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Research and development of the algorithms to determine the operational personal quantities for photon using photoluminescent dosimeter

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Abstract: Objective: This study presents the results of investigating the dosimetric characteristics of Inlight Al_2O_3:C dosimeters to develop algorithms for determining effective dose, equivalent doses for lens and skin organs by evaluating the operational personal dose equivalent Hp(10) and the ICRU 95 operational personal doses. These quantities are the best approximate values to evaluate the dose limits specified in Circular 19/2012/TT-BKHCN on occupational radiation exposure control. These quantities are calibrated with the ISO 4037 standard dose fields. Research object and method: Investigating dosimetric characteristics of optically stimulated luminescent dosimeter (OSLD) – Inlight type, and applying them in the development of the personal dosimetry algorithms for radiation workers working in the radiation field of gamma and X-ray, using the method of comparing values calculated by both recently developed algorithms and Landauer's algorithm with the reference values for assessing uncertainty. Result: Initially, the algorithms have been developed to evaluate the effective energy of radiation beams using the multi-filter technique, to determine the energy of incident beam air Kerma and conversion coefficients from air Kerma to operational personal dose equivalents Hp(d), and the ICRU 95 new operational quantities. The NTTU-OSLD algorithm has shown a great improvement in energy estimation. This will be useful for other applications such as lens dose measurement by nanodot. Conclusion: The algorithms allow the evaluation of the energy of the incident beam, air Kerma, effective dose, lens and skin equivalent doses through the measurement of the quantities Hp(10), Hp(3), and Hp(0.07) as well as Hp, $D_{p,lens}$, and $D_{p,\,local\ skin}$ according to ICRU 95.

Keywords: *Operational personal dose equivalents Hp(d), Optically stimulated luminescent dosimeter (OSLD), New ICRU 95 operational personal dose, Energy, Kerma.*

I. INTRODUCTION

Working in ionizing radiation environments, health protection and occupational exposure control for radiation workers are crucial issues and regulated by Article 27 of the Atomic Energy Law 2008 [1] and Article 5 of Decree 142/2020/ND-CP, which stipulates that radiation workers must be equipped with personal dosimeters [2]. For radiation protection for radiation workers and the environment, the ICRP has recommended dose limits based on quantities such as effective dose, E and equivalent dose H [3,4] to optimize the use of ionizing radiation and minimize radiation risk. The effective dose and equivalent dose are quantities that cannot be directly measured, therefore ICRP and ICRU have proposed operational personal dose equivalent Hp(d) in their reports [5-9]. Recently, ICRU 95 has introduced new operational quantities: personal dose Hp, Hp, lens and Hp, local skin

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to overcome the limitations of using the quantities Hp(d) which overestimated individual dose limits.

Currently, passive dosimeters such as film dosimeters, glass dosimeters, thermoluminescent dosimeters (TLD) and optically stimulated luminescent dosimeters (OSLD) are widely used. The TLD and OSLD are mainly designed by Harshaw and Landauer companies, respectively, to measure operational dose equivalents Hp(d). Although these methods have contributed significantly to the assessment of occupational personal doses and achieved many scientific and commercial successes, there are still some limitations in practical applications. In a recent study by NTTU's group, when investigating the doses received by interventional staff using InLight - OSL dosimeter, it was found that although the operating X-ray machine voltage was on average around 80-90 kVp, the radiation energy reaching the chest area of medical staff (under lead aprons) during interventional procedures was evaluated much higher (Figure 1) [10]. Most of the calculated energies were above 100 keV even up to 662 keV; for dosimeters worn on chest level and above aprons, the energies of the incident beam are about 80-90 keV. This did not match the actual values. These results were evaluated by Landauer's software. This may lead to errors in assessing dose equivalent Hp(d) due to inaccurate determination of the calibration factor CF and conversion coefficient Cp from air Kerma to operational dose equivalents [11].

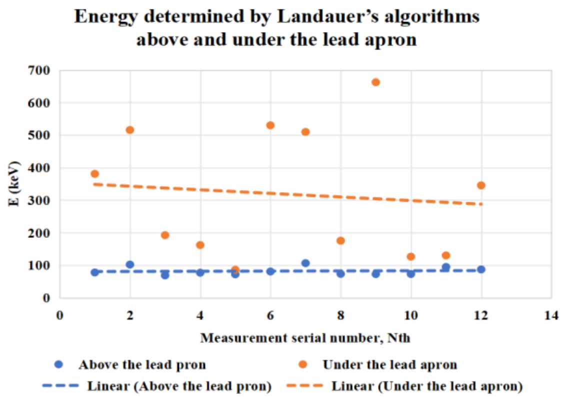

Fig.1. The difference in X-ray energy determined by Landauer's algorithms above and under the lead apron.

