Intercomparison of Neutron Personal Dose Equivalent Measured by Thermoluminescence Dosimeters

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Abstract: This paper presents an inter-laboratory comparison of neutron personal dose equivalent measured by the Harshaw thermoluminescence albedo neutron dosimeters, TLDs between the National Institute of Metrology of China (NIMC) and the Institute for Nuclear Science and Technology of Vietnam (INST). Three sets of TLDs (each set consisting of five TLDs) were prepared for each laboratory. Each set was then irradiated to the corresponding same nominal standard values of neutron personal dose equivalent ($H_p(10)^i_{n-std}$) of 1.0 mSv, 2.0 mSv, and 3.0 mSv, respectively at these two laboratories. The irradiated TLDs were then read-out at the INST using the Harshaw 4500 TLD reader to obtain neutron personal dose equivalents at the NIMC ($H_p(10)^i_{n-NIMC}$) and at the INST ($H_p(10)^i_{n-INST}$), which are corresponding to different values of $H_p(10)^i_{n-std}$. Comparisons between the corresponding pair values of $H_p(10)^i_{n-NIMC}$ and $H_p(10)^i_{n-INST}$ shows good agreements within 10% with the combined uncertainty of 20.1% (k=1). This implies that the TLDs can be used for safety assessment of occupational neutron personal dose equivalents. This intercomparison result also confirms the capabilities of these two laboratories (i.e., NIMC, INST) on deliveries of neutron personal dose equivalent standard values for calibrations of personal TLDs.

Keywords: *Dosimeters, TLD Reader, Personal dose equivalent.*

I. INTRODUCTION

There are various utilities of neutrons in research works, education, and daily demands. Accompanying with many helpful aspects, there are potential threats revealed from applications of neutron sources at radiation facilities. Thus neutron safety assessment is a crucial need for personnel working at neutron fields. There are different types of neutron measuring devices for the purposes of neutron monitoring and safety assessment, including active ones [1, 2, 3, 4] and passive ones [5]. While the active ones have the advantage on real-time vision of the devices' readings (possibly, neutron ambient dose equivalent – $H^*(10)$ rates [1, 3, 4] or integrated neutron personal dose equivalents - $H_p(10)$ [6]), the passive ones possess the advantage on read-out data storage and retrieval for legal evidences (possibly, integrated neutron personal dose equivalents - $H_p(10)$ [5]). For management of occupational neutron personal dose equivalents, thermoluminescence albedo neutron dosimeters (TLDs) are widely used.

In this work, comparisons of $H_p(10)$ due to neutrons, measured by the Harshaw TLDs (card type of GN-6776; holder type of 8806), were performed between the National Institute of Metrology of China (NIMC) and the Institute for Nuclear Science and Technology of Vietnam (INST). Three sets of the TLDs (each set i^{th} consisting of five TLDs) were prepared for each laboratory (except an extra set of ten TLDs prepared for each laboratory to measure background radiation). Each set i^{th} (i = 1 to 3) was then irradiated to the corresponding i^{th} same nominal standard value of neutron personal dose equivalent ($H_p(10)^i_{n-std}$) of 1.0 mSv, 2.0 mSv, and 3.0 mSv, respectively at the NIMC and at the INST. The irradiated TLDs were then read-out at the INST using the Harshaw 4500 TLD reader (with the same setting parameters) in order to obtain neutron personal dose equivalents at the NIMC ($H_p(10)^i_{n-NIMC}$) and at the INST ($H_p(10)^i_{n-INST}$), which are corresponding to different values of $H_p(10)^i_{n-std}$. Comparisons between corresponding pair values of $H_p(10)^i_{n-INST}$ and $H_p(10)^i_{n-INST}$ were made to verify the feasibility of using the Harshaw TLDs in managing occupational neutron personal dose equivalents for safety assessment.

