Exposure optimization caused by handling of radiopharmaceuticals

M. Fülöp[1*], M., J. Hudzietzová[2], J. Sabol[3], P. Povinec[4], A. Vondrák[5], A., P. Ragan[1], L. Foltínová[6].

[1]*ABRS, s.r.o., Pomlejská 106, Šamorín, 93101, Slovakia*
[2]*Czech Technical University in Prague, Faculty of Biomedical Engineering, nám. Sítná 3105, 272 01 Kladno Czech Republic*
[3]*Faculty of Security Management PACR in Prague, Lhotecká 559/7, Prague, 143 01, Czech Republic*
[4]*BIONT, a. s., Karloveská 63, Bratislava, 842 29, Slovakia*
[5]*IZOTOPCENTRUM, s.r.o., Rázusová 24, Nitra, 949 01, Slovakia*
[6]*EUBA, University of Economics in Bratislava, Dolnozemská cesta 1, Bratislava, 852 35, Slovakia*

[*]Corresponding author's e-mail: marko.fulop@gmail.com

Abstract. Handling of radiopharmaceuticals during their preparation and application consists of several operations that, depending on the geometry and duration of irradiation, causes various skin exposure on the hands. The results of personal monitoring show that approximately 10 % of workers at nuclear medicine departments in Slovakia and the Czech Republic regularly receive an increased skin exposure, which is close to the investigation level set by the respective regulatory authorities. The reasons for such elevated exposure are not usually revealed and identified. The presentation proposes a new way of identifying the probable cause associated with specific procedures for handling radiopharmaceuticals that may have caused excessive skin exposure. During this manipulation, the hands of the person in the vicinity of the manipulated sources are usually inhomogeneously exposed. Contact with radioactive sources involves the preparation and administration of radiopharmaceuticals to patients. The ORAMED project found a direct relationship between the overall distribution of the personal dose equivalent of $H_p(0.07)$ characterizing skin exposure when preparing or administering radiopharmaceuticals to patients using various individual methods or techniques [1, 2, 3]. In workers with excessive skin exposure, dose distribution is visibly disrupted by such excessive exposure. Dose distribution is performed by additional measurements at 12 sites of the hands. The proposed new way is to use two dosimeters, one of which is a finger dosimeter. This two-detector monitor was used in the nuclear medicine department to identify the actual irradiation of the skin of the hands due to a probable violation of prescribed work procedures for manipulation with positron radiopharmaceuticals.

KEYWORDS: Nuclear medicine, worker, skin exposure, radiopharmaceutical, personal dose equivalent.

1 INTRODUCTION

Although nuclear medicine personnel demonstrate the adoption of good working practices, higher exposure values are regularly recorded each year for some workers who engage in similar activities to their colleagues.

The contribution of both gamma and positron radiation to the dose should be taken into account when handling hand skin exposure when handling positron radiopharmaceuticals. Positrons are accompanied by gamma radiation. It is formed by destroying positrons and electrons when they meet. Positrons have a relatively low penetration compared to gamma radiation. Therefore, workers handling unshielded syringes or infusion tubes filled with positron radiopharmaceuticals are more often informed of the risk of exposing hands to gamma radiation than for positrons.

Perhaps this could also be said of some experts in the field of radiation protection. For example, finger dosimeters are often equipped with 0.9 mm thick TLDs that underestimate the monitored skin exposure caused by positrons emitted by ^{18}F. In addition, finger dosimeters are usually worn on those parts of the hands into which positrons rarely penetrate during standard manipulations with positron radiopharmaceuticals.

The presentation proposes a new way of identifying the probable cause associated with specific handling procedures that are likely to lead to excessive skin exposure. The proposed measures contribute to

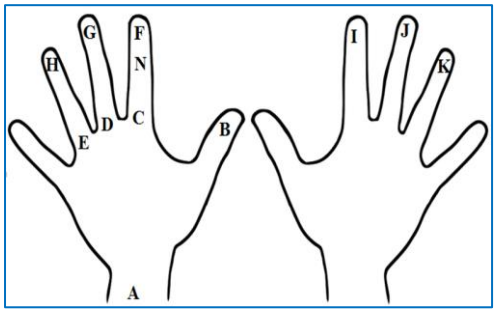
improving the routine monitoring of radiopharmaceutical manipulations in order to help assess work habits leading to above-average exposure of some workers.

