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How much do ^{68}Ga-, ^{177}Lu- and ^{131}I-based radiopharmaceuticals contribute to the global radiation exposure of nuclear medicine staff?

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Abstract

Background: The radiation exposure of nuclear medicine personnel, especially concerning extremity doses, has been a significant focus over the past two decades. This study addresses the evolving practice of NM, particularly with the rise of radionuclide therapy and theranostic procedures, which involve a variety of radionuclides such as ^{68}Ga, ^{177}Lu, and ^{131}I. Traditional studies have concentrated on common radioisotopes like ^{99m}Tc, ^{18}F, and ^{90}Y, but there is limited data on these radionuclides, which are more and more frequently used. This study, part of the European SINFONIA project, aims to fill this gap by providing new dosimetry data through a multicenter approach. The research monitors extremity doses to hands, eye lens doses, and whole-body doses in nuclear medicine staff handling ^{68}Ga, ^{177}Lu, and ^{131}I. It examines the type of activities performed and the protective measures used. The study extrapolates measured doses to annual doses, comparing them with annual dose limits, and assesses the contribution of these specific procedures to the overall occupational dose of nuclear medicine personnel.

Results: Measurements were conducted from November 2020 to August 2023 across nine hospitals. The highest whole-body, eye lens and extremity doses were observed for ^{68}Ga. Average maximum extremity doses, normalized per manipulated activity, were found of 6200 µSv/GBq, 30 µSv/GBq and 260 µSV/GBq for ^{68}Ga, ^{177}Lu and ^{131}I, respectively. Average whole-body doses stayed below 60 µSv/GBq for all 3 isotopes and below 200 µSv/GBq for the eye lens dose. The variation in doses also depends on the task performed. For ^{68}Ga there is a risk of reaching the annual dose limit for skin dose during synthesis and dispensing.

Conclusions: This study's measurement campaigns across various European countries have provided new and extensive occupational dosimetry data for nuclear medicine staff handling ^{68}Ga, ^{177}Lu and ^{131}I radiopharmaceuticals. The results indicate that ^{68}Ga contributes significantly to the global occupational dose, despite its relatively low usage compared to other isotopes. Staff working in radiopharmacy hot labs, labeling and dispensing ^{177}Lu contribute less to the finger dose compared to other isotopes.

Keywords: Nuclear medicine staff, Occupational exposure, ^{68}Gallium, ^{177}Lutetium, ^{131}Iodine

Background

The radiation exposure of nuclear medicine (NM) personnel has received quite some attention over the last two decades by carefully monitoring extremity doses for the most common radioisotopes, such as ^{99m}Tc, ^{18}F and ^{90}Y, showing that there is a real risk to exceed the annual dose limit to the skin, especially at the fingertips [1–8]. As a result, wearing a ring dosemeter, in addition to the whole-body dosemeter, became more and more normal practice for NM staff and reports have been published with recommended correction factors to assess the maximum skin dose on the hand, based on the dose measured by the ring dosemeter [9–11].

However, NM practice has evolved strongly during the last years with the upcoming radionuclide therapy and theranostic procedures. This resulted in a larger variety of radionuclides that are handled, higher activities manipulated for the therapeutic procedures and exposure to a greater variety of radiation types (gamma, beta, positrons, ...). In the international literature, small-scale studies can be found for these new emerging radioisotopes within the theranostic isotope family, such as ^{68}Ga [12, 13] and ^{177}Lu [2, 14–17], but they are scarce and with varying study design and set-up. A recent review paper has also been published on extremity dosimetry for NM staff for emerging isotopes, where only 5 papers (published after 2000] were found for ^{177}Lu, 2 papers for ^{68}Ga and additionally for the more long-used isotope, ^{131}I, only 8 papers were found [18].

Therefore, as part of the European SINFONIA project, this study aims to provide new dosimetry data by a multicenter approach for NM staff, specifically working with ^{68}Ga, ^{177}Lu and/or ^{131}I. Besides monitoring the extremity doses to the hands, also eye lens doses and whole-body doses have been monitored for the above-mentioned isotopes, considering the type of activity performed (preparation, dispensing or administration of radiopharmaceuticals) and type of protection used. An extrapolation of measured doses to annual doses is performed and compared with the corresponding annual dose limits. Finally, the contribution of the radiation dose from these specific procedures to the global occupational dose for NM personnel, which is measured on monthly basis with the routine dosemeters, is assessed. As such, this multicenter approach enables us to estimate the impact of ^{68}Ga-, ^{177}Lu- and ^{131}I-based radiopharmaceuticals on the global exposure of NM staff.

Material and methods

Study design

We conducted a multi-center, prospective dosimetry study to assess the radiation exposure of NM staff, while handling ^{177}Lu, ^{68}Ga, ^{131}I during routine activities, providing to each participant the following dosemeter set:

- Small thermoluminescent detectors (TLD) attached on gloves at 5 different locations at the level of fingertips and the base of the fingers (Fig. 1A) to monitor extremity doses in terms of the operational quantity $H_p(0.07)$. MTS-N (Radcard, Poland) has

(a) (b) (c)

Fig. 1 Dosemeters used for the measurement of extremity doses (**a**), eye lens doses (**b**) and whole-body dose (**c**)

been used for ^{177}Lu measurements, MCP-Ns (Radcard, Poland) for ^{68}Ga measurements and MCP-N (Radcard, Poland) for ^{131}I measurements. The performance of a TLD depends on the type and energy of the radiation it needs to measure and the choice of TLD types in this study has been based on the study performed by Van Hoey et al. [19].

