Estimation of the skin exposure of the hands of workers handling selected radiopharmaceuticals using a finger dosimeter by applying a correction factor

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Abstract. Over the past few years, new devices for the preparation or application of radiopharmaceuticals have been put into operation in order to reduce the exposure of hands compared to manual methods. Despite the fact that many workplaces are equipped with modern technology, there are situations when a worker gets contaminated or performs a non-standard working procedures, which could lead to the elevated exposure during such operations and thus, to contribute significantly to the higher annual exposure. Increased exposure may not be reflected in the results obtained from finger dosimeters, which are usually worn on the roots of the fingers, since the highest exposure is often located at the tips of the fingers. The purpose of the paper is to overview the skin exposure related to the use of some new technologies developed over the last 10 years. At the same time, the evaluation of the local skin exposure and the correction factor associated with the manipulation involving ^{68}Ga-labelled positron radiopharmaceuticals is to be analysed and compared with the situation characterized by ^{18}F-labelled radiopharmaceuticals.

KEYWORDS: Radiation protection; finger dosimeter; Skin exposure; Correction factor; Radiopharmaceuticals; Nuclear medicine.

1 INTRODUCTION

The exposure limit is a quantitative indicator for limiting the dose of an individual exposed to ionizing radiation due to planned procedures related to the use of radiation or nuclear technologies in the industry, medicine, and other areas [1]. In 2016, a new Atomic Act [1] came into force in the Czech Republic, together with the Decree on Radiation Protection and Security of the Radionuclide Source [2]. In the case of radiation workers, the exposure limit for the eye lens was set in terms of the personal equivalent dose to be 100 mSv in five consecutive calendar years and 50 mSv in one calendar year. The exposure limit for the skin averaged over 1 cm^2 of the exposed area, remained unchanged (500 mSv per year, regardless of the exposed area's size).

Earlier, several authors [3-6] pointed out that there may be cases among nuclear medicine workers whose exposure of the skin on the surface of a hand may be above 500 mSv. These results were obtained from measurements using many thermoluminescent dosimeters (TLDs) placed on the palm and back of the hand. Dose distributions on the hand's skin indicated an extensive range of maximum local skin doses of the monitored workers, with the most common site of maximum values being at the tip of the index finger where the finger dosimeter is not routinely worn. Thanks to these findings, an effort was made to optimize radiation protection as to the skin of hands of workers handling radiopharmaceuticals in nuclear medicine workplaces so as not to exceed the introduced exposure limit.

Recently, technological equipment (automatic filling stations, applicators, and injectors of radiopharmaceuticals) has been increasingly used to reduce the exposure of hands during the relevant operations with radiopharmaceuticals [7-10].

Although many workplaces are equipped with modern technology, there may be workers with higher exposure to the skin of the hand, which can significantly contribute to higher annual exposure (eg, due to worker's contamination or the worker may perform a non-standard working procedure). Increased exposure may not be reflected in results obtained from finger dosimeters, usually worn on the fingers' roots, as the highest dose is often found on the fingertips. For this reason, it is appropriate to introduce a correction factor defined as the ratio of the exposure at the point of expected maximum exposure (most often at the tip of the index finger) to the exposure at the position, where typically the finger dosimeter is placed (usually index finger root).

Based on the results of the project Optimization of Radiation Protection of Medical Staff (ORAMED), it was recommended to use a correction factor of 6 [3]. At the time of the ORAMED project (in 2008-2011), however, not all workplaces had automatic equipment for preparing and applying radiopharmaceuticals. These operations were usually performed manually. A question arose about the change of the correction factor at similar workplaces during the last ten years, provided that these facilities underwent an improvement of their technological equipment or/and introduced new positron radiopharmaceuticals such as e.g., ^{68}Ga.

The paper aims to review the situation regarding hand skin exposure during the last ten years for nuclear medicine workers using new technological equipment. At the same time, the paper deals with the assessment of local exposure of the skin of the hand and the correction factor associated with the manipulation of the positron radiopharmaceutical labeled with ^{68}Ga and compare it with the correction factor for radiopharmaceutical labeled with ^{18}F.

