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Technical Paper

Assessment of Occupational Exposure Dose to Radiation Workers in Secondary Standard Dosimetry Laboratory of Mongolia

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Abstract - The most accurate calculation strategies available should be used for the estimation of radiation doses in the potential accident associated with radioactive sources in laboratories. The objective of this study was to estimate skin dose, eye dose and personal dose equivalent to radiation workers in the Secondary Standards Dosimetry Laboratory (SSDL) in Mongolia which nationwide provides calibration services for dosimetry instrument and ensures that radiation measurements are consistent with International System of Units (SI). Using a computer code for skin contamination dosimetry, VARSKIN, in case of unexpected accidental exposure scenarios, we compared the results of computer code with the measurements of thermoluminescent dosimeter (TLD). Among the most frequently used radionuclides in the laboratory practices, ^{137}Cs radiation source was selected and analysis of data obtained from TLD was also described in this study. We studied a point and cylindrical source geometry assuming varying thicknesses of absorbing layers. The computer code was successfully used to calculate directional dose equivalent H′ (0.07) in terms of control of skin dose and area monitoring, personal dose equivalent $H_p(10)$ in terms of effective dose and individual monitoring. Results indicated a good comparison between the calculation results and measurement data. The deviations between calculated and measured doses were found to be within the range of 2.6% for different time interval measurements. For the skin depth of 0.07 mm, dose rates were 7~12 times higher than the depth of 3 mm and 10 mm for eye and equivalent dose, respectively.

Key words : SSDL, Radiation worker, Dose assessment, VARSKIN

INTRODUCTION

The International Commission on Radiological Protection (ICRP) describes the skin as an essential organ for which radiation monitoring must be undertaken. Annual dose limits to skin are 50 mSv for the general public and 500 mSv for radiation workers. The estimation of skin dose is not simple topic. For the most of radionuclide contaminants of concern, the dose to skin consists of electron and photon. The contributions to the skin dose of these types of radiation depend on their energy distributions and the attenuation of the contamination. Radiation measurement instruments such as survey meters or personal dosimeters do not provide any useful information in the cases of accidents. It is therefore imperative to provide tolerable assessment of skin dose in case any worker accidentally gets exposed. Previous studies of skin dose were mostly performed using computational dosimetry codes such as VARSKIN code and Monte Carlo simulations, but there has been rarely performed using laboratory data (Amato and Italiano 2018; Dubeau *et al*. 2018). Exposure of hands and fingertips to relevant dose rates has been of great

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interest in the presence of high or moderate activities in university laboratories where operational radiation protection has not been usually optimized in terms of manipulation shields, tools and procedures. Radiation safety officers are therefore needed to estimate the potential exposure of given amounts of radionuclides and to assess skin doses from abnormal exposures that may occur under emergency situations. The objective of this study is to estimate skin dose, eye dose and equivalent dose to the occupational worker of Secondary Standard Dosimetry Laboratory (SSDL) of Nuclear Energy Commission (NEC) in Mongolia. Calculation results of skin dose, eye dose and equivalent dose from the radiation source of ^{137}Cs were compared with the dose limit of 500 mSv per year whose limits were established from the ICRP.

MATERIALS AND METHODS

1. VARSKIN code

VARSKIN dosimetry code was developed to estimate the skin doses resulting from the spectrum of beta energies emitted from various radioactive contaminants, especially, skin dose at 0.07 mm and dose at a depth of 10 mm (Hamby *et al*. 2013; Hamby and Mangini 2018). Because VARSKIN code was based on the dose-point kernel method, the code needed the numerical integration of a point kernel over the entire source volume and dose averaging area of interest. While VARSKIN calculations were much faster than Monte Carlo simulations, their accuracy was sacrificed with the simplification of point kernel. The point kernel was generally given by Eq. (1).

$$\dot{D}_{\beta(r)} = \left[\frac{Gy}{sec}\right] = \frac{1.6\times10^{-10}\left[\frac{J\cdot g}{MeV\cdot kg}\right]\cdot A\left[\frac{dis}{sec}\right]\cdot Y\left[\frac{\beta}{dis}\right]\cdot \bar{E}_{\beta}\left[\frac{MeV}{\beta}\right]\cdot F_{\beta}(\xi)}{4\pi r^2\cdot\rho\left[\frac{g}{cm^3}\right]\cdot X_{90}[cm]} \quad (1)$$

where

A: activity ($dis\cdot sec^{-1}$)

