Effect of the Scattering Radiation in Air and Two Type of Slap Phantom between PMMA and the ISO Water Phantom for Personal Dosimeters Calibration

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Abstract. The calibration of personal dosimeter to determine the quantities of the personal dose equivalent, $H_p(d)$, is required to be placed on a suitable phantom in order to provide a reasonable approximation to the radiation backscattering properties as equivalent as part of body. The dosimeter which is worn on the trunk usually calibrated with slap phantom which recommended in ICRU 47 with dimension of 30 cm (w) x 30 cm (h) x 15 cm (t) PMMA slab phantom to achieve uniformity in calibration procedures, on the other hand the International Organization for Standardization (ISO), ISO 4037-3, proposed the ISO water slap phantom, with PMMA walls, same dimension but different wall thickness (front wall 2.5 mm and other side wall 10 mm thick) and fill with water. However, some laboratories are still calibrating a personal dosimeter in air in term of ambient dose equivalent, $H^*(d)$. This research study the effect of the scattering radiation in two type of those slap phantoms and in air, to calibrate two type of OSL (XA and LA) and electronic personal dosimeters. The X-ray and Cs-137 radiation field with the energy range from 33 to 662 keV were used. The results of this study will be discussed.

1. Introduction
The personal dose equivalent, $H_p(d)$, be known in standardization of radiation protection to define as the operational quantity for individual monitoring of external exposure in ICRU standard tissue at a depth $d$, in the body of an exposed person. ICRU report 47 recommended depth, $d$, being 10 mm for strongly penetrating radiation and 0.07 mm for weakly penetrating radiation. ICRU 47 also recommended the 30 cm x 30 cm x 15 cm PMMA slab phantom to achieve a uniformity in calibration procedures[1], on the other hand the International Organization for Standardization (ISO), in ISO 4037-3, has proposed the ISO water slap phantom, which consists of a 30 cm x 30cm x 15 cm water phantom with PMMA walls (front wall 2.5 mm thick and other side wall 10 mm thick)[2]. But at the same time some laboratories were still calibrate it in air, in terms of ambient dose equivalent, $H^*(d)$. The accuracy and precision of the calibration of the personal dosimeters are important for the radiation protection, so the calibration laboratory should calibrate those dosimeters in the appropriate condition in order to obtain the proper results for user.

This study focused on the effect of the scattering radiation in air and two type of slap phantom between PMMA and the ISO water phantom by comparison of the calibration results from two type of
OSL dosimeters (XA and LA) and also the calibration results from electronic personal dosimeters in the energy range of the x-ray (33 to 118 keV) and Cs-137 (662 keV).

2. Materials and Methods

The study was performed by the cooperation of Dosimetry Calibration Laboratory of Thailand Institute of Nuclear Technology (TINT) for $^{137}$Cs gamma radiation field and the Secondary Standard Dosimetry Laboratory of Office of Atoms for Peace (OAP) for the X-ray narrow spectrum series (N40 - N150). Two types of the OSL dosimeters (manufacturer by Landauer), XA (used in X-Ray, Gamma and Beta measurement) and LA (used in X-Ray, Gamma, Beta and Neutron measurement) type, and the Electronic personal dosimeters (EPDs) (model RAD-60s, manufacturer by RADOS) were used in the measurement. OSL holder is covered by 1 mm thick PVC, whereas the EPD device had a plastic case and aluminium sheet inside.

Before starting the calibration procedure, the OSL dosimeters were carefully selected in order to unify the accuracy and precision of the dosimeters. 85 XAs and 75 LAs type were irradiated at 1.0 mSv for $H_p(10)$ in the $^{137}$Cs gamma radiation field, then select the OSLs that had the error less than ±5.0% to be used in this study. Finally, 67 XAs and 51 LAs of the OSL dosimeters were selected.