It also allows the introduction of corrections of the undervalued personal dose equivalent of $H_p(0.07)$ from positrons due to the use of 0.9 mm thick TLDs in the finger monitor.

2 METHODS

In order to determine the extent of gamma and positron exposure of the hands of nuclear medicine workers, a validated mapping method is applied using a pair of TLDs located at 12 hand locations that are significantly irradiated when handling radiopharmaceuticals and also where skin exposure dosimeters have been placed as it is shown in Fig. 1.

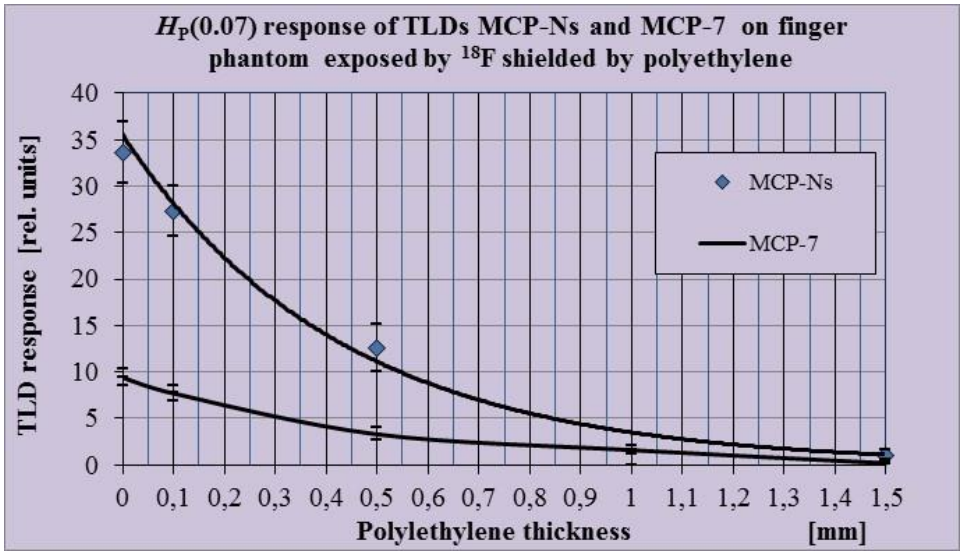
Figure 1: Positions of dosimeters for mapping the irradiation of the right hand skin in $H_p(0.07)$.



Each pair of TLDs consists of an MCP-7 dosimeter with a thickness of 0.9 mm and a dosimeter MCP-Ns with an effective sensitive layer thickness of about 0.05 mm. The dosimeters MCP-7 and MCP-Ns are made from the same thermoluminescent material [4].

Measurements of the *H*p(0.07) personal dose equivalent TLD responses of MCP-Ns and MCP-7 to annihilation photons and positrons emitted by ^{18}F as a function of the thickness of the polyethylene shielding layer of the positron source ^{18}F are shown in Fig. 2.

Figure 2: $H_p(0.07)$ personal dose equivalent response of TLDs MCP-Ns and MCP-7 to annihilation photons and positrons emitted by the ^{18}F as a function of the thickness of the polyethylene shielding layer of the positron source ^{18}F [5].