2 MATERIAL AND METHODS

Selected nuclear medicine departments using ^{18}F- and ^{68}Ga-labeled radiopharmaceuticals participated in this pilot study, which was also included in experiments with ^{18}F-labeled radiopharmaceuticals within the ORAMED project. Thermoluminescent dosimeters placed at 10 locations on the hand were used to determine $H_p(0.07)$. The maximum skin exposure of each worker was related to the manipulated activity of the radiopharmaceutical. Subsequently, the average values related to the position on the tip of the index finger (radiopharmaceutical marking, filling of the radiopharmaceutical into syringes, and application of application) were compared in selected occupational groups, and a correction factor was determined for the monitored workplaces.

Also at one workplace of nuclear medicine, selected workers (quality control, pharmacists and doctors) compared $H_p(0.07)$ measured using finger dosimeters in the years 2010 - 2019 (the reference value was considered to be the value of $H_p(0.07)$ in 2010). The finger dosimeters were worn by the workers on the roots of the fingers. Since the size of the irradiation is influenced by several factors, the work also analyzed the number of examined patients for each year and the amount of processed activity.

3 RESULTS

The values of correction factors for selected positron radiopharmaceuticals are summarized in Table 1.

Table 1: Values of correction factors based on the measurement in different years.

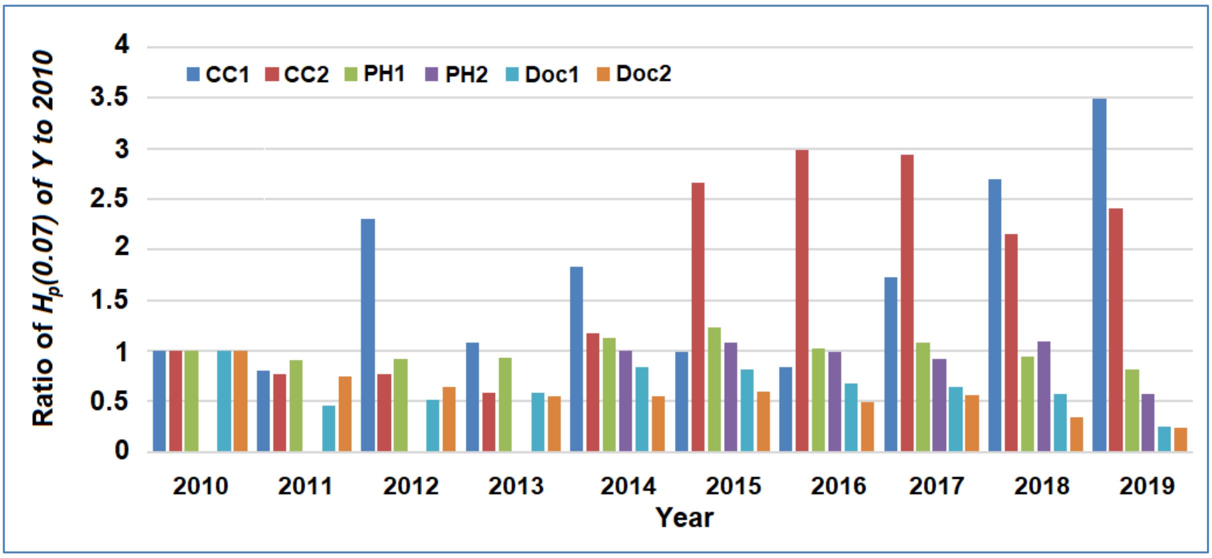
Radionuclide	Year	**Correction factor**		
		Workplace 1	Workplace 2	Both Workplaces
^{18}F	2009 - 2011*	3	3,5	3,3
^{18}F	2019 - 2020	x**	2,0 ± 1,0	-
^{68}Ga	2019	2,7 ± 1,8	4,6 ± 2,3	3,5 ± 2,2

*Monitoring of workplaces within the ORAMED project
**Part of the measurement was not completed due to COVID-19

Due to the introduction of more advanced technological equipment at one of the workplaces, a slightly reduced value of the correction factor for radiopharmaceuticals marked ^{18}F was shown. On the other hand, at the same workplace, the newly introduced positron radiopharmaceuticals labelled with ^{68}Ga, the correction factor has increased by more than twofold. At the second workplace, the correction factor for the ^{18}F-labeled radiopharmaceutical was not significantly different from the correction factor for the newly introduced ^{68}Ga-labeled radiopharmaceutical (in evaluating ^{68}Ga correction factor, the non-standard working procedures were not taken into account), mainly because the workers applied deep-rooted approach when working with radiopharmaceuticals.

