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Assessment of the exposure to ionizing radiation of the Nuclear Medicine Department in the Greater Poland Cancer Centre in years 2008–2023

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Abstract

Background: The aim of the study was to analyze the individual doses received by the staff of the Nuclear Medicine Department at the Greater Poland Cancer Centre, with a special focus on differences between groups and changes in dose values over time.

Materials and methods: The analysis was performed based on radiation exposure doses from the reports of accredited laboratory received by the Nuclear Medicine Department personnel in the Greater Poland Cancer Centre between 2008–2023. The nuclear medicine staff was divided into 5 groups: nurses, medical secretaries, nuclear medicine physicians, cleaning personnel and nuclear medicine radiographers further divided into two subgroups: those preparing radiopharmaceuticals and performing examinations (Group A) and those who perform only examinations (Group B).

Results: It was found that personnel who had contact with radioisotopes, i.e., the nurses and radiographers who prepare the radiopharmaceuticals, received higher doses than other employees. However, despite the increase, all employees of the Department receive doses below the limits resulting from the legal regulation.

Conclusion: In this study we found that nurses and radiographers handling radiopharmaceuticals receive higher radiation doses than other employees. The study advocates for further research into advanced protective measures and technologies to enhance safety in nuclear medicine practices.

Key words: radiation protection; individual dosimetry; nuclear medicine; radioactive isotopes

Introduction

Nuclear medicine is a field of medicine that uses radioactive isotopes, mostly technetium-99m [^{99m}Tc] and fluorine-18 [^{18}F], labeled with appropriate ligands, for diagnosis [1]. [^{99m}Tc] is gamma-emitter, generator-produced isotope with a half-life ($T_{1/2}$) of 6 hours, while [^{18}F] with a $T_{1/2}$ of 110 minutes, is produced in a cyclotron, where a proton beam hits the target material and, as a result of a nuclear reaction, turns the stable oxygen-18 [^{18}O] radioisotope into an [^{18}F] radioisotope that emits positrons. In addition to the above-mentioned isotopes, we can also use alpha- and beta-emitters. However, around 80% of nuclear medicine studies are based on [^{99m}Tc], thus, gamma radiation is the most commonly used radiation in nuclear medicine [1]. Nuclear medicine techniques provide complementary information about anatomical and morphological changes that occur in the body, so they are used to individualize treatment keeping damage to the patient as small as possible. The evolving role of nuclear medicine methods used in medical practices requires modern and efficient radiation protection [2–8].

Medical personnel exposed to ionizing radiation are subject to dose assessment using individual dosimetry of the entire body, eyes and hands. The most commonly used are thermoluminescent dosimeters (TLD). In the 1960s, a material based on lithium fluoride with an admixture of magnesium and titanium (LiF:Mg,Ti) called MTS-N was developed. These are sintered tablets made from powdered and cold-pressed natural form of lithium fluoride with magnesium and titanium (MTS-N). Depending on their purpose, the tablets are placed in special cassettes or rings. Nowadays, MTS-N detectors are thoroughly tested and are routinely used in Poland, including in the Greater Poland Cancer Center for individual dose measurements [9].

Based on personnel radiation exposure, two categories can be distinguished: A, which includes people whose effective dose exceeds 6 millisievert [mSv] per year and B, which includes employees who may receive an effective dose above 1 mSv per year or an equivalent dose exceeding 0,3 of the dose limits for eye lenses, skin and limbs. The radiation dose limit expressed as an effective dose for employees working in radiation exposure is obtained from Atomic Law Act (Ustawa - Prawo Atomowe, Dz.U. z 2023 poz. 1173) and it should not exceed 20 mSv per year [10]. In addition, dose limits defined as equivalent doses are 15 mSv for eye lenses and 150 mSv for skin, hands, forearms, feet and legs [10]. The system of radiation protection that is used worldwide is based on the recommendations of the International Commission for Radiation Protection (ICRP) and of the International Commission on Radiation Units and Measurements (ICRU), described mainly in ICRP 60, and substantially revised and updated in 2007 with the publication of ICRP 103 (ICRP 2007). The ICRP system of radiation protection is based on three fundamental principles: justification, optimisation and dose limitation. Using of shields appropriate for the type of emitters used, increasing the distance from radiation sources and minimizing the time spent near them, are only an emanation of the optimization principle defined by ICRP with respect to the medical staff [11]. In nuclear medicine the patients are the main source of radiation during the examination, therefore radiation protection is manifested by keeping a safe distance from them and taking into account the As Low As Reasonably Achievable (ALARA) method. The dosimetry control for work conducted in the nuclear medicine departments should be accurate and cover not only the entire body but also the hands, particularly for individuals involved in preparing and administering radiopharmaceuticals. Therefore, it is extremely important for the nuclear medicine employees to monitor the doses received [10, 12, 13].