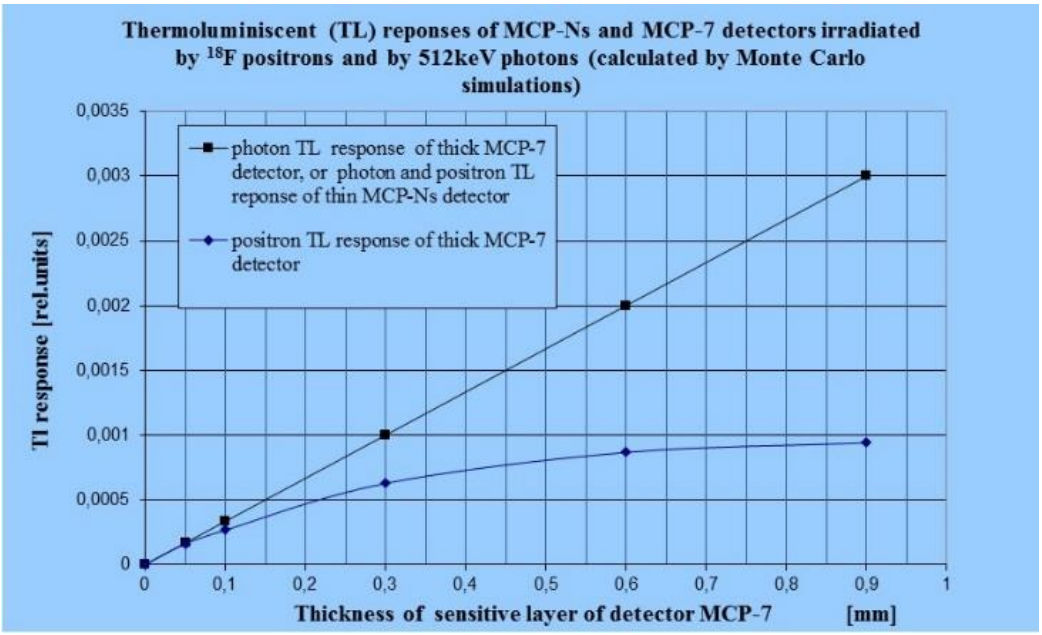
This figure shows that the positron source can also be an unshielded ^{18}F-FDG syringe having a wall thickness equivalent to 1 mm polyethylene.
The responses of the TLDs MCP-7 and MCP-Ns to annihilation photons and positrons of ^{18}F source are shown in the Fig. 3 as a function of the thickness of the sensitive layer.

In this figure, a linear dependence of the TLD responses of MCP-Ns on the intensity of irradiation with ^{18}F positrons or 511 keV annihilation photons can be observed.

Similarly, the TLD response of MCP-7 is linearly dependent on the intensity of 511 keV photons. However, when the MCP-7 TLD is exposed to the positrons of the ^{18}F source, the response dependence is not linear because, unlike the thin sensitive layer of the MCP-N TLD, the positrons in the larger sensitive volume of the MCP-7 TLD, are highly absorbed [5].

The responses of the TLDs MCP-7 and MCP-Ns to annihilation photons and positrons emitted by the ^{18}F source were simulated by the Monte Carlo code MCNPX.

Figure 3: The responses of the TLDs MCP-7 of thickness up to 0,9 mm to annihilation photons and positrons emitted by the ^{18}F source [5].



For measuring positrons so-called thick TLDs at their thickness of 0.9 mm, the efficiency decreases to less than 1/3.

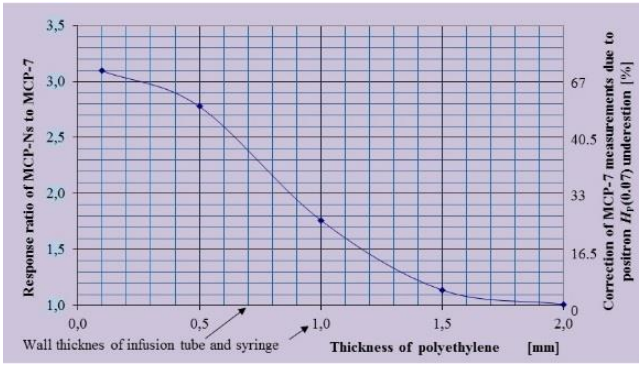
The differences in shapes of the responses of TLDs MCP-7 and MCP-Ns, shown in Figs. 2 and 3, can be used to selective determination of the $H_p(0.07)$ due to positron and photon components of the radiation field at the site of simultaneous measurement with both detectors.