Fig. 1 illustrates the ratio of changes of $H_p(0.07)$ during the period of 2010-2019 compared to the year 2010.

Figure 1: Ratio the personal dose equivalent $H_p(0.07)$ in an indicated year (Y) related to its value in 2010.



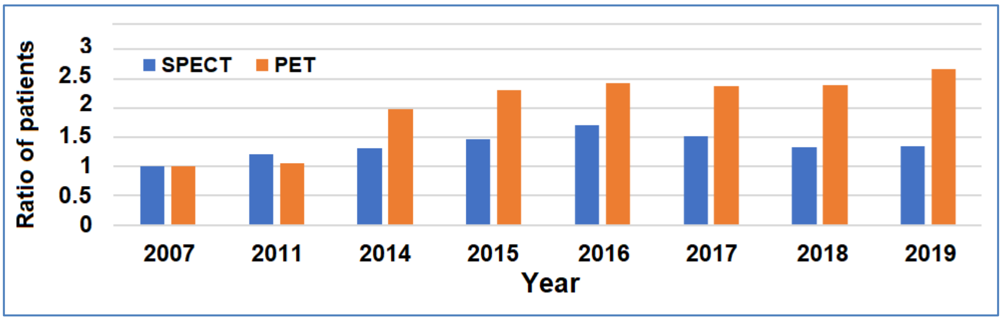
In the case of quality control (CC) workers of the radiopharmaceuticals, in years from 2010 to 2019, there was noticed an increase in $H_p(0.07)$ measured at the root of the fingers (on average by about 75 % on the left hand of CC1 and 87 % on the right hand of CC2). This increase in hand skin doses is attributed mainly to the increased radiopharmaceutical production (number of productions) and handling of ^{68}Ga-labeled radiopharmaceuticals.

Regarding the pharmacists (PH), both workers showed greater radiation exposure to the right hand, which decreased slightly compared to 2010 (on average by 0.4 % for PH1 and 6.8 % for PH2). The drop in hands' exposure is mainly due to a change in technological equipment (in 2010, the preparation of radiopharmaceuticals was carried out manually, today automatic fillers for radiopharmaceuticals are already used).

The physicians (Doc) performing the application received greater exposure on the right hand, and even in this case, there was a reduction in the exposure compared to 2010 (on average by 42 % for Doc1 and 48 % for Doc2). The decrease in the hands' radiation exposure is mainly due to the improvement of the skill (longer period of practice in handling radioactive sources) and more frequent use of syringe shielding than before.

The number of patients examined during the observed period for SPECT and PET at a selected workplace of nuclear medicine is illustrated in Fig. 2, which shows the ratio of the number of examined patients in a given year to the number of patients examined in 2007).

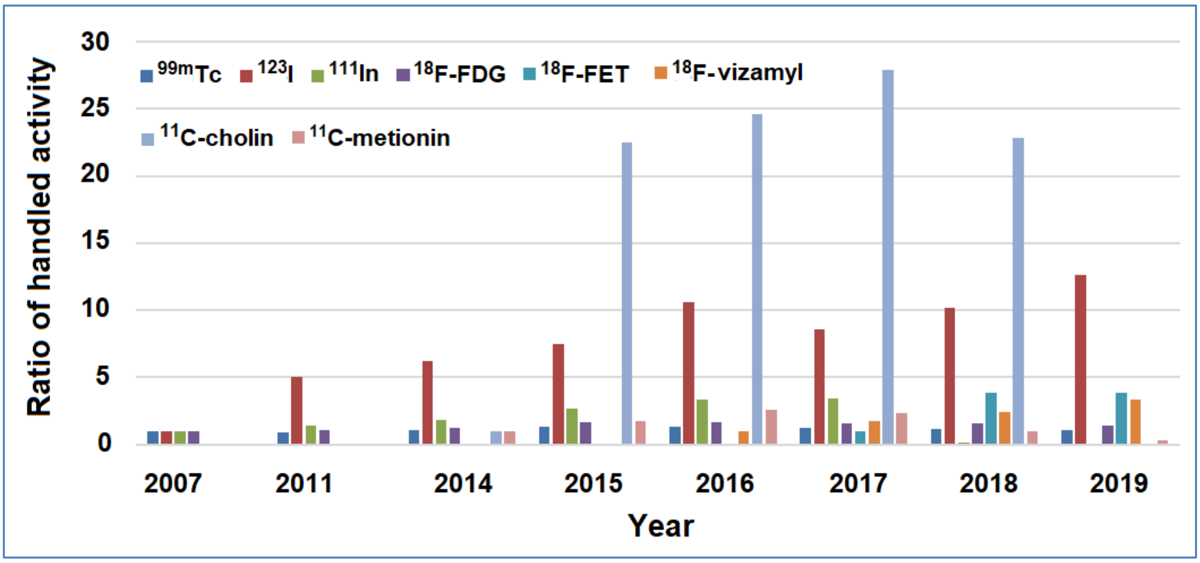
Figure 2: The ratio of the number of patients examined by SPECT and PET in the years 2007 – 2019 related to the situation in 2007 (no data available for some years).