II. MATERIALS AND METHODS

II.1. Neutron reference fields

The neutron reference field at the NIMC equipped with an X4-type $^{241}Am-Be$ neutron source with the neutron emission rate of 7.66 × 10^6 s^{-1} (on 23 November 2011; the standard uncertainty of 1.0%, k=1), this value is traceable to the NIMC standard using Manganese Sulphate bath method. The anisotropy correction factor of 1.05 with the standard uncertainty of 1.0% (k=1) measured with the long counter with BF_3 detector at the NIMC [7]. The neutron irradiation facility has inner dimensions of 600 cm (height) × 600 cm (width) × 1000 cm (length). The neutron reference field was used to deliver the standard values of $H_p(10)^i_{n-std}$ in this comparison and for the routine calibration works at the NIMC [7]. The neutron reference field at the INST is equipped with an X14-type $^{241}Am-Be$ source (supplied by Hopewell Designs, Inc., USA) in the cubic room with inner dimensions of 700 cm × 700 cm × 700 cm. The source's neutron emission rate of 1.299 × 10^7 s^{-1} (on 23 January 2015; the standard uncertainty of 1.5%, k=1). The anisotropy correction factor of 1.030 at 100 cm from the source with the standard uncertainty of 0.1% (k=1) was simulated using MCNP5 code [8]. This neutron reference field was used to deliver the standard values of $H_p(10)^i_{n-std}$ in this comparison and for the routine calibrations at the INST. From this $^{241}Am-Be$ source, several neutron reference fields have been established [8, 9]. The main dosimetric quantities of these neutron reference fields were characterized and can be found in previous works [8-13]

II.2. Thermoluminescence neutron dosimeters and reader

The construction of a TLD card (type of GN-6776) consists of four thermoluminescence chips (marked as: from I to IV, see Fig. 1). While the chips I and IV are ^6LiF crystals, sensitive to both neutrons and photons, the chips II and III are ^7LiF crystals, only sensitive to photons. This configuration permits the TLD measuring both neutrons and photons in mixed radiation fields. Therefore, the neutron personal dose equivalent and the photon personal dose equivalent are achieved after reading out the TLDs. The qualities of the TLDs used in the comparison were selected taking into account their batch homogeneity, linearity, detection threshold, and reproducibility following the recommendations from ISO 21909:2005 [14]. The technical specifications of this type Harshaw TLDs can be found in Ref. [15].

The Harshaw 4500-type TLD reader was used for measuring the values of $H_p(10)^i_{n-NIMC}$ and $H_p(10)^i_{n-INST}$ under the same setting parameters following the manufacturer's recommendations (i.e., keeping preheat temperature at $165^o\ C$ for 5 s; acquired temperature rate of $10^o\ C.s^{-1}$ up to $300^o\ C$ during $16\ (2/3)\ s$; annealed temperature at $300^o\ C$ for 5 s). The factor k_{nd} of the TLD reader was set based on the data read-out from the TLDs irradiated at 2.0 mSv at the NIMC. More details on the Harshaw 4500-type TLD reader can be found from a website [16].

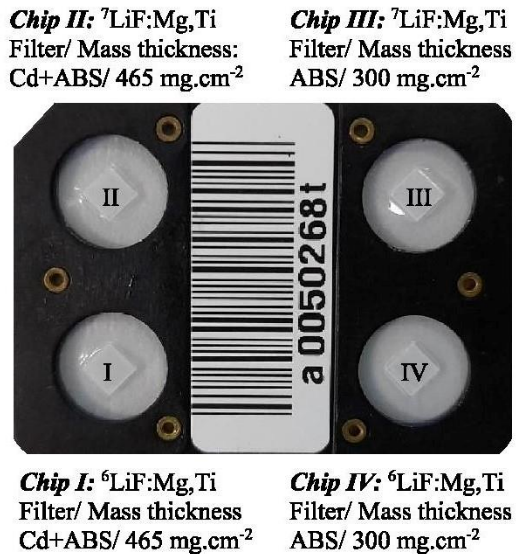

Figure 1: Construction of the Harshaw TLD albedo neutron dosimeter card (type GN-6776).

