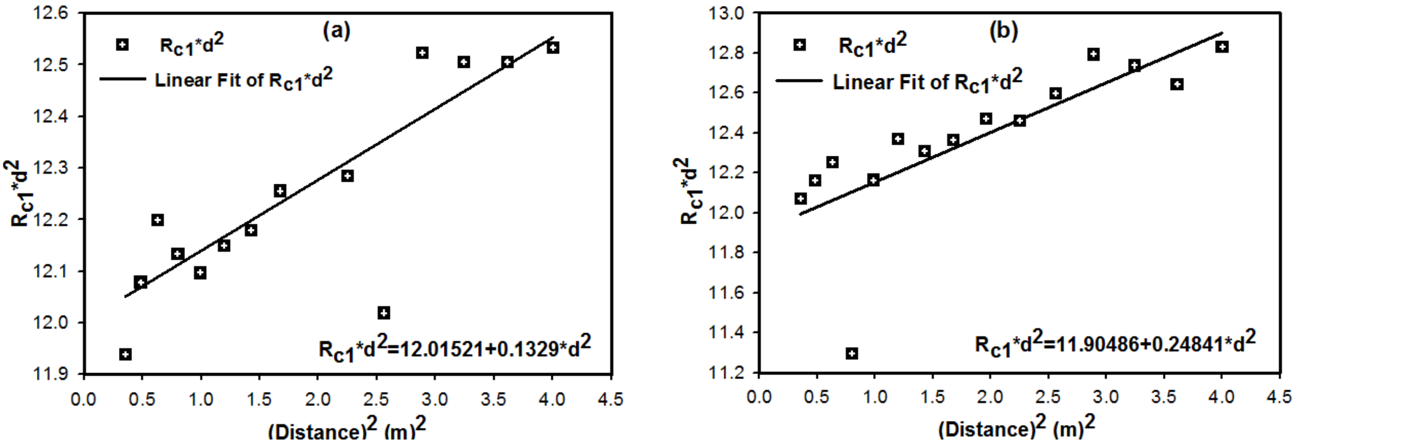

Figure 3. Graphical plots used to calculate [RS (%/m²)] from the fitted equations for remmeter (a) ASP2e/NRD and (b) E600/NRD

Calibration of neutron 9 Remmeter: The calibration factors of the typical nine inch remmeters (S/N. 9177/2628 and 9072/2616) were determined and presented in Table 1. Prior to estimate these calibration factors, remmeters responses were verified in a reference irradiation position of the calibrator facility. In the present experiments, remmeter was placed at a shortage distance 59.5 cm to ensure that the beam solid angle fully covered with a vertical height as adjusted to the detector along the central beam line. The calibration factors of the remmeters are useful indicator to check the consistency between the calculated free field dose equivalent (FFDE) and the corrected free field dose equivalent (R_c) as presented in Table 1. From this table it is seen that the calculated CF values are very close to the unit value and hence indicates a good agreement between calculated FFDE and corrected dose equivalent (i.e., R_c). Therefore, this assured that the presently scattered contribution is relatively small in the measured neutron dose equivalent for the present ambient condition.

Comparison of measured dose equivalent rates and calculated FFDE rates: The free field dose equivalent (FFDE) rates were calculated based on the Equation 1 to estimate the dose equivalent rate due to neutrons from the source alone, and hence in the absence of background caused by neutrons scattered into the detection instrument from the walls, air in the room, source support and background from the sources in the shielded OB 26/1 irradiator. This calculated FFDE reasonably simulates the FFDE free-in-air that excludes the ambiance scattering effect on the neutron field. Thus, the calculated FFDE free-in-air was used as a baseline to estimate the ambiance contribution on the neutron field scattering. Subsequently, FFDE was determined experimentally that includes the background caused by neutrons scattered in the laboratory ambiance. Then, the calculated FFDE rates were compared with the measured dose equivalent as shown in Fig. 4 and Fig. 5. This comparison between the calculated FFDE and the measured dose equivalent at a given location in the neutron source room served as a measure of the relative contribution of the neutrons scattered from the walls, ceiling, floor, air in the room, and any other structures in the calibration room. The Fig. 4 shows the ratio of the measured dose equivalent rate to calculated FFDE rate for the moderated ^{241}Am-Be spectra at different source to detector distances. From this figure it is obvious that the scattered contribution of the neutron field due to the laboratory ambiance influence is relatively small at all the distances.