The aim of the study was to analyze the individual doses received by the Nuclear Medicine Department staff in the Greater Poland Cancer Centre, with special focus on differences between the groups and changes in the dose values over time.

Materials and methods

It was a retrospective, single center analysis performed based on radiation exposure doses from the reports of an accredited laboratory received by the Nuclear Medicine Department personnel at the Greater Poland Cancer Centre from 2008 to 2023. Individual dose equivalents from individual thermoluminescent dosimeters showing the exposure of the whole body measured at a depth of 10 mm — Hp (10) were analyzed, as well as doses equivalent to hand dosimeters showing the exposure to ionizing radiation of employees' hands measured at a depth of 0.07 mm — Hp (0.07). The range of whole-body dosimeters spans from 0.1 mSv to 10 Sv, while ring dosimeters have a range of 0.1 mSv to 1 Sv. Since 2020, eye dose monitoring has also been conducted using eye dosimeters, measuring the exposure of workers' eyes at a depth of 3 mm — Hp (3). All of these values represent the dose absorbed in soft tissues at a specified depth, according to the definitions of Hp (10), Hp (0.07) and Hp (3).

The analyzed nuclear medicine staff was divided into 5 groups: nurses, medical secretaries, nuclear medicine physicians, cleaning personnel and nuclear medicine radiographers. Two subgroups were distinguished among the radiographers: persons preparing radiopharmaceuticals and performing examinations (Group A) and those who perform only examinations (Group B).

Statistical analysis was performed using Statistica StatSoft version 13.3. The normality of the data distribution was assessed using the Shapiro-Wilk test and according to the results, an appropriate test was performed to estimate the significance of the analyzed data. The $p < 0.05$ level was assumed to indicate significance in accordance with the available literature. Differences between the two groups most exposed to radiation (nurses and Group A radiographers) were also checked. If a worker's whole-body dose Hp (10) was less than 0.10 mSv (below the dosimeter detection range), it was assumed that no dose was received, and a value of 0 was assigned. This approach complies with current regulations, which require that doses below the detection threshold be treated as non-detectable and, therefore, recorded as zero to ensure accuracy in dose reporting.

The analysis included the number of examinations performed in the Nuclear Medicine Department between January 2008 and December 2023 divided by individual procedures, i.e., positron emission tomography/computed tomography (PET/CT), whole body scintigraphy (WBS) and sentinel lymph node scintigraphy (SLN), which were obtained from the Integrated IT System (Esculap) designed for coding examinations. Additionally, data from the radiopharmaceutical preparation book were used in this analysis to assess the amount of prepared doses per person. Moreover, in the last quarter of 2022, we began [^{68}Ga]Ga-PSMA-11 synthesis (n = 18 procedures), which we also performed in 2023 (n = 42 procedures), we expanded our analysis based on this data.

The standard doses used in the Department were as follows: for WBS (750 megabecquerel [MBq]), for SLN (80 MBq), whereas the activity for the PET/CT studies ([^{18}F]FDG) was prepared according to the European Association of Nuclear Medicine (EANM) guidelines and the regulations of the Ministry of Health (3-7 MBq/kg body weight). The activities for [^{68}Ga]Ga-PSMA-11 procedures are also prepared in line with the EANM guidelines, ensuring standardization of procedures and safety for both patients and staff [14–16].