Ratios of $H_p(0.07)$ of dose equivalent responses MCP-Ns and MCP-7 dosimeters, and underestimations of the positron $H_p(0.07)$ dose equivalent measured by MCP-7 in comparison to MCP-Ns irradiated by ^{18}F source shielded by polyethylene of various thicknesses (calculated by Monte Carlo simulations), is shown in Fig.4.

The percentages corrections $[\text{MCP-7}]_{corr}$ were calculated by equation (1):

$$[\text{MCP}-7]_{corr}(\%) = \frac{[\text{MCP}-\text{Ns}]-[\text{MCP}-7]}{[\text{MCP}-\text{Ns}]} \cdot 100 \qquad (1)$$

Figure 4: Ratios of $H_p(0.07)$ of dose equivalent responses MCP-Ns and MCP-7 dosimeters, and percentages underestimations of the positron $H_p(0.07)$ dose equivalent measured by MCP-7 in comparison to MCP-Ns irradiated by ^{18}F source shielded by polyethylene of various thicknesses [5].



3 RESULTS

The newly proposed method of two detectors monitoring the personal dose equivalent of *H*p(0.07) of the skin of the hands was verified by hand dose mapping of 11 nuclear medicine staff who were preparing, or administering the radiopharmaceutical ^{18}F-FDG to 450 patients in 18 measurement cycles. The results of personnel exposure measurements in mSv per one measurement cycle (25) patients are given in Table 1.

Table 1: Results of verification of the properties of the proposed two-detector monitor of personal dose equivalent $H_p(0.07)$ of skin irradiation on the hands by measuring the staff of the nuclear medicine department preparing, or administering the radiopharmaceutical ^{18}F -FDG to patients

Place of monitoring, also in Fig.1	Proper handling of radiopharmaceutical			Improper handling of radiopharmaceutical			Amount of positron dose not registered by TLD MCP-7, see Eq.(1)
	MCP-Ns	MCP-7	MCP-7/ MCP-Ns	MCP-Ns	MCP-7	MCP-7/ MCP-Ns	
B-thumb	8,18	9,42	1,15	-	-	-	-
B-thumb	4,29	5,21	1,22	-	-	-	-
B-thumb	10,55	10,69	1,01	-	-	-	-
B-thumb	14.18	12.61	0.89	-	-	-	11 %
F-index finger	35	5,22	1,20	-	-	-	-
F-index finger	20,83	27,73	1,33	-	-	-	-
F-index finger	53.72	48.9	0.9	-	-	-	10 %
I-index finger back	11.52	8.73	0.76	-	-	-	24 %
B-thumb	12.00	11.22	0.93	-	-	-	7 %
F-index finger	6.16	4.13	0.67	6.16	4.13	0.67	33 %
F-index finger	-	-	-	7.99	4.45	0.56	44 %
F-index finger	-	-	-	19.65	5.25	0.27	73 %
F-index finger	-	-	-	19.43	8.03	0.41	59 %
F-index finger	-	-	-	8.79	4.65	0.53	47 %
F-index finger	-	-	-	16.48	9.06	0.55	45 %
F-index finger	-	-	-	40.22	18.49	046	55 %
F-index finger	-	-	-	14.56	7.94	0.55	45 %
G-middle finger	-	-	-	21.89	7.72	0.35	66 %
X1 B-thumb	-	-	-	94.35	53.62	0.57	44 %
X2 B-thumb	-	-	-	99.51	60.26	0.61	39 %

The "improper handling" column in the table indicates that the worker is significantly exposed with positrons on his hands. Thus, when handling a positron radiopharmaceutical, the worker probably removed or ignored the protective shield. This mishandling cannot be detected with a standard finger monitor (using TLD 0.9 mm MCP-7), which underestimates positrons gamma radiation contributions, as is shown in Fig.3.

A personal monitor with two detectors from the recorded skin irradiation can detect whether it was also caused by positrons. It will also make it possible to estimate the magnitude of this positron irradiation and thus quantify the radiation risks posed by the presence of positrons when was the personal monitor exposed [5].