In reality, the discrepancies between effective dose E and operational dose equivalent Hp(d) existed. This occurred due to the nature of their definitions [12] has pointed out that:

1. The personal dose equivalent Hp(d) is determined at a depth d in the human body, but conversion factors are calculated for phantoms with simple geometries such as slabs, pillars, and rods.

2. The evaluation of personal and environmental dose equivalents at a specific depth of d = 10 mm does not reflect the complexity of the human body geometry with organs (tissues) located at different positions in the body, which is clearly explained in the definition and calculation of the effective dose E. For neutrons with energies below 1 MeV, this leads to overestimation and underestimation for neutrons with energies above 1 MeV [13].

3. At low photon energies (Ep < 70 keV), selecting a depth of d = 10 mm for assessment of personal and environmental dose equivalents has led to a significantly overestimated effective dose.

To address this issue, ICRU 95 has

introduced new operational quantities: the personal dose equivalent Hp, the absorbed dose to local skin $D_{p,\text{ local skin}}$ and the absorbed dose to the lens of the eye $D_{p,\text{ lens}}$ [9].

Currently, research is being encouraged to develop methods for determining and calibrating these new operational quantities. However, it will take time to accept them as legal quantities like the personal dose equivalent Hp(d).

Due to the above reasons, the research group aims to develop algorithms to assess the operational quantity Hp(10) and the new ICRU 95 operational quantities.

II. DEVELOPMENT OF ALGORITHMS TO DETERMINE OPERATIONAL PERSONAL DOSE EQUIVALENT

1. Determine the operational personal dose equivalent

According to the definition, the dose equivalent H at a point in a tissue is determined as diagram in Fig. 2.:

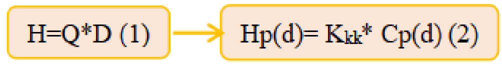

Fig.2. The definition dose equivalent H

Where Q is the radiation quality factor dependent on the energy of the radiation, and D is the absorbed dose in the tissue. Hp(d) is the dose equivalent at a depth of d = 10 mm for estimating effective dose - whole body dose; at a depth of d = 3 mm for estimating lens dose; and at a depth of d = 0.07 mm for estimating skin dose. Hp(d) has the unit of sievert (Sv); K_{kk} is air Kerma, with a unit of Gy and Cp(d) = Hp(d) / K_{kk} is the conversion coefficient from air Kerma to the dose equivalent at the corresponding depth d with the unit of Sv/Gy [4, 5, 8].

In practice, to evaluate Hp(d), it is necessary to determine K_{kk}, this quantity Hp(d) will be determined as diagram in Fig. 3.:

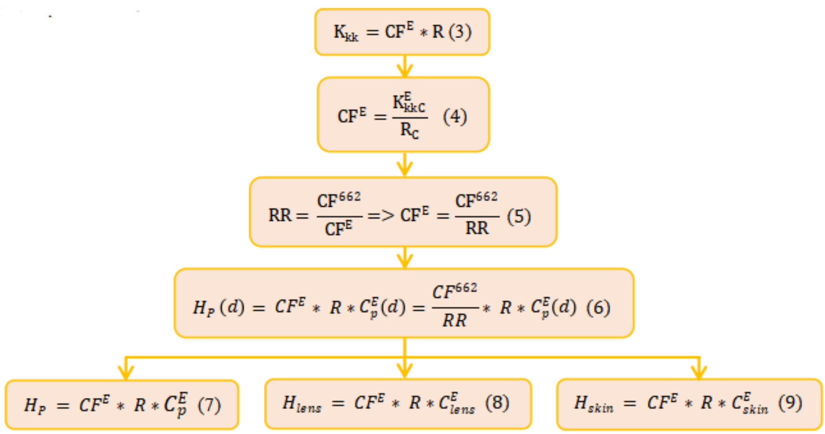

Fig. 3. Diagram of the quantity Hp(d) determination

Where CF^E is the calibration factor (Kerma/reading: Gy/reading or mGy/reading) of the dosimeter, where Kerma is the reference Kerma in air given by the Secondary Dosimetry, at the energy E. K^E_{kkC} is the reference Kerma at energy E, R_c is the reading of the calibrated dosimeter with the reference Kerma K^E_{kkC}. CF^E is a function of energy and depends on the effective atomic number Z of the dosimeter material. Each type of dosimeter has its energy response. The sensitivity of the dosimeter is the reading of the dosimeter per unit dose (reading/dose), or the inverse of the calibration factor. For convenience, the concept of relative sensitivity RR is used, normalised to the sensitivity at the energy of 662 keV (Cs-137 standard source) or 1250 keV (Co-60 standard source).