Results

The nurses, in the analyzed period, received a typical Hp (10) dose of 0.9 mSv (the lowest 0,2 mSv in 2008, the highest 1.5 mSv in 2012) and a typical Hp(0,07) dose to the hands of 10,4 mSv, ranging from 2.4 to 17.3 mSv (the lowest in 2008, the highest in 2022). The nuclear medicine physicians received a typical Hp (10) dose of 0.1 mSv, in the range of 0–0.4 mSv (the lowest in 2012-2023, the highest in 2010 and 2011) and a typical Hp (0.07) dose of 1.9 mSv (the lowest 0 mSv in 2017, 2019–2021, and in 2023), the highest 23.5 mSv in 2008). The cleaning personnel received a typical Hp (10) dose of 0.1 mSv (the highest 0.5 mSv in 2017) and a typical Hp (0.07) dose to the hands of 0.2 mSv (the highest 0.5 mSv in 2009).

Among the radiographers, group A received a typical Hp (10) dose of 1,5 mSv (the lowest 0.1 mSv in 2008, the highest 2.5 mSv in 2017) and the typical Hp (0.07) dose of 24.3 mSv (the lowest 9.1 mSv in 2020, the highest 43.1 mSv in 2019), while in group B, the typical Hp (10) dose was 0.03 mSv (the highest 0.2 mSv in 2013). Each year, the medical secretaries did not receive any measurable dose (0 mSv). Data from all years are presented in tables 1, 2 and in figures 1–2. Based on individual analysis of [^{68}Ga]Ga-PSMA-11 synthesis, we observed that the radiographer who performed the majority of the syntheses in 2022 and 2023 (n = 8 and n = 26, respectively) received a notably higher Hp (0.07) dose per quarter (51.8±10.1 vs 13.6±2.6, respectively) compared to the second radiographer with the second highest number of performed syntheses (n = 5 and n = 6, respectively).

The lowest number of examinations (n = 2845) was performed in 2008 (2559 WBS and 286 SLN), while the highest (n = 6963) was performed in 2019 (4145 WBS, 1298 SLN and 1520 PET). There was a steady increase in WBS examinations, beginning with a modest count in 2008 and ascending consistently through the years, with the highest number of WBS (n = 4145) in 2019. The frequency of SLN demonstrated a gradual rise (the highest number of procedures (n = 1344) was performed in 2015) over the whole analyzed time. The PET/CT examinations exhibited an incremental, but relatively stable growth (the highest number of PET/CT studies (n = 1754) was performed in 2022). The aggregate count of all examinations showed a significant upward trend (beside COVID period, where we noticed decrease in all procedures) indicating an overall increase in the use of these diagnostic imaging techniques.

The number of nursing staff showed minor variations throughout the years (from 1 in 2008, then two in 2009 and ended up with 3 in 2018). In the group of nuclear medicine physicians, the number of employees remained constant at two until 2019, when the group increased by one person. Subsequently, in 2021, the group ultimately grew to four members. Only one physician in the described group had a ring dosimeter, meaning that Hp (0.07) dose measurements applied to only one individual. The systematic increase in the number of Group A radiographers was evident, starting with one employee in 2008, raised to two in 2010, then to 3 in 2011 and to 4 in 2015 and ended up with 5 in 2019. In Group B, there was one radiographer until 2016. Then, the group increased by two employees. The cleaning staff's numbers remained the most constant among all categories, with a steady presence of one employee throughout the analyzed period. In the Department, over the span of 15 years, there was customarily one medical secretary on staff, with the exception of one particular year (2016). In 2018, a second secretary was hired, and to this day, there are two secretaries employed in the department.