The number of PET scans has increased by a factor of 2.5 over the last ten years, while the number of SPECT scans has remained almost the same. Although the number of PET examinations at the monitored nuclear medicine institution has increased over the years, there has been a reduction in the irradiation of the hand's skin in some occupational groups.

Fig. 3 summarizes the ratio of the manipulated activity of a given radiopharmaceutical compared to the activity spent in 2007. The graph illustrates only radiopharmaceuticals that have been used in the workplace for at least 3 years (there are no data from 18F-Neuraceq, ^{68}Ga-DOTATOC, or ^{68}Ga-PSMA radiopharmaceuticals that have been used in the workplace until 2019). The radiopharmaceutical ^{18}F-FET, ^{18}F-vizamyl, ^{11}C-choline, and ^{11}C-methionine are always related to the first year of use.

Figure 3: The ratio of the amount of manipulated activity of selected radiopharmaceuticals in a given year to the amount of manipulated activity in 2007.



Although the manipulated activity of some radiopharmaceuticals increased during the observed period, based on data from finger dosimeters (finger root), there was a reduction in hand skin exposure in some occupational groups.

In most cases, the values below the examination level were observed using finger dosimeters at the monitored workplace. The exception were pharmacists who received the dose above 150 mSv/year in some years (5 cases in 10 years, or 4 cases in 6 years). Based on repeated measurements in 2019 - 2020, a correction factor of 2 was estimated from several measurements of radiation exposure of hands when handling ^{18}F at one of the workplaces. Since both workplaces are assumed to use similar technologies, it can be assumed that they will have at present a similar correction factor for ^{18}F-labeled radiopharmaceuticals (we would like to identify the impact of the new technology at this workplace in the future, but the specification of this correction factor for ^{18}F will be possible only after the end of the COVID pandemic).

Therefore, if we applied a correction factor of 2 at the above-mentioned workplace, the examination level would already be exceeded by both pharmacists in all years of their monitoring. One worker, who was mainly engaged in the professional quality control, could exceed the level of 50 mSv/year in 4 cases during 10 years when applying the correction factor for ^{18}F of 2.

In addition, one a quality control worker engaged in ^{68}Ga labeling, based on more detailed monitoring with 10 TLDs in multiple positions, was found to have received an average of 6.4 mSv/GBq at the tip of the index finger (repeated measurements were performed on this worker) . However, based on monitoring with a finger dosimeter, this higher exposure was not observed.

4 CONCLUSION

More detailed monitoring of hand skin exposure on several locations is time-consuming, and in some cases, the worker may feel discomfort when performing work. On the other hand, this method of measurement can reveal cases that are not detected by conventional monitoring methods using finger dosimeters. Based on these more detailed measurements, it is possible to analyze the dose distribution on hand during the worker's operations and then derive and take appropriate measures to exclude non-standard operations and minimize such exposure.

If the worker is wearing "only" a finger dosimeter, the correction factor is a suitable tool for a "faster" estimate of the expected exposure at the fingertips. Due to technological progress, it is possible to reduce the skin's exposure by reducing the handling time of the source and extending the distance between fingertips and the source. In practice, however, there may be cases where the worker is not aware of non-standard working procedures leading to increased exposure, which is not "captured" by the finger dosimeter. For this reason, the worker can regularly repeat his work habits, as the measured value from the finger dosimeter often does not even reach the value of the examination level.

5 ACKNOWLEDGEMENTS

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