Where: Hp(d) is the operational personal dose equivalent at depth d, Sv or mSv; CF^E is the calibration factor at E energy (Gy/reading or mGy/reading) Cp(d) conversion factor from air Kerma to Hp(d) (Sv/Gy or mSv/mGy).

In addition, the readings R of the dosimeter also need to be corrected for the losing effects of signal over time (fading effect) C_{fad} and the non-linear response effect $C_{suplinear}$ or mode factor (switching mode from low to high). Since personal dosimeters are usually processed after 1-3 months and depend on which calibration factor is used, then it can be supposed that $C_{fad} = 1$. In the region of radiation protection exposure, $C_{suplinear}$ is equal to 1, too.

2. Development of algorithms to determine operational personal dose equivalent Hp(d) by OSLD

2.1. Preparation of dosimeter and calibration

OSL-Inlight type XA dosimeters and MicroStar Reader of Landauer company were used in this experiment. Each dosimeter was read three times and then the average value was taken after subtracting background reading from each dosimeter reading.

OSL-Inlight dosimeters were calibrated with 5 standard fields of X-ray including N40 (33.3 keV), N60 (47.9 keV), N80 (65 keV), N100 (83.3 keV), N120 (100 keV), and Cs-137 (662 keV) standard field. The reference Kerma for the X-ray fields and Cs-137 field were 2 mGy and 5 mGy, respectively. The dosimeters were calibrated at the secondary standard dosimetry laboratory of the Center for Nuclear Technology in Ho Chi Minh City with a slab phantom.

The design of the OSL-Inlight dosimeter is shown in Fig.4.0:

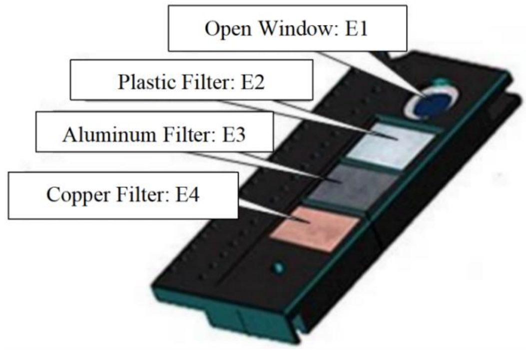

Fig.4. *OSL-Inlight type XA dosimeter [11]*

The OSL chips are placed under 4 different windows with various filters: an open window to measure beta dose, a plastic window to measure the skin dose equivalent Hp(0.07); an aluminium window to measure the dose equivalent of the lens Hp(3); a copper window to measure the whole body dose equivalent Hp(10) [11]. The reference conditions are shown in Table 5 (see below).

2.1.1. Determine energy E of the incident beam

Table 1: Signal ratio between different filters

Signal ratio between different filters				
RQ*	**keV**	**E1/E4**	**E2/E4**	**E3/E4**
N-40	**33.3**	5.03	5.08	4.18
N-60	**47.9**	2.22	2.25	2.02
N-80	**65.0**	1.50	1.55	1.46
N-100	**83.3**	1.25	1.28	1.21
N-120	**100.0**	1.20	1.24	1.14
Cs-137	**662.0**	1.02	1.06	1.02

*(*RQ: Radiation quality)*

Using the multi-filter technique as described above, we can determine the energy of the incident beam by setting up the signal ratios under different filters. Table 1 presents the results of the signal ratio under filters of E1, E2, E3, and E4. The experimental ratios of E1/E4, E2/E4, and E3/E4 are the functions of energy. E1/E4L, E2/E4L, E3/E4L and E3/E4L are the calculated corresponding values.

2.1.2. Determine relative sensitivity/efficiency

Using the formula (5) in Figure 3 to get the calibration factor and to calculate the relative efficiency under different filters of the Inlight dosimeter (Table 2).