Statistically significant differences between nurses and group A radiographers in doses delivered to the whole body were found in years 2016 (0.9 ±0.3 *vs.* 2 ± 1; $p = 0.007$) and 2017 (0.7 ± 0.4 *vs.* 3 ± 1; $p = 0.001$). Doses received on finger dosimeters were found significant in 2008 (2.4 ± 0.2 *vs.* 21 ± 12; $p = 0.009$), 2013 (10 ± 4 *vs.* 18 ± 9; $p = 0.022$), 2016 (11 ± 4 vs. 27 ± 11; $p = 0.0007$), 2018 (8.9 ± 1.0 *vs.* 41.5 ± 5.9; $p = 0.003$) and 2019 (7.3 ± 0.9 *vs.* 43.1 ± 7.2; $p = 0.004$).

Discussion

Radiological protection in nuclear medicine requires precise whole-body dosimetry control for all employees. It is also very important to monitor the equivalent doses for the personnel who prepare the radiopharmaceuticals, usually using finger dosimeters. The doses received by workers of nuclear medicine facilities in various parts of the world range from 1 to 50 mSv per year [11]. In our analysis, the main focus was on differences in received doses among groups of personnel, as well as changes in dose values over time. It was noted that persons who had direct contact with radiopharmaceuticals during preparation and administration receive higher radiation doses than the rest of the staff. Moreover, with the respect of [^{68}Ga]Ga-PSMA-11 synthesis, we noticed, that technician who performed majority of analyses from Group A received notably higher finger doses compared to others from this group. High dose values for the group of physicians [e.g., in 2008 dose Hp (0.07) — 23.5 mSv] in the early years of the Department (2008–2012) are due to the small number of employees and because radiopharmaceuticals were also prepared by a physician. Jha et al. in their analysis showed that the nuclear medicine physician who injects the radiopharmaceutical received the highest dose from all persons involved in the [^{18}F]FDG injection process [17].

Similar results were obtained from Zargan et al. in their study, where they concluded that the chemist group and the person who injects [^{18}F]FDG received the highest doses [18]. It was also noticed in our study that the dose values increased over time for radiographers from group A and in the case of equivalent doses also for nurses and even though all staff received a low level of radiation doses, in these above-mentioned groups the dose level increase was notable. This situation may result from the growing number of examinations, e.g., PET/CT and development of the Department (in 2015 the second gammacamera was installed in our department). Reversely, we noticed a decrease in the number of studies during the COVID pandemic in 2020 and 2021, which was also seen in Hp (10) and Hp (0.07) doses for all analyzed groups. Villoing et al. in their multicenter study compared the doses for nuclear medicine technologists over a long period of time (since 1979 to 2015) and concluded that the introduction of hybrid imaging like PET/CT or single photon emission computed tomography/computed tomography (SPECT/CT) increased radiation doses for nuclear medicine technologists who perform these procedures, radiochemists who prepare radiopharmaceuticals and for nurses or physicians who inject doses [19]. In our department first SPECT/CT studies were conducted in early 2011 and PET/CT studies in May 2009. Over time, there has been an increased number of studies performed in our department. However, as mentioned earlier, the introduction of hybrid imaging, especially PET/CT, has also led to an increase in doses received by personnel involved in this procedure. Additionally, the number of employees who prepare and administer radiopharmaceuticals, along with their experience, can also contribute to the increase in doses. The distribution of the workload among workers, the radiation protection practices followed by the personnel, and the radiation safety facilities provided by the employers may also be important [11]. For the rest of the staff (except the physicians for whom doses decreased over the years) no notable differences in doses received in 2008-2023 were observed.