Y: beta yield per disintegration ($\beta\cdot dis^{-1}$)

$\tilde{E}$: mean energy ($MeV\cdot\beta^{-1}$)

$F_{\beta}(\xi)$: scaled absorbed dose distribution

ξ: parameter for density scaled distance from the source point to the dose point

r: physical distance between the source point and the dose point

ρ: density ($g\cdot cm^{-3}$)

X_{90}: ratio normalized to the distance

Five source geometries were available such as point, disk, cylinder, spherical and slab source. Source activity was assumed to be evenly distributed throughout the area or volume of all source geometries. The point source geometry was simple to use in determining whether a regulatory limit was exceeded or not. The point source geometry did not account for electron self-shielding, so a three-dimensional source geometry was best for particulate contamination (Hamby and Mangini 2018). The point source model did not require any data describing the physical dimensions of the source and generally yielded the highest dose rate for a given activity of available source geometries. For electron dosimetry, a point source was automatically modeled as a cylindrical source with a thickness and a radius of 1 micron and a density of 0.001 $g\cdot cm^{-3}$. In this study, the point source and cylindrical source geometry were selected (Hamby *et al*. 2013).

2. TLD measurements

Irradiations of TLD were performed by ^{137}Cs source with G10 gamma beam irradiator as shown in Fig. 1. The irradiator was used in SSDL where a source to detector distance (SDD) was 200 cm. The beam profiles shown in Fig. 2 were measured by the Physikalisch-Technische Werkstätten (PTW) M32002 reference chamber. The energy response of PTW M32002 chamber could measure the energy within the range of 45 keV to 1.3 MeV. It achieved the measurement by a thin

Fig. 1. ^{137}Cs source with G10 gamma beam irradiator.

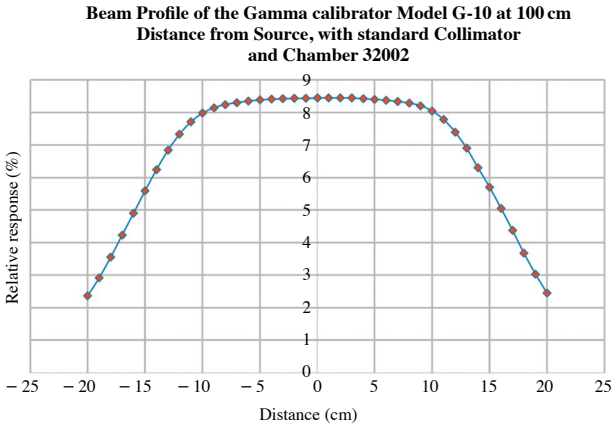

Fig. 2. Beam profile of G10 gamma beam irradiator.

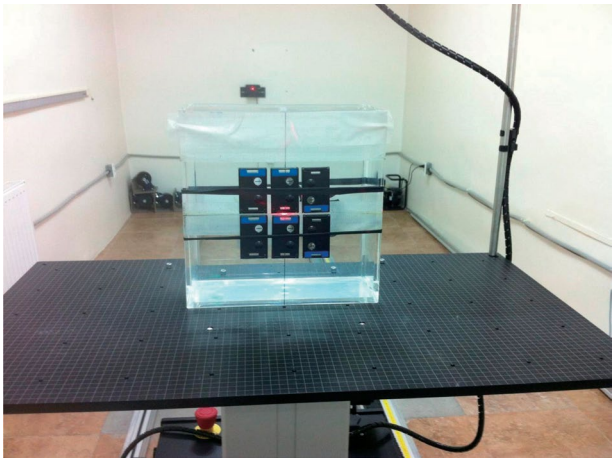

Fig. 3. Irradiation of TLD.

layer of aluminum within its inner wall surface and provided increased photoelectric yield to compensate for absorption. With SDD of 200 cm, the TLDs were irradiated in a water phantom of 30 cm × 30 cm × 15 cm made by PTW as shown in Fig. 3. The irradiated TLDs available for this study were TLD-100 chips (Harshaw-4500) with dimensions of 3.2 mm × 3.2 mm × 0.89 mm. The time intervals between irradiation and reading were 3 days (Budanec *et al*. 2008). For the use of VARSKIN code, the air gap was limited to a maximum of 20 cm. In this study, air gap was selected as 20 cm from the point source of maximum limit. TLDs were irradiated at 200 cm from the radiation source of ^{137}Cs. Using the inverse square law, the radiation dose at 20 cm from a point source was calculated using Eq. (2).

$$\dot{D}_1 X_1^2 = \dot{D}_2 X_2^2 \quad (2)$$

where D and X are dose rate and distance to the point of interest, respectively. From Eq. (2), radiation dose at 20 cm was compared with that calculated by VARSKIN code.