Relative efficiencies under different filters					
RQ	**keV**	**RR1**	**RR2**	**RR3**	**RR4**
N-40	**33.3**	3.53	3.55	3.36	1.01
N-60	**47.9**	4.08	4.07	4.13	2.08
N-80	**65.0**	2.12	2.18	2.43	1.56
N-100	**83.3**	1.62	1.64	1.93	1.52
N-120	**100.0**	1.59	1.61	1.89	1.31
Cs-137	**662.0**	0.92	0.95	1.05	1.00

Table 2: Relative efficiencies under different filters

2.2. Algorithm development

2.2.1. Algorithm for determining energy E

After obtaining all the above-mentioned experimental data, using MATLAB software to find fitted functions to describe the experimental curves.

The dependence of the reading ratios under the different filters on the energy E (keV) has been determined by equation (1) with the fitted coefficients of a, b, and c shown in Table 3. Figure 5 illustrates calculated (line) and experimental (dot) curves of reading ratios under different filters with energy.

$$y = a*\exp(-b*E)+c \qquad (1)$$

Table 3: The coefficients of a, b, and c are based on the function matched by the Curve Fitting Toolbox

Ratio	a	b	c
E1/E4	64.550	0.085	1.148
E2/E4	65.810	0.085	1.188
E3/E4	41.810	0.079	1.110

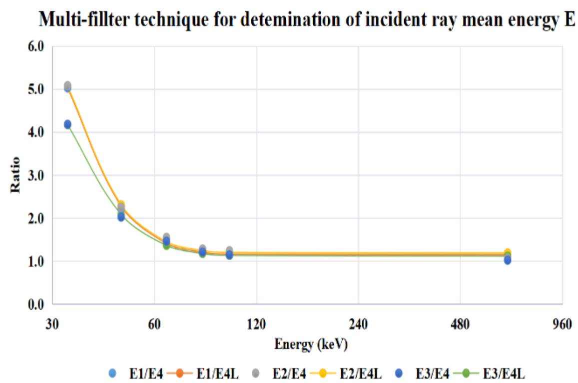

Fig. 1. *The dependence of reading ratio under different filter on energy: experimental data (dots) and calculated values (lines) by semi-empirical formula (1)*

From the semi-empirical formula (1), we can evaluate the energy of the incident beam, if the ratio of readings is known. Since the results of the three energy values calculated from three different curves are quite consistent, we can choose the best function related to the E2/E4 ratio for convenience. The E can be determined by the following formula:

$$E = -\frac{\ln\left(\frac{\frac{E2}{E4}-1.188}{65.81}\right)}{0.085}(\text{keV}) \qquad (2)$$

The ratio $\frac{E2}{E4}$ must be larger than 1.188. For dosimeters with high Z, the energy dependence of the sensitivity is very strong in the region of energy less than 100 keV. When the energy is greater than 100 keV, the sensitivity is less dependent on energy. Therefore, in common practice, we usually use the reference calibration factor at the energy emitted from Cs-137 or Co-60 sources as a standard for calibration factors at energy ≥ 100 keV.

For the relative energy sensitivity RR, the Curve Fitting Toolbox of MATLAB was used. In this case, the dependence of RR with the energy under different filters of RR_1, RR_2, RR_3, and RR_4 is described by Gaussian functions (3), (4), (5), and (6) with correlation coefficients $R^2 = 0.99$.

$$RR_1 = 2.596 * e^{-\left(\frac{E-43.26}{16.91}\right)^2} + 7.567e + 14 * e^{-\left(\frac{E+7.007e+4}{1.207e+4}\right)^2} \quad (3)$$

$$RR_2 = 2.56 * e^{-\left(\frac{E-43.26}{17.35}\right)^2} + 3.233e + 14 * e^{-\left(\frac{E+7.003e+4}{1.222e+4}\right)^2} \quad (4)$$

$$RR_3 = 2.627 * e^{-\left(\frac{E-44.65}{17.01}\right)^2} + 1.057e + 9 * e^{-\left(\frac{E+65180}{14440}\right)^2} \quad (5)$$

$$RR_4 = 0.8605 * e^{-\left(\frac{E-48.75}{10.52}\right)^2} + 1.537 * e^{-\left(\frac{E-76.37}{59.55}\right)^2} + e^{-\left(\frac{E-661.7}{90.72}\right)^2} \quad (6)$$

The difference between the RR values calculated by the above algorithms and the experimental data is presented in Table 4 and Figure 6about the detector and the DAQ system are reported in [12].