II.3. Irradiation parameters

Each set i^{th} of five TLDs was attached on an ISO water slab phantom (30 cm × 30 cm × 15 cm) and placed at 75 cm from the neutron source's center so that the central beam line of the neutron field is perpendicular to the water phantom's surface at its center. The each set i^{th} of five TLDs was then irradiated to the corresponding same nominal standard values of $H_p(10)^{i}_{n-std}$ of 1.0 mSv, 2.0 mSv, and 3.0 mSv at the NIMC and the INST. The distance of 75 cm was selected for irradiation with expectation that no-scattered components affect to total values of $H_p(10)^{i}_{n-std}$, thus the neutron fluence-to-personal dose equivalent conversion coefficient of 411 $pSv.cm^2$ can be applied [18].

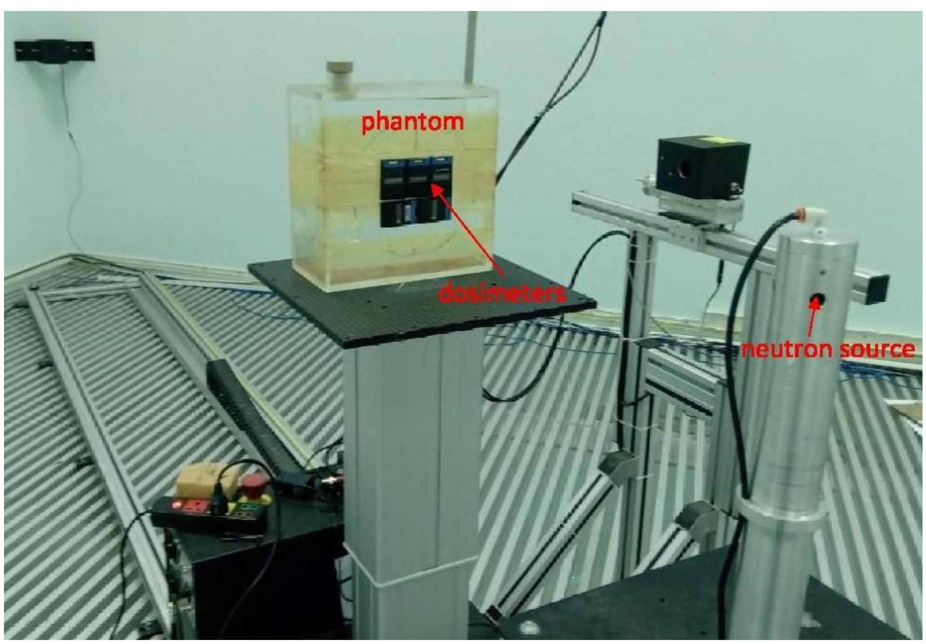

Figure 2: Geometry for irradiation of the Harshaw thermoluminescence albedo neutron dosimeters.

The values of $H_p(10)^i_{n-std}$ delivered to the TLDs can be calculated based on the neutron personal dose equivalent rate which is calcualted as Eq. (1).

$$\dot{H}_p(10)_{n-std} = \frac{B.F_1(\theta)}{4.\pi.l^2}.h_{p\varphi} \quad (1)$$

where, B is the neutron source's emission rate; $F_1(\theta)$ is the source anisotropy correction factor; $h_{p\varphi}$ is the neutron fluence-to-personal dose equivalent conversion coefficient which is 411 $pSv.cm^2$, taken from ISO 8529-3 [18].

III. RESULTS AND DISCUSSION

III. 1. Measured neutron personal dose equivalents

The measured values of $H_p(10)^i_{n-NIMC}$ and $H_p(10)^i_{n-INST}$ are presented in Table 1 in comparison with the nominal standard values of $H_p(10)^i_{n-std}$.

Table 1: Nominal neutron personal dose equivalents ($H_p(10)^i_{n-std}$) and those measured by the Harshaw thermoluminescence albedo neutron dosimeters at the National Institute of Metrology of China ($H_p(10)^i_{n-NIMC}$) and at the Institute for Nuclear Science and Technology of Vietnam ($H_p(10)^i_{n-INST}$) and ($H_p(10)^i_{n-INST}/H_p(10)^i_{n-NIMC}$ ratio.