Table 1. TLD measurements and personal dose equivalent $H_p(10)$ using VARSKIN

Isotope	Activity	Energy	Time intervals	$H_p(10)$ (mSv)		Ratio
	Bq	keV	s	TLD	VARSKIN	
^{137}Cs	7.4×10^{11}	662	242.12	107.0	109.8	0.97
			605.30	260.0	274.8	0.95
			1210.60	534.0	548.4	0.97
			2421.21	1048	1098	0.95
			6053.02	2602	2748	0.95

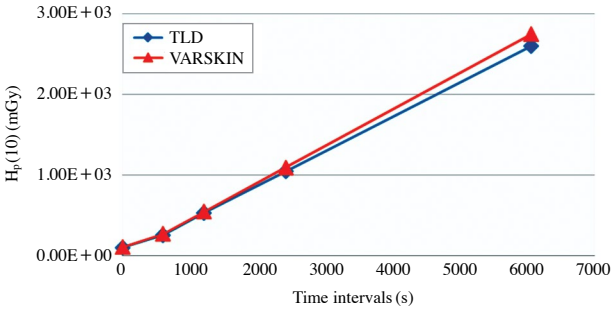

Fig. 4. Comparison results between TLD and VARSKIN.

RESULTS AND DISCUSSION

In this study, after the irradiation of TLD measurements were performed by Harshaw 4500 reader in Radiation Control Laboratory (RCL) of General Agency for Specialized Investigation in Mongolia. The results showed that there were no appreciable differences between measured data and calculated doses by VARSKIN code. TLDs were used to verify the dose calculation model in different time intervals. Differences between calculated and measured doses were found to be within 2.6% for different time intervals. These findings confirmed that the model adequately described the experiment. Table 1 shows results of personal dose equivalent of TLD measurements and dose calculations for the purpose of comparison (Bakali *et al*. 2001). Results between measured and calculated values using the VARSKIN code were in good agreement. The agreement in the case of personal dose equivalent was shown in Fig. 4.

Doses of VARSKIN were converted from $mGy \cdot h^{-1}$ to $nGy \cdot min^{-1}$. The dose rates were specific to the defined source strength, geometry, skin depth, source covering area

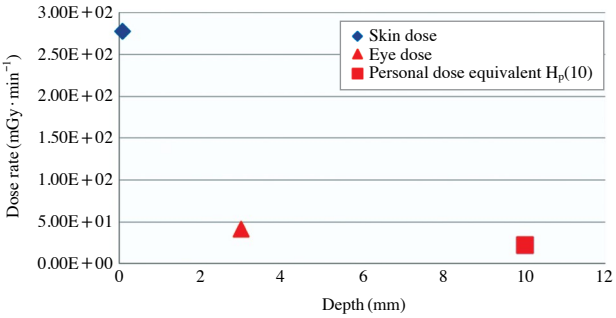

Fig. 5. Dose rate as a function of depth from ^{137}Cs source.

Table 2. Sensitivity analysis between point and cylindrical geometry for ^{137}Cs source

Isotope	Activity	Energy	Time intervals	VARSKIN geometry	
				Point	Cylinder
	Bq	keV	s	mSv	
^{137}Cs	7.4×10^{11}	662	242.12	109.8	100.6
			605.30	274.8	250.8
			1210.60	548.4	502.8
			2421.21	1098.0	1005.6
			6053.02	2748.0	2508.0