Table 4: Ratio of RR (Relative efficiencies) under the different filters: experimental values (RR) and calculated values (RRL) by semi-empirical formulas

Ratio of RR					
RQ	**keV**	**RR1/RR1L**	**RR2/RR2L**	**RR3/RR3L**	**RR4/RR4**
N-40	**33.3**	1.01	1.00	0.91	0.99
N-60	**47.9**	1.01	1.00	0.93	1.01
N-80	**65.0**	1.01	1.00	0.88	1.03
N-100	**83.3**	1.07	1.05	0.89	0.98
N-120	**100.0**	0.95	0.93	0.91	1.03
Cs-137	**662.0**	1.09	1.06	0.96	1.00

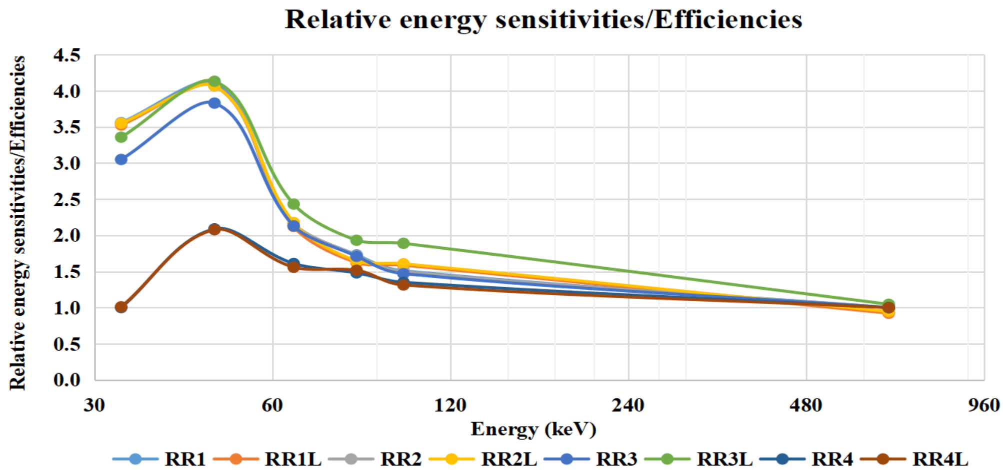

Fig.6. Relative efficiencies curves calculated by semi-empirical formulas and experimental data

It can be seen that the maximum difference between experimental and calculated values RR from the semi-empirical formulas (3), (4), (5) and (6) is around 22 % (see Table 4). The limited number of reference points in experimental curves is one of the main reasons for this difference.

2.2.1.1. Algorithm for calculating the conversion coefficients, Cp(d)

In addition, in the final point, find the conversion coefficients Cp(d) for calculating Hp(d). The Cp(d) includes Cp(10), Cp(3), and Cp(0.07), which are conversion coefficients from air Kerma to dose equivalent Hp(d), calculated by the Monte Carlo methods in the ICRP 78, and ISO 4037 part 3.

Based on the data from ISO 4037 part 3 and ICRU 95, we have developed algorithms suitable for each energy range to provide conversion coefficients with the lowest possible error.

a. Conversion coefficient from Kerma to Hp(10)

For different energy levels, different fitting functions for Cp(10) are shown, as follows:

$$y = 3x10^{-8}x^4 - 2x10^{-6}x^3 - 0.0007x^2 + 0.0884x - 0.9204 \quad (7)$$

(With values $x \geq 16.3$ keV and $x \leq 90$ keV)

$$y = -8x10^{-9}x^3 + 2x10^{-5}x^2 - 0.0075x + 2.3837 \quad (8)$$

(With values $x > 90$ keV and $x < 248$ keV)

$$y = 5x10^{-7}x^2 - 0.001x + 1.634 \quad (9)$$

(With values $x \geq 248$ keV)

b. Conversion coefficient from Kerma to Hp(3)

For different energy levels, different fitting functions for Cp(3) are shown, as follows:

$$y = -0.0013x^2 - 0.0992x - 0.6175 \quad (10)$$

(With values $x \geq 8.5$ keV và $x \leq 33$ keV)

$$y = 1x10^{-8}x^4 - 3x10^{-7}x^3 - 0.0005x^2 + 0.0557x - 0.0324 \quad (11)$$

(With values $x > 33$ keV and $x \leq 65$ keV)

$$y = 9x10^{-6}x^2 - 0.0049x + 1.9726 \quad (12)$$

(With values $x > 65$ keV and $x < 288$ keV)

$$y = 3x10^{-7}x^2 - 0.0006x + 1.4613 \quad (13)$$

(With values $x \geq 288$ keV)

c. Conversion coefficient from Kerma to Hp(0.07)