The comparative variation of the calculated FFDE and measured dose equivalent of the neutron field with distances indicates a similar trend with small difference between them, and hence points to an insignificant contribution of the scattered neutron for the present ambient condition. The graphical view of this comparative assessment is shown in Fig. 5 for remmeter (a) ASP2e/NRD#9177/2628 and E600/NRD# 9072/2616.

Estimation of Uncertainty: In the present study the combined uncertainty of neutron field for the measurement was estimated based on the type A and type B uncertainty of the scatter factors and other influence quantities on the typical 9" remmeters. The combined uncertainty was determine by combining the Type A and Type B uncertainties with using the statistical rules (Eq. 7). The estimated combined uncertainty ($k=1$) for the measurement are presented in Table 2.

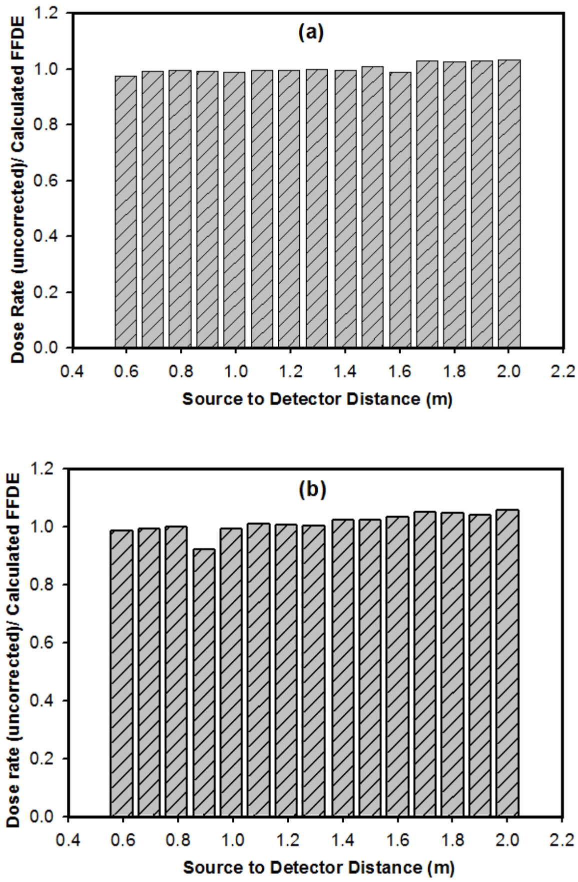

Figure 4. Ratio of measured dose rate (uncorrected) to FFDE for remmeter (a) ASP2e/NRD and (b) E600/NRD.

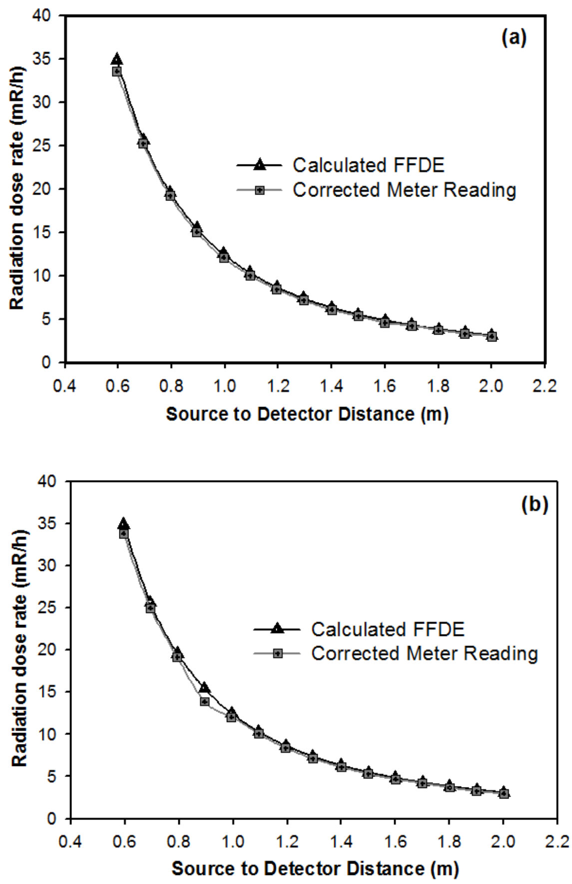

Figure 5. Comparative variation of radiation dose rates with SSD (a) remmeter (a) ASP2e/NRD and (b) E600/NRD.