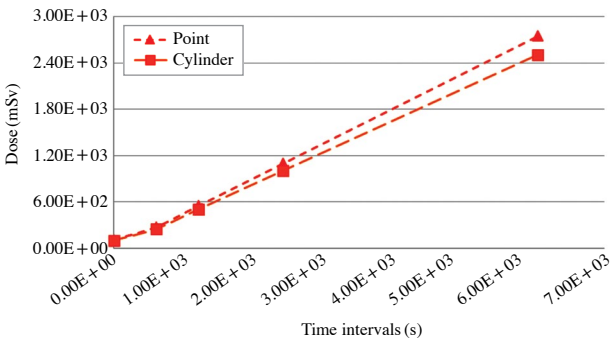

Fig. 6. Sensitivity analysis between point and cylindrical geometry for ^{137}Cs source.

and radius. Fig. 5 shows a rapid increase in dose at the shallowest of depths due to increasing population of charged particles creating build up before electronic equilibrium is reached. Electronic equilibrium occurs at about 0.07 mm, and then dose decreases with increase with depth. A depth interval of skin dose, eye dose and equivalent dose were considered. Especially, at skin depth of 0.07 mm, dose rate was 7∼12 times higher than the depth of 3 mm and 10 mm. This high value could be explained as a result of dose contributions from the electron on the surface of skin. Additionally, calculation results showed that the exact dose contributor to the skin could be differentiated between photon and electron dose.

In this study, several comparison results were provided between one-dimensional point source and two-dimensional cylindrical source. A sensitivity analysis using geometry parameters was available in VARSKIN code. Results showed that the most sensitive source dimension for calculating dose was source thickness. Also, the dose varied substantially for small differences in the value of the input parameters. All the related parameters were taken from the certificate of ^{137}Cs cylindrical source with a thickness of 19.2 mm, a radius of 8.7 mm and a density of 8 g·cm^{-3}. In this calculation, point and cylindrical source geometry were selected and radiation doses were estimated at the depth of 10 mm and the area of 1 cm^2 (Hamby *et al*. 2013). The comparison results are shown in Table 2. Fig. 6 shows a sensitivity analysis between point and cylindrical modeling geometry with ^{137}Cs source and a good agreement was observed with the previous study.

CONCLUSION

VARSKIN code was a useful tool for estimating skin dose at 0.07 mm, eye dose at 3 mm and personal dose equivalent at a depth of 10 mm. We compared the results of TLD measurements and VARSKIN calculations for a point geometry of ^{137}Cs radiation source. We found good comparison results between TLD measurements and calculations using VARSKIN code for the case of one-dimensional source model in terms of personal dose equivalent $H_p(10)$. The deviations between calculated and measured doses were within the range of 2.6% for different time interval measurements. Calculation results showed that values of directional dose equivalent H′ (0.07) were 7∼12 times higher than personal dose equivalent $H_p(10)$ which was dose rate over area of 1 cm^2. Calculation results could give more precise results in a reasonable time and improve the accuracy of assessing skin doses in routine as well as accidental exposure. Even in cases of laboratory accidents, it was found that occupational radiation doses to laboratory workers by the unexpected exposures could be assessed using VARSKIN code.

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REFERENCES

Amato E and Italiano A. 2018. Evaluation of skin absorbed doses during manipulation of radioactive sources: a comparison between the VARSKIN code and Monte Carlo simulations. *J. Radiol. Prot.* **38**(1):262-272.

Bakali M, Fernandez F, Bouassoule T, Castelo J and Gonzalez A. 2001. Hot particle dosimetry at nuclear power plants. *Radiat. Meas.* **34**(1-6):487-490.

Budanec M, Knezevic Z, Bokulic T, Mrcela I, Vrtar M, Vekic B and Kusic Z. 2008. Comparison of doses calculated by the Monte Carlo method and measured by LiF TLD in the build-up region for a ^{60}Co photon beam. *Appl. Radiat. Isot.* **66**(12): 1925-1929.

Dubeau J, Witharana SSH, Sun J, Heinmiller BE and Chase WJ. 2018. A comparison of beta skin doses calculated with VARSKIN 5.35.3 and MCNP 5. *Radiat. Prot. Dosimetry* **182**(4):502-507.

Hamby DM and Mangini CD. 2018. VARSKIN 6, A computer code for skin contamination dosimetry. NUREG/CR-6918, Rev. 3.

Hamby DM, Lodwick CJ, Palmer TS, Reese SR, Higley KA, Caffrey JA, Sherbini S, Saba M and Bush-Goddard SP. 2013. The new VARSKIN 4 photon skin dosimetry model. *Radiat. Prot. Dosimetry* **154**(3):356-363.

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