For different energy levels, different fitting functions for Cp(0.07) are shown, as follows:

$$y = 0.0003x^2 - 0.0015x + 0.8843 \quad (14)$$

(With values $x \geq 8.5$ keV and $x \leq 43$ keV)

$$y = 6x10^{-6}x^3 + 0.0013x^2 + 0.0931x + 0.5437 \quad (15)$$

(With values $x > 43$ keV and $x \leq 65$ keV)

$$y = 1x10^{-5}x^2 - 0.0054x + 2.0956 \quad (16)$$

(With values $x > 65$ keV and $x < 288$ keV)

$$y = 4x10^{-7}x^2 - 0.0008x + 1.5449 \quad (17)$$

(With values $x \geq 288$ keV)

The difference between the conversion coefficient from Kerma to Hp(d) evaluated by the above-mentioned recently developed algorithms and data from the ISO 4037 part 3 lies in the range from 1% to 5%.

2.2.1.2 Development of algorithms for

calculating the air Kerma conversion coefficients to new operational quantities (ICRU 95)

a. Conversion coefficient from Kerma to Personal dose equivalent, Hp

For different energy levels, different fitting functions are used, as follows:

$$y = -444780x^4 + 35941x^3 - 161.45x^2 + 0.0557x - 0.0073 \quad (18)$$

(With values $x \geq 0.05$ MeV and $x \leq 0.039$ MeV

$$y = 6566x^5 - 54967x^4 + 17391x^3 - 2595.6x^2 + 180.11x - 3.217 \quad (19)$$

(With values $x \geq 0.04$ MeV and $x \leq 0.2$ MeV)

$$y = -0.3172x^3 + 0.8409x^2 - 0.78121x + 1.2578 \quad (20)$$

(With values $x \geq 0.21$ MeV and $x \leq 1.04$ MeV)

$$y = 0.0001x^3 - 0.003x^2 - 0.0003x + 1.0009 \quad (21)$$

(With values $x \geq 1.05$ MeV and $x \leq 8.04$ MeV)

$$y = 0.0002x^2 - 0.0216x + 1.0445 \quad (22)$$

(With values $x \geq 8.05$ MeV)

b. Conversion coefficient from Kerma to absorbed dose in Lens $D_{p,\,lens}$

For different energy levels, different fitting functions are used, as follows:

$$y = 373499x^5 - 166857x^4 + 29600x^3 - 2687.7x^2 + 126.48x - 0.8903 \quad (23)$$

(With values $x \geq 0.013$ MeV and $x \leq 0.15$ MeV)

$$y = -11.939x^4 + 19.988x^3 - 11.037x^2 + 1.9039x + 1.2405 \quad (24)$$

(With values $x \geq 0.16$ MeV and $x < 0.69$ MeV)

$$y = -0.006x^4 + 0.089x^3 - 0.425x^2 + 0.533x + 0.9512 \quad (25)$$

(With values $x \geq 0.69$ MeV and $x < 6$ MeV)

$$y = 1.7734x^{-1.005} \quad (26)$$

(With values $x \geq 6$ MeV)

c. Conversion coefficient from Kerma to absorbed dose in local Skin $D_{p,\,local\ skin}$ (dose-Slab phantom)

For different energy levels, different fitting functions are used, as follows:

$$y = -339829x^5 + 155760x^4 - 24782x^3 + 1500.2x^2 - 17.655x + 1.0271 \quad (27)$$

(With values $x \geq 0.01$ MeV and $x \leq 0.17$ MeV)

$$y = -0.5306x^5 + 3.6596x^4 - 9.8661x^3 + 13.107x^2 - 8.8195x + 2.6428 \quad (28)$$

(With values $x \geq 0.171$ MeV and $x \leq 2.1$ MeV

$$y = 0.1586x^{-1.128} \quad (29)$$

(With values $x \geq 2.11$ MeV)

The calculated conversion coefficients from Kerma to new dose equivalent quantities by the above-mentioned semi-empirical formulas are a good fit. It can be seen that the calculated values are almost matched with ICRU 95 data within the range from 0% to 2%, with only a few points getting an error of up to 5%. See also figures from 7 to 12.