Table 2 illustrates such a procedure for quantifying the risk according to the size ratio of doses due to photons and positrons.

Table 2: Possible procedure of quantification of the risk of skin exposure monitored using a new two-detector hand-held monitor in case of deviations from prescribed work procedures

Cycle No.	Finger monitor in mSv per one measurement cycle		Handling with positron radiopharmaceuticals	Underestimation of $H_p(0.07)$ measured by MCP-7, see Eq.1 [%]
	with MCP-Ns	with MCP-7		
1	14.18	12.61	Illicit handling	16 %
2	53.72	48.9	Illicit handling	10 %
3	11.52	8.73	Illicit handling	24 %
4	12.00	11.22	Illicit handling	7 %
5	6.16	4.13	Possible overexposure handling	33 %
6	7.99	4.45	Possible overexposure handling	44 %
7	**19.65**	**5.25**	**Possible limitation handling**	**73 %**
8	**19.43**	**8.03**	**Possible limitation handling**	**59 %**
9	8.79	4.65	Possible overexposure handling	47 %
10	16.48	9.06	Possible overexposure handling	45 %
11	40.22	18.49	Possible overexposure handling	55 %
12	14.56	7.94	Possible overexposure handling	45 %
13	**21.89**	**7.72**	**Possible limitation handling**	**65 %**
14	94.35	53.62	Possible overexposure handling	43 %
15	99.51	60.26	Possible overexposure handling	39 %

In Table 2, the radiation risk is derived from the dose equivalent $H_p(0.07)$ measured by the classical MCP-7 TLD versus $H_p(0.07)$ measured by the MCP-Ns TLD. The highest level of risk identified as a possible limitation handling is due to the intensity of the radiation field of photons and positrons that is higher than about 60 % of the value measured by a conventional finger monitor.

It has to be admitted that in rare cases there occasionally appears a worker whose exposure reaches an unusually higher level of exposure. The reasons behind it is not always easy fully to identify.

4 CONCLUSION

Based on detailed monitoring of the skin exposure of the hands of nuclear medicine personnel, which administered ^{18}F-FDG to patients, a significant underestimation of the dose was observed using conventional finger dosimeters. The reason was using a classical TLD (0.9 mm thick), which underestimated the $H_p(0.07)$ values caused by positrons. Therefore, it has been proposed to innovate a conventional finger dosimeter by adding a detector to create a simple two-detector monitor that determines the positron dose with sufficient accuracy. In the conditions of routine work in the

department of nuclear medicine, several examples have shown that the innovative two-detector monitor method can additionally estimate possible inconsistent adherence of workers to unusual work procedures leading to the above-average exposure of the hands when handling positron radiopharmaceuticals.

5 ACKNOWLEDGEMENTS

The paper was partially supported by project SGS18/00/OHK4/1T/17.

6 REFERENCES

[1] Vanhavere F., Carinou E., et al., 2012. ORAMED: Optimization of radiation protection of medical staff. EURADOS – Report 2012-02, Braunschweig. Retrieved 2 Jan. 2021 from https://eurados.sckcen.be/~/media/Files/Eurados/documents/EURADOS_Report_ 201202.pdf.

[2] Ginjaume M., Pérez, S., et., 2008. Comparison of TLD-100 and MCP-Ns for use as an extremity dosemeter for PET nuclear medicine staff. Radiation Measurements, Volume 43, Issues 2–6, pp. 607-610. Retrieved 2 Jan. 2021 from https://doi.org/ 10.1016/j.radmeas. 2007.11.048.

[3] Gaza R. et al., 2006. Experimental determination of the dose deposition profile of a 90Sr beta source. Radiation Protection Dosimetry, Vol. 120, No. 1-4, pp. 33-37.

[4] Web: www.radpro-int.com

[5] Fülöp M., Makaiová, I. et al., 2010. Estimation of hand doses from positrons during FDG manipulation. Proceedings of an International Symposium on Standards, Applications and Quality Assurance in Medical Radiation Dosimetry, Vol. 2, pp. 455-462. 9-12 Nov. 2010, Vienna.