The radiological protection in nuclear medicine was also discussed in other studies [20, 21]. They show a similar conclusion to our study, where the highest dose of radiation is received by employees who have direct contact with radioactive isotopes, among others nurses or radiopharmacists (average expected annual equivalent dose for radiopharmacists' hands is 50 mSv, for nurses 5.1 mSv, and for the rest of the staff, e.g., ward attendants — 0.23 mSv [20]). In our analysis, in 2016 the typical Hp (10) dose for radiographers from group A was 1.7 mSv, for nurses it was 0.9 mSv and for the rest, e.g., cleaning personnel, it was 0.1 mSv. The maximum typical annual Hp (10) dose received by group A was 2.5 mSv in 2017 when we performed 6,398 procedures in our department but, still, it is below the limit resulting from legal regulations. Compared to year 2019, where the highest number of procedures included in the analyzed time was performed (n = 6963) radiographers from this group received lower Hp (10) dose — 2.1 mSv. Radiographers who only look after patients (group B) in most cases received doses below 0.1 mSv. Leide-Svegborn et al. in their work [22] showed that the procedures using [^{18}F] caused considerably higher finger doses (close to dose limits) than the procedures using [^{99m}Tc] (estimated annual equivalent dose for employees' hands was 414 mSv and 46 mSv, respectively). This can be explained by the higher energy used in PET imaging (5ll keV) compared to the energy used in procedures with ^{99m}Tc (140 keV) [11]. This topic was also discussed in another study [23], which also emphasized that the preparation of PET/CT examinations in nuclear medicine laboratories is associated with greater exposure to radiation for all personnel than in the SPECT/CT, where [^{99m}Tc] is used (technicians PET/CT received 6 mSv, radiopharmacists 1 mSv, and the rest of the personnel below 0.1 mSv). Pant et al. compared finger doses for staff handling [^{99m}Tc] and Iodine-131 [^{131}I]. As might be predicted, personnel handling [^{131}I] received higher doses than the group involved only in [^{99m}Tc] studies [24]. In this study, we did not compare a similar group, because radiographers (group A) have contact with both isotopes, therefore assessing exposure and confirming the thesis presented by the authors is significantly challenging. However, it is observed that a group of radiographers who prepare isotopes and perform examinations have notably higher doses compared to the group of radiographers who only perform examinations. Additionally, as was mentioned before, we also noticed that the radiographer who performed the majority of [^{68}Ga]Ga-PSMA-11 syntheses received higher finger dose in the last quarter of 2022, compared to the second radiographer with the highest number of performed syntheses. The same observation was seen in the whole 2023 between these two persons. Even though we were unable to distinguish doses received from [^{18}F], [^{99m}Tc] or [^{68}Ga] in Group A, we noticed that beginning synthesis of [^{68}Ga]Ga-PSMA-11 notably increased doses to the finger for radiographers from this group. Our results are similar to those presented by Saat et al., where they assumed that personnel who prepare and administer radiopharmaceuticals usually receive notable radiation doses (especially to their hands), however, these doses do not exceed acceptable limits [25].

Pavičar B et al. in their study presented in 2021, compared the doses delivered to technologist and nurses during the [^{18}F]FDG PET/CT procedures [26]. They found that nurses received slightly higher Hp (10) doses compared to the technologist, which is also in concordance with the study published by Emad El-dinn et al. [27]. In our study we noticed an inverse relationship: radiographers from group A received higher Hp (10) and Hp (0.07) doses compared to the group of nurses. The difference between our study and the two above mentioned ones is that in ours we analyzed all isotopes available in our department over a long period of time (15 years), while in the other studies, only [^{18}F] procedures were analyzed.

In 2020, the eye dose monitoring was also introduced using an eye dosimeter. During the analyzed years (2020–2023), where this type of dosimetry was available, we did not notice any significant increase of the doses for all groups included in the analysis. These results are similar to the one presented by Leide-Svegborn, where he noticed that doses for the eyes and thyroid were below allowed dose limits [22].

In our study, certain limitations were encountered that should be noted. Firstly, there was no differentiation among various radiopharmaceuticals; all nuclear medicine radiographers from group A were exposed to both fluorine and technetium. Furthermore, the analysis conducted was single-centre and retrospective in nature. Therefore, to validate the findings obtained, larger-scale and multicentre studies are required. This approach would help in confirming the results and potentially provide a more comprehensive understanding of the implications associated with exposure to these radiopharmaceuticals. Even with this limitation, our study, together with all cited articles, shows how important it is for the safety of personnel to have a systematic analysis of the doses received by nuclear medicine employees, with particular emphasis on those who prepare and administer the radiopharmaceuticals.