Seq.	$H_p(10)^i_{n-std}$ (mSv)	$H_p(10)^i_{n-NIMC}$ (mSv)	$H_p(10)^i_{n-INST}$ (mSv)	Ratio INST/NIMC
1	1.0	1.1	1.2	1.09
2	2.0	2.0	2.2	1.10
3	3.0	3.2	3.5	1.09

III.2. Uncertainty budgets of measured neutron personal dose equivalents

The uncertainties of $H_p(10)^i_{n-INST}$ and $H_p(10)^i_{n-NIMC}$ were calculated taking into account the budgets contributed from batch homogeneity, linearity, reproducibility, etc, which are presented in Table 2. As a result, the combined uncertainty of 20.1 % (k=1) can be deduced, which is acceptable for radiation protection purpose. The discrepancy between $H_p(10)^i_{n-INST}$ and $H_p(10)^i_{n-NIMC}$ is within 10%. That means the Harshaw thermoluminescence albedo neutron dosimeters (card type GN-6776, holder type 8806) can be reliably used for managing occupational neutron dose equivalents of personnel working in neutron fields.

Table 2: Uncertainty budgets and combined uncertainty of neutron personal dose equivalents measured by the Harshaw thermoluminescence albedo neutron dosimeters (card type GN-6776, holder type 8806)

No.	**Uncertainty budget**	**Value (%)**
1	Batch homogeneity of TLDs	15.0
2	Linearity of TLDs	5.0
3	Reproducibility of TLDs	10.0
4	Stability of the TLD reader	5.0
5	Uncertainty of standard value of $H_p(10)$	5.0
6	Others (distance, time, temperature,...)	2.0
Combined uncertainty (k=1)		20.1

IV. CONCLUSION

The comparison of neutron personal dose equivalents, $H_p(10)$, have been performed between the National Institute of Metrology of China and the Institute for Nuclear Science and Technology of Vietnam (using the Harshaw thermoluminescence albedo neutron dosimeters - card type GN-6776, holder type 8806). The discrepancy of $H_p(10)$ values between these two laboratory is consistent within 10% with the combined uncertainty of 20.1% (k=1). That confirms the capabilities of these two laboratories on deliveries of standard values of $H_p(10)$ for calibrations of neutron dosimeters and radiation safety assessment for the purpose of radiation protection.

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SO SÁNH LIÊN PHÒNG VỀ XÁC ĐỊNH TƯƠNG ĐƯƠNG LIỀU CÁ NHÂN NEUTRON SỬ DỤNG LIỀU KẾ NHIỆT PHÁT QUANG

Tóm tắt: Báo cáo này trình bày kết quả so sánh liên phòng về xác định tương đương liều cá nhân neutron sử dụng liều kế nhiệt phát quang sản xuất bởi hãng Harshaw, TLD, giữa Viện đo lường quốc gia Trung Quốc (NIMC) và Viện Khoa học và Kỹ thuật hạt nhân, Việt Nam (INST). Ba nhóm liều kế TLD (mỗi nhóm gồm 5 TLD) được chuẩn bị cho mỗi phòng thí nghiệm. Mỗi nhóm sau đó được chiếu với cùng một tương đương liều cá nhân danh định, $H_p(10)_{n-std}^{i}$, lần lượt là 1 mSv, 2 mSv và 3 mSv. Các TLD đều được đọc tại INST bằng hệ đọc liều kế Harshaw 4500 để đánh giá tương đương liều cá nhân neutron tại từng phòng thí nghiệm. So sánh kết quả xác định tương đương liều cá nhân neutron giữa NIMC và INST cho thấy sự phù hợp trong vòng 10% với độ không đảm bảo đo tổng cộng 20,1% (k=1). Điều này cho thấy các TLD có thể sử dụng để kiểm soát tương đương liều cá nhân neutron cho các nhân viên bức xạ. Kết quả của so sánh liên phòng cũng khẳng định năng lực của hai phòng thí nghiệm (NIMC và INST) trong việc hiệu chuẩn các thiết bị đo liều cá nhân neutron.

Từ khóa: liều kế, *tương đương liều cá nhân neutron, hệ đọc liều kế*