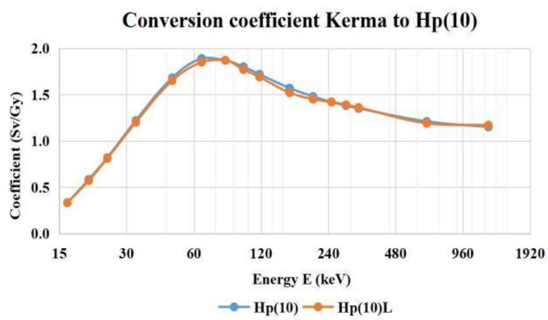

Fig. 7. Semi-empirical and data curves of the conversion factor from Air Kerma to Hp(10)

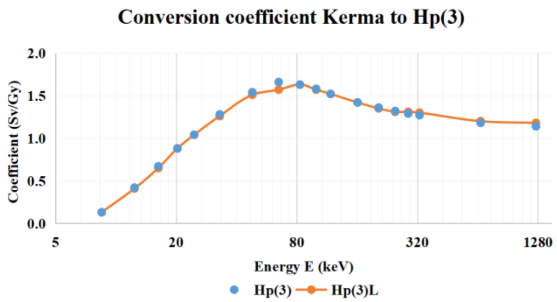

Fig. 8. Semi-empirical and data curves of the conversion factor from Air Kerma to Hp(3)

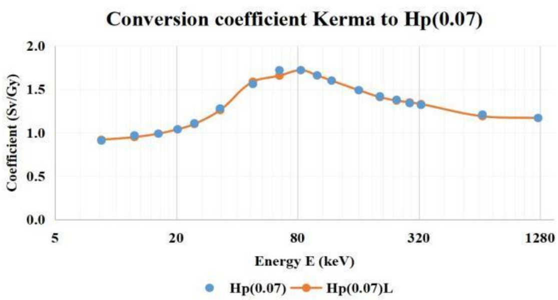

Fig. 9. Semi-empirical and data curves of the conversion factor from Air Kerma to Hp(0.07)

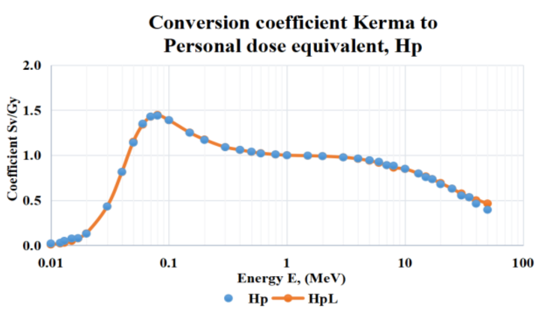

Fig. 10. Semi-empirical and data curves of the conversion factor from Air Kerma to Hp

according to ICRU 95

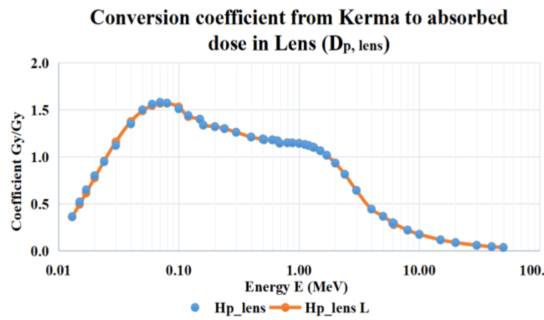

Fig. 11. Semi-empirical and data curves of the conversion factor from Air Kerma to Dp, lens according to ICRU 95

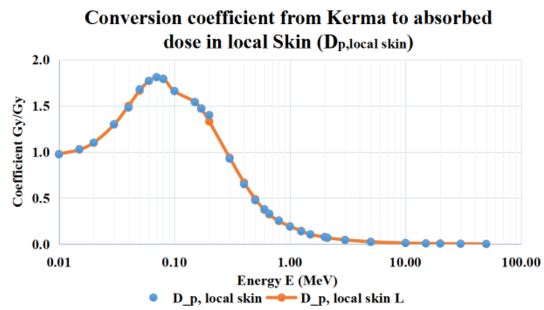

Fig. 12. Semi-empirical and data curves of the conversion factor from Air Kerma to Dp, local skin according to ICRU 95

2.3 Comparison of the operational personal dose received by two algorithms

The aforementioned algorithms were denoted as NTTU-OSLD, and the algorithms provided by Landauer company were denoted as LANDAUER-OSLD. Two algorithms were applied to evaluate some quantities against reference values such as energy, Kerma, operational personal dose, Hp(d) and Hp, Dp, lens, Dp, local skin

The comparison is calculated as follows:

Δ%=(Calculated values-Reference values)/(Reference values) (30)

The reference values are shown in Table 5.

The results of E, Kerma and Hp(d) calculated by the NTTU-OSLD algorithm were shown in Table 6

The results of Hp(d) calculated by the Landauer OSL algorithm are shown in Table 7

The results of calculating the new personal doses in ICRU 95 (noted as Hp, $D_{p, lens}$ and $D_{p, local\ skin}$) are presented in Table 8.