2.1. Calibration procedure 1: ISO water slab phantom

This procedure based on the use of ISO water slab phantom, which is recommended by ISO 4037-3 as a phantom for personal dosimeter. The phantom was placed at a distance of 1 meter measured from the radiation source. The Dosimeters were carefully installed on the surface of phantom to ensure that all dosimeters were irradiated with the same quality of radiation beam. In each irradiation batch, 6 XAs and 6 LAs of the OSL dosimeter were irradiated at the same time on the phantom while 6 EPDs could be irradiated at once.

The dosimeters were irradiated at 1.0 mSv for Personal Dose Equivalent ($H_p(10)$) (calculated from the reference Air Kerma Rate) using the $^{137}$Cs gamma radioactive source (662 keV) and the X-ray narrow spectrum series (33, 48, 65, 83, 100 and 118 keV). The radiation qualities that used in this study are showed in Table 1.

The reading dose of the OSLs were read out by OSL automatic reader (InLight Reader, manufacturer by Landauer) at the Laboratory of Radiation Dose Measurement and Assessment of TINT, while the EPDs were read directly from their indicator after the irradiated.

| Radiation Quality | Series | Effective Energy (keV) | Air Kerma Rates (Gy/h) | $H_p(10)/K_s$ (Sv/Gy) | $H'(10)/K_s$ (Sv/Gy) |
|-------------------|--------|------------------------|------------------------|-----------------------|-----------------------|
| X-ray             | N-40   | 33                     | 7.180E-03              | 1.22                  | 1.17                  |
|                   | N-60   | 48                     | 6.245E-03              | 1.71                  | 1.58                  |
|                   | N-80   | 65                     | 6.294E-03              | 1.89                  | 1.73                  |
|                   | N-100  | 83                     | 6.027E-03              | 2.21                  | 1.71                  |
|                   | N-120  | 100                    | 6.269E-03              | 1.81                  | 1.64                  |
|                   | N-150  | 118                    | 1.167E-02              | 2.24                  | 1.58                  |
| S-Cs-137          | -      | 662                    | 7.577E-03              | 1.21                  | 1.20                  |

2.2. Calibration procedure 2: PMMA slab phantom

The setting up procedure of this experiment was the same as stated in procedure 1, but the ISO water slab phantom was replaced by PMMA slab phantom, (recommended by ICRU 47). The radiation qualities, in terms of $H_p(10)$, were the same as indicated in Table 1.
2.3. Calibration procedure 3: “in air” condition
The setting up procedure of this experiment was the same as stated in procedure 1 and 2. The 52 cm (w) x 35 cm (h) x 11 cm (t) foam sheet was selected to attach the dosimeters and called as a “in air” condition. The dosimeters were irradiated at 1.0 mSv for Ambient Dose Equivalent (H*(10)) with the radiation qualities as indicated in Table 1.

The statistical difference of the reading results of each calibration procedures were examined by a “two-sample t-stat model method”. It indicates whether or not the difference between two groups’ averages of the calibration procedures. The statistical analysis, “t-value” and the “t-critical” of a t-test, was used in this study. The following criteria were used to justify the different; (a) if “t-value” less than the “t-critical” means the results are not statistically significant different, and (b) if the “t-value” is greater than the “t-critical” means the reading results are statistically significant different.

3. Results
The Figure 1, 2 and 3 show the results of the irradiation of OSLs (XA and LA type) and EPDs on the ISO water slab phantom (calibration procedure 1), PMMA slab phantom (calibration procedure 2), and “in air” condition (calibration procedure 3), respectively.

The results showed that the reading dose of OSLs type XA and LA on the PMMA slab phantom produced the scattering radiation at nearly the same of ISO water slap phantom. The highest scattering from PMMA was observed at energy of 83 keV from X-ray. The lowest scattering radiation was observed in the “in air” irradiation. The main reason of the difference was the material density of each phantoms. The density of PMMA slab phantom, ISO water slab phantom and foam sheet are 1.17–1.20 g/cm³, 1 g/cm³ and 0.01–0.02 g/cm³, respectively. On the other hand, the scattering radiation of EPDs on all phantoms had few differences. The effective energy from 33 to 65 keV presented that the reading dose were not difference on each phantom, whereas at the effective energy from 83 to 662 keV showed a few difference reading dose, “in air” condition presented the lowest reading dose than the ISO water slap phantom and PMMA slap phantom.