Conclusion

Personnel who had direct contact with radioisotopes, namely the nurses and radiographers who prepare the radiopharmaceuticals, received higher radiation doses compared to the other employees.

However, despite the increase, over the years all employees of the Nuclear Medicine Department received doses below the limits resulting from the legal regulation.

Ethical approval

Ethical approval was not necessary for the preparation of this article.

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Conflict of interests

Authors declare no conflict of interests.

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Figure 1. Typical dose values measured at a depth of 10 mm Hp (10) for each group of personnel in 2008–2023

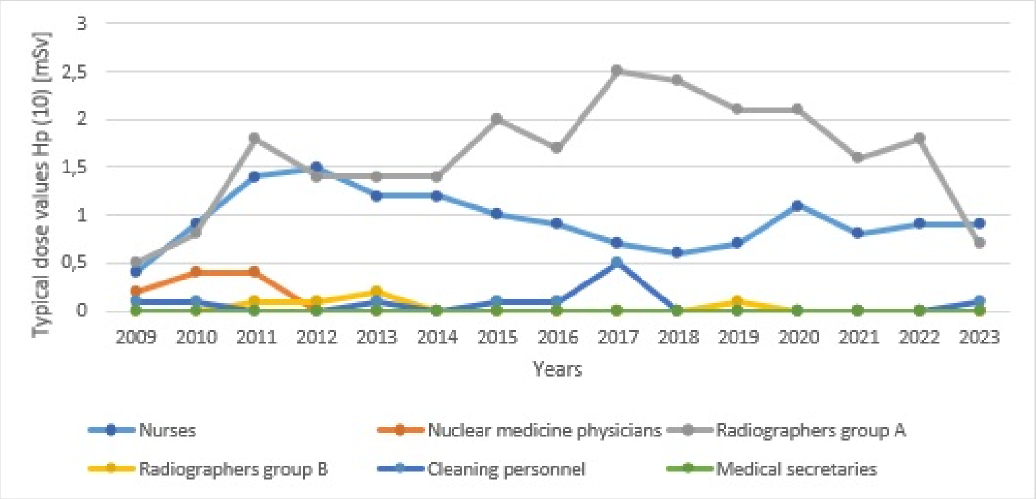

Figure 1 Typical dose values measured at a depth of 10 mm Hp (10) for each group of personnel in 2008-2023

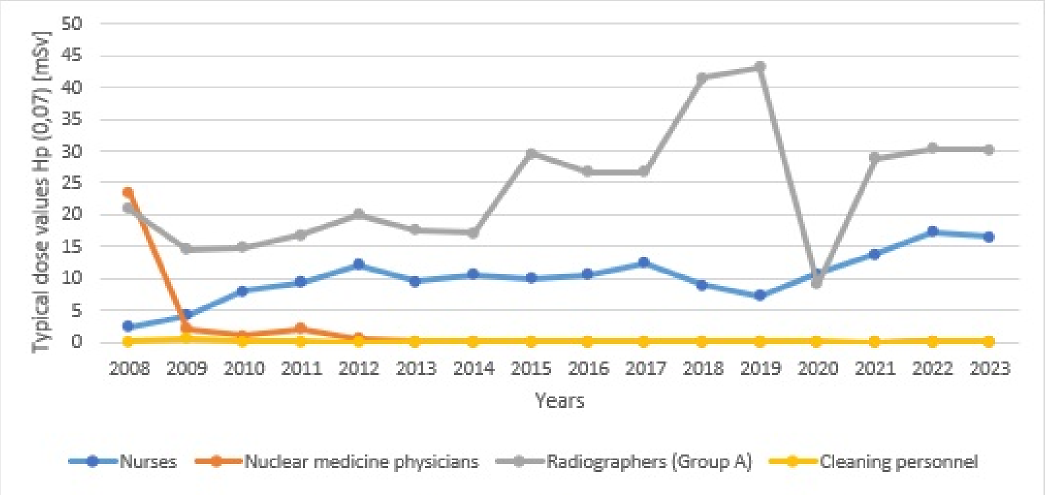

Figure 2 Typical dose values measured at a depth of 0,07 mm Hp (0,07) for groups of personnel in 2008-2023