From Tables 6 and 7, it was found that the energy values estimated by the NTTU-OSLD are in good compliance with the reference values and rather better than those estimated by LANDAUER-OSLD.

Table 5. Reference values used for calibration

RQ	Kerma (mGy)	Hp(0.07) (mSv)	Hp(3) (mSv)	Hp(10) (mSv)	E (keV)	Hp (mSv)	$D_{p, lens}$ (mGy)	$D_{p, local\ skin}$ (mGy)
N-40	2.00	2.56	2.56	2.44	33.30	1.09	2.38	2.96
N-60	2.00	3.12	3.12	3.36	47.90	2.15	2.94	3.28
N-80	2.00	3.44	3.44	3.78	65.00	2.78	3.14	3.58
N-100	2.00	3.44	3.44	3.74	83.30	2.87	3.12	3.54
N-120	2.00	3.32	3.32	3.60	100.00	2.78	3.02	3.32
Cs-137	5.00	6.05	5.90	6.05	662.00	5.08	5.90	1.66

Table 5. Calculated values of E, Kerm and, Hp(d) by NTTU-OSLD and their differences to reference values in Δ%

RQ	E keV	Δ%	Kerma mGy	Δ%	Hp(10) mSv	Δ%	Hp(3) mSv	Δ%	Hp(0.07) mSv	Δ%
N-40	33.4	0	1.74	-13	2.52	3	2.64	3	2.37	-3
N-60	48.8	2	1.95	-3	3.24	-4	3.27	5	3.44	2
N-80	61.9	-5	1.89	-6	3.70	-2	3.00	-13	3.57	-6
N-100	80.2	-4	1.98	-1	3.56	-5	3.20	-7	3.43	-8
N-120	94.2	-6	1.76	-12	3.34	-7	3.29	-1	3.32	-8
Cs-137	662.0	0	4.84	-3	5.72	-5	5.66	-4	5.95	-2

Table 6. Calculated values of E and Hp(d) by Landauer algorithm and their differences to reference values in Δ%

RQ	E (keV)	Δ%	Deep Dose (mSv)	Δ%	Lens Dose (mSv)	Δ%	Shallow Dose (mSv)	Δ%
N-40	47.7	43	2.06	-16	2.16	-16	2.16	-16
N-60	63.4	32	3.58	7	3.55	14	3.43	10
N-80	87.9	35	2.82	-25	2.76	-20	2.65	-23
N-100	141.6	70	3.21	-14	3.21	-7	3.16	-8
N-120	231.8	132	3.11	-14	3.11	-6	3.15	-5
Cs-137	662.0	0	5.61	-7	5.60	-5	5.53	-9

Table 7. Calculated values of Hp, $D_{p, lens}$, $D_{p, local\ skin}$ and the differences to reference values in Δ%

RQ	Hp (mSv)	Δ%	$D_{p, lens}$ (mGy)	Δ%	$D_{p, local\ skin}$ (mGy)	Δ%
N-40	1.18	8	2.49	5	2.83	-4
N-60	2.19	2	3.01	2	3.55	8
N-80	2.64	-5	2.66	-15	3.03	-15
N-100	2.54	-11	3.39	9	3.49	-1
N-120	2.34	-16	2.86	-5	3.23	-3
Cs-137	4.89	-4	5.90	0	1.68	1

Taking into account on main contributors to uncertainty such as relative efficiencies, reference values, deviation of reading, and conversion factors of energy, the uncertainties of assessments Hp(d) calculated by both two algorithms NTTU-OSLD and LANDAUER-OSLD are around 18,5% which is acceptable and within the frame of "trumpet curve" [14].

III. CONCLUSION

The research team has developed algorithms for determining energy, calibration factors, and conversion factors from Kerma to operational personal dose equivalent, including new operational quantities in ICRU 95.

Based on that, the personal dose calculation software named the NTTU-OSLD also has been developed. The obtained Hp(d) values are consistent with the reference values and the results calculated by the software of Landauer company. However, those of the incident beams calculated by the NTTU-OSLD algorithms are rather better than the energy values of the Landauer algorithm. The new ICRU 95 operational quantities, Hp, $D_{p, lens}$, and $D_{p, local\ skin}$ were also estimated.

The NTTU-OSLD algorithm has showed a great improvement in energy estimation that will be useful for other applications such as for lens dose measurement by nanodot.

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