Figure 1. The reading dose of OSLs, XA type on ISO water slab phantom, PMMA slab phantom and “in air” condition.
Figure 2. The reading dose of OSLs, LA type on ISO water slab phantom, PMMA slab phantom and “in air” condition.

Figure 3. The reading dose of EPDs on ISO water slab phantom, PMMA slab phantom and “in air” condition.

A justification value of two-sample t-stat model with the significant level of 0.05 were used for analysis the reading doses in this experiment and are shown in Table 2, 3 and 4.

Table 2. The statistical analysis results between PMMA slab phantom & ISO water slab phantom of OSLs, XAs and LAs type dosimeter and the Electronic personal dosimeters (EPDs).

| Eff. Energy (keV) | XA t-value | XA t-critical | LA t-value | LA T-critical | EPD t-value | EPD t-critical |
|------------------|------------|---------------|------------|---------------|------------|---------------|
| 33               | 2.113      | 2.228         | 1.320      | 2.228         | 0.488      | 2.228         |
| 48               | 0.529      | 2.447         | 0.223      | 2.228         | 0.173      | 2.228         |
| 65               | 0.233      | 2.228         | 1.620      | 2.228         | 0.168      | 2.228         |
| 83               | 1.533      | 2.228         | 2.179      | 2.228         | 0.417      | 2.228         |
| 100              | 0.373      | 2.228         | 0.187      | 2.228         | 0.337      | 2.228         |
| 118              | 0.793      | 2.228         | 0.627      | 2.228         | 0.360      | 2.228         |
| 662              | 1.838      | 2.228         | 0.865      | 2.365         | 0.606      | 2.228         |
The results of this study showed that the reading results at the effective energy from 83 to 662 keV were "significantly different in statistic point of view". The reason to explain this behaviour is because the ambient dose and it was regarded in term of ambient dose equivalent, $H_\text{eq}$.

The reading dose of EPDs on the solid phantom, water phantom and "in air" condition were not reach to the detector of EPD. Moreover, the results of EPDs reading dose at the effective energy 33 to 662 keV were "significantly different in statistic point of view" at the effective energy of the x-ray from 33 to 65 keV. However, this study showed that the reading dose at the effective energy from 83 to 662 keV were "significantly different in statistic point of view". The reason to explain this behaviour is because of the EPD case contained aluminium sheet inside, therefore the low scattering radiation energy could not reach to the detector of EPD. Moreover, the results of EPDs reading dose at the effective energy 33 and 48 keV of the x-ray showed the under estimation result. The manufacturer company was aware of this behaviour, hence it is recommended in the equipment specification that the effective energy of photon should be more than 60 keV.

It is a matter of facts that selection of phantom is very important for the calibration of the personal dosimeter in order to determine the radiation qualities for human. It is not recommended for the calibration the personal dosimeter in term of $H_\text{eq}$ (10). In practical, the personal dosimeter calibration using PMMA phantom is more comfortable than water phantom. However, in order to harmonize and unify the proficiency testing, the accredited laboratories have adopt the water phantom for personal dosimeter calibration, as recommended by the ISO. Nevertheless, the results of this study showed that the effect of the scattering radiation between the PMMA phantom and ISO water phantom are not significantly different. The comparison of calibration procedure recommended by ICRU and ISO are

**Table 3.** The statistical analysis results between PMMA slab phantom & “in air” condition of OSLs, XAs and LAs type of the OSL dosimeter and the Electronic personal dosimeters (EPDs).