Conclusion

The scatter correction factors have been determined. Subsequently, the neutron radiation field has been standardized with the determined correction factors. Based on the standardized neutron radiation field, calibration factors of the remmeters (ASP2e/NRD#9177/2628 and E600/NRD#9072/2616) at different SSDs have been determined. The average response of the remmeters was found to be 1.0010.162 and 1.0130.164, which meets an excellent agreement of a neutron detector to be used for area monitoring according to ICRP recommendation. The combined uncertainty of neutron dose measurement was estimated, and its minimum and maximum ranges were 0.755% ($k=1$) and 2.123% ($k=1$) in the case of remmeter ASP2e/NRD#9177/2628; whereas this ranges were 0.775 ($k=1$) and 2.495 ($k=1$) for the remmeter E600/NRD9072/2616. The result obtained in the present experiments could be useful as a reference method to optimize the radiation protection systems in the neutron field.

Authors' contribution: The manuscript was written by M. Shamsuzzaman and M. S. Rahman. The figures were prepared by M. Shamsuzzaman and J. Ferdous. The Experimental work was conducted by J. Ferdous, T. Siddiqua, M. Shamsuzzaman and M. S. Rahman. The detector's response was verified by J. Ferdous, T. Siddiqua and M. M. H. Bhuiyan. The experimental results were analyzed and discussed by J. Ferdous, M. Shamsuzzaman and M. S. Rahman. The manuscript was reviewed by M. S. Rahman, P. Paul, A. K. Deb and S.R. Chakraborty.

REFERENCES

Buchler Gm BH. Neutron calibrator OB 26/1-BA: Operational manual (Braunschweig, Germany) (1986).

Eisenhauer, C. M., Schwartz, R. B., Johnson, T. 1982. Measurement of neutrons reflected from the surfaces of a calibration room, *Health Physics*, *Vol. 42*, pp. 489 – 495.

Eisenhauer, C. M., Schwartz, R.B., McCall, R. C. 1987. Effect of air scatter on calibration of instruments for detecting neutrons, *Radiation Protection Dosimetry*, *Vol. 19*, pp. 77 – 84.

Eric, J. H., Amato, J. G. 2006. Radiobiology for the Radiologist (6th edition). Lippincott Williams and Wilkins Publishing (ISBN 0-7817-4151-3), pp 656.

IAEA (International Atomic Energy Agency), Calibration of Radiation Protection Monitoring Instrument, IAEA Safety Report Series No. 16 (2000a.), IAEA, Veinna.

ICRP (International Radiological Protection Commission) 1990 Recommendations of the International Commission on Radiological Protection, ICRP publication 60 (1991), Ann. ICRP 21 (1-3).

ICRP (International Radiological Protection Commission), Recommendations of the International Commission on Radiological Protection, ICRP publication 103 (2007), Pergamon press, Oxford.

ISO (International Organization for Standardization) Reference neutron radiations, part1: characteristics and methods of production (2001), ISO 8529-1.

ISO (International standard for organization) Procedures for calibrating and determining the response of neutron-measuring devices used for radiation protection purposes (1996), 10647 (E).

ISO (International Organization for Standardization) Reference neutron radiations- Part 3: Calibration of area and personal dosimeters and determination of response as a function of energy and angle of incidence (1998 en), ISO 8529-3.

ISO (International Organization for Standardization), Reference neutron radiations- Part 2: Calibration fundamentals of radiation protection devices related to the basic quantities characterizing the radiation field (2000 en), ISO 8529-2.

Jozefowicz, K., Golnik, N., Zielczynski, M. 2004. Standard fields of old neutron sources-parameters and traceability. *Radiation Protection Dosimetry, Vol. 110 (1/4)*, 107-110.

Lim, K. S., Kim, B. H., Chang, S. Y. 2005. Calibration of Neutron Measuring Instruments by ^{252}Cf Neutron Source, Transactions of the Korean Nuclear Society Autumn Meeting, Busan, Korea, October 27-28.

Sharmin, S., Rahman, A. F. M. M., Shamsuzzaman, M. 2008. Characteristics of radiation measuring instruments for low energy range (33 Kev – 662 Kev). *Jahangirnagar Physics Studies*, *Vol. 14*, pp. 11-17.

Vega-Carrillo, H. R., Manzanares-Acuna, E., Iñiguez, M. P., *et al*. 2007. Study of room-return neutrons, *Radiation Measurement*, *Vol. 42*, pp. 413 – 419.

IAEA (International Atomic Energy Agency) (2008) Measurement uncertainty. A practical guide for secondary standard dosimetry laboratories, TECHDOC-1585.

****