Table 1. Typical dose values Hp (10) for each group of personnel in 2008–2023

Group of personnel		**Nurses**	**Nuclear medicine physicians**	**Radio-graphers (Group A)**	**Radio-graphers (group B)**	**Cleaning personnel**	**Medical secretaries**
Ty	**2008**	0.2 ± 0	0.1 ± 0.1	0.1 ± 0	0	0.1 ± 0	-

pical dose values Hp (10) [mSv]	**2009**	0.4 ± 0.1	0.2 ± 0.2	0.5 ± 0.3	0	0.1 ± 0	0
	2010	0.9 ± 0.3	0.4 ± 0.3	0.8 ± 0.6	0	0.1 ± 0	0
	2011	1.4 ± 0.4	0.4 ± 0.4	1.8 ± 0.8	0.1 ± 0	0	0
	2012	1.5 ± 0.1	0	1.4 ± 0.3	0.1 ± 0	0	0
	2013	1.2 ± 0.1	0	1.4 ± 0.3	0.2 ± 0	0.1 ± 0	0
	2014	1.2 ± 0.1	0	1.4 ± 0.8	0	0	0
	2015	1.0 ± 0.4	0	2.0 ± 1.2	0	0.1 ± 0	0
	2016	0.9 ± 0.2	0	1.7 ± 0.4	0	0.1 ± 0	0
	2017	0.7 ± 0.2	0	2.5 ± 1.1	0	0.5 ± 0	0
	2018	0.6 ± 0.1	0	2.4 ± 0.4	0	0	0
	2019	0.7 ± 0.1	0	2.1 ± 0.4	0	0	0
	2020	1.1 ± 0.1	0	2.1 ± 1.2	0	0	0
	2021	0.8 ± 0.1	0	1.6 ± 0.2	0	0	0
	2022	0.9 ± 0.1	0	1.8 ± 0.1	0	0	0
	2023	0.9 ± 0.2	0	0.7 ± 0.5	0	0.1 ± 0	0

Table 2. Typical dose values Hp (0.07) for groups of personnel in 2008–2023

Group of personnel		**Nurses**	**Nuclear medicine physicians**	**Radio-graphers (Group A)**	**Cleaning personnel**
Typical dose values Hp (0.07) [mSv]	**2008**	2.4 ± 0	23.5 ± 0	21.0 ± 0	0.2 ± 0
	2009	4.2 ± 0.7	2.1 ± 0	14.6 ± 1.6	0.5 ± 0
	2010	8.1 ± 1.8	1.0 ± 0	14.9 ± 2.1	0.2 ± 0
	2011	9.4 ± 3.6	2.1 ± 0	16.8 ± 3.4	0.2 ± 0
	2012	12.0 ± 3.2	0.6 ± 0	20.0 ± 8.0	0
	2013	9.5 ± 2.6	0.1 ± 0	17.6 ± 6.3	0.1 ± 0
	2014	10.5 ± 1.3	0.2 ± 0	17.1 ± 5.9	0.1 ± 0
	2015	10.0 ± 1.0	0.1 ± 0	29.6 ± 19.0	0.2 ± 0
	2016	10.6 ± 2.8	0.2 ± 0	26.8 ± 5.8	0.2 ± 0
	2017	12.4 ± 2.7	0	26.8 ± 5.4	0.2 ± 0
	2018	8.9 ± 1.0	0.1 ± 0	41.5 ± 5.9	0.2 ± 0
	2019	7.3 ± 0.9	0	43.1 ± 7.2	0.1 ± 0

	2020	10.8 ± 1.2	0	9.1 ± 3.2	0.1 ± 0
	2021	13.8 ± 1.0	0	28.8 ± 4.7	0
	2022	17.3 ± 4.0	0.1 ± 0	30.3 ± 4.0	0.1 ± 0
	2023	16.6 ± 3.6	0	30.2 ± 5.0	0.1 ± 0