| Eff. Energy (keV) | XA t-value | XA t-critical | LA t-value | LA T-critical | EPD t-value | EPD t-critical |
|------------------|------------|---------------|------------|---------------|-------------|---------------|
| 33               | 6.731      | 2.228         | 6.031      | 2.228         | 0.752       | 2.228         |
| 48               | 9.349      | 2.228         | 8.768      | 2.228         | 1.373       | 2.228         |
| 65               | 18.024     | 2.228         | 10.062     | 2.228         | 0.440       | 2.228         |
| 83               | 5.317      | 2.228         | 9.456      | 2.447         | 5.020       | 2.228         |
| 100              | 5.225      | 2.228         | 6.112      | 2.228         | 9.243       | 2.228         |
| 118              | 7.187      | 2.228         | 4.762      | 2.228         | 9.193       | 2.228         |
| 662              | 3.532      | 2.228         | 3.414      | 2.228         | 10.376      | 2.228         |

**Table 4.** The statistical analysis results between ISO water slab phantom & “in air” condition of OSLs, XAs and LAs type dosimeter and the Electronic personal dosimeters (EPDs).

| Eff. Energy (keV) | XA t-value | XA t-critical | LA t-value | LA T-critical | EPD t-value | EPD t-critical |
|------------------|------------|---------------|------------|---------------|-------------|---------------|
| 33               | 4.663      | 2.228         | 4.554      | 2.228         | 1.275       | 2.228         |
| 48               | 20.764     | 2.228         | 6.203      | 2.447         | 1.588       | 2.228         |
| 65               | 9.013      | 2.228         | 9.766      | 2.228         | 0.278       | 2.228         |
| 83               | 6.930      | 2.228         | 6.663      | 2.365         | 4.984       | 2.228         |
| 100              | 7.198      | 2.228         | 4.961      | 2.228         | 8.796       | 2.228         |
| 118              | 8.624      | 2.228         | 4.712      | 2.228         | 8.346       | 2.228         |
| 662              | 1.847      | 2.228         | 1.668      | 2.228         | 10.836      | 2.228         |

**4. Conclusion and Discussion**

By comparing the reading dose from OSLs, XA and LA type from the experiment between the PMMA phantom and ISO water phantom, the results were “not significantly different in statistic point of view”, in contrast the reading dose “in air” condition from OSLs were “significantly different in statistic point of view” from the others (PMMA and ISO water phantoms). The reason of the difference was the calibration of OSL reader, the OSL reader which used in this study was calibrated in term of the personal dose equivalent, $H_\text{eq}$(10)[3]. However, the reading results of “in air” condition was the ambient dose and it was regarded in term of ambient dose equivalent, $H$ (10)). Thus the reading results were lower than the PMMA phantom and ISO water phantom results.

The reading dose of EPDs on the solid phantom, water phantom and “in air” condition were “not significantly different in statistic point of view” at the effective energy of the x-ray from 33 to 65 keV. However, this study showed that the reading dose at the effective energy from 83 to 662 keV were “significantly different in statistic point of view”. The reason to explain this behaviour is because of the EPD case contained aluminium sheet inside, therefore the low scattering radiation energy could not reach to the detector of EPD. Moreover, the results of EPDs reading dose at the effective energy 33 and 48 keV of the x-ray showed the under estimation result. The manufacturer company was aware of this behaviour, hence it is recommended in the equipment specification that the effective energy of photon should be more than 60 keV[4].

It is a matter of facts that selection of phantom is very important for the calibration of the personal dosimeter in order to determine the radiation qualities for human. It is not recommended for the calibration the personal dosimeter in term of $H_\text{eq}$ (10). In practical, the personal dosimeter calibration using PMMA phantom is more comfortable than water phantom. However, in order to harmonize and unify the proficiency testing, the accredited laboratories have adopt the water phantom for personal dosimeter calibration, as recommended by the ISO. Nevertheless, the results of this study showed that the effect of the scattering radiation between the PMMA phantom and ISO water phantom are not significantly different. The comparison of calibration procedure recommended by ICRU and ISO are
not implying any important differences in former dose estimation. Thus, the dosimetry calibration laboratory can use both phantoms for calibration in term of $H_p(10)$.

References
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