- Eye lens dosemeters (Eye-D™, Radcard, Poland) that can be attached to the head next to both eyes (on the temple) by means of a headband (Fig. 1B) to monitor eye lens doses in terms of the operational quantity $H_p(3)$.
- A whole-body dosemeter (InLight®, Landauer) to be worn at chest height (Fig. 1C) to measure whole-body dose in terms of the operational quantities $H_p(10)$ and $H_p(0.07)$.

These dosemeters had to be worn next to the routine dosemeters available to the participant. Such a separate set of dosemeters was provided to each participant, for each radionuclide under study and only to be worn when handling the specified radionuclide. The same set of dosemeters per person and per radionuclide was worn for at least one month, with extensions for low-frequency procedures such as ^{177}Lu and ^{131}I. The goal was to monitor at least 3 procedures per dosemeter set.

For each type of dosemeters in the set, minimum two additional dosemeters were provided to the participating centers to measure background radiation, with the average background signal subtracted from the measured signal of the corresponding dosemeter type. For each of the well-characterized detector types, a detection limit (DL) of 50 μSv was defined as a representative value, for $H_p(10)$, $H_p(3)$ and $H_p(0.07)$. Every background-subtracted dose measurement below this DL, is assigned a dose value of 50 μSv.

Study analysis

In addition to wearing the dosemeters, participating staff recorded procedure details on pre-prepared sheets, such as the amount of manipulated activity, a description of the tasks performed, the use and specifications of any protective equipment. This information facilitates dosimetry analysis and comparison between isotopes, tasks and centers.

The measurements spanned from November 2020 to August 2023, involving 9 hospitals (indicated with letters C to K), coming from Belgium (C, D, E, K), Switzerland (G, J), The Netherlands (I), Spain (F) and Italy (H). Six hospitals participated for ^{177}Lu, 6 hospitals for ^{68}Ga and 2 hospitals for ^{131}I. Six hospitals (C, E, F, G, J, K) are university hospitals, 1 general hospital (D) and 2 national cancer centers (I, H) are included. All involved nuclear medicine departments belong to (one of) the largest departments in their city

Table 1 Overview of how the different tasks were performed in participating hospitals and number of NM staff involved for ^{177}Lu procedures

Lu-177	TASK				# sets	# persons
Hospital	Synthesis	QC	Dispensing	Administration		
D	Automatic	Unshielded	Manual, unshielded	Automatic	13	2
E	Automatic	(un)shielded	Manual, shielded	Automatic	14	7
F	/	/	/	Semi-automatic, shielded	15	6
I	Automatic	(un)shielded	Automatic	Automatic	18	13
J	Automatic	/	Automatic/manual	Semi-automatic, shielded	7	5
K	Manual, shielded	Unshielded	Manual, shielded	Automatic	2	1

/: This task in not performed in the respective hospital

Table 2 Overview of how the different tasks were performed in participating hospitals and number of NM staff involved for ^{68}Ga procedures

Ga-68	TASK				# sets	# persons
Hospital	Elution/synthesis	QC	Dispensing	Administration		
C	Automatic	Unshielded	Manual, unshielded	Manual, shielded	5	3
D	Automatic	Unshielded	Automatic	Manual, shielded	14	4
E	Automatic	(un)shielded	Manual, unshielded	Manual, shielded	4	4
F	/	/	/	Manual, shielded	16	6
G	Automatic	Unshielded	Manual, shielded	Manual, shielded	16	5
H	Automatic	Unshielded	Manual, unshielded	Manual, shielded	10	5

/: This task in not performed in the respective hospital

or even country. Tables 1 and 2 provide an overview of the manipulation processes, for ^{177}Lu and ^{68}Ga respectively, including elution/synthesis, quality control (QC), dispensing, and administration, for each participating hospital, along with the number of data sets and people involved. For ^{131}I, only the administration of ^{131}I pills was involved in the measurements with 5 data sets obtained from 4 people in hospital E and 8 data sets obtained from 3 people in hospital F. The radionuclide calibrators in all hospitals, used for the activity measurements, meet the criteria for QC as requested by their national authorities and comprise daily QC tests (Zero adjustments, background, bias correction, accuracy and constancy), monthly or quarterly QC tests (energy response) and yearly QC tests (mainly linearity). Most institutes work with calibration factors and isotope-specific factors, provided by the device manufacturer or by a certified body (such as centers G and J). These are defined with calibrated long-lived sources, such as Co-57, Co-60 and Cs-137. Only in hospitals D, E and K, the radionuclide calibrators are calibrated/verified, specifically with a Ga-68 and/or Lu-177 source.

Routine yearly occupational dose data were collected for staff that has worn at least two dosemeter sets for the same radionuclide within the study. It was collected both for whole-body dose and ring dose and was provided on monthly basis. Moreover, the yearly workload of these staff members was evaluated in terms of isotopes handled, the amount of activity per isotope and the specific tasks performed. As such we investigated the occupational dose contribution of the isotopes under study to the global dose burden of these NM staff, including the exposure from all isotopes handled in routine practice.

Finally, for the different dose quantities, an extrapolation to the yearly occupational dose is made by multiplying for a specific participant its average measured dose per manipulated activity with the provided annual total manipulated activity for a specific isotope. For the eye lens dose and extremity dose, the average maximum dose is always considered. In this way, we evaluated whether the isotope under study provides a significant risk to reach the corresponding annual dose limit and/or if routine monitoring is recommended, if this isotope would be the only one used.

Ethical considerations

Ethical approval was obtained, where necessary, from all Committees for Medical Ethics associated with the participating hospitals. The study adhered to the guidelines for good clinical practice (ICH/GCP) and the Helsinki Declaration, ensuring the protection of human participants. Prior to participation, each participant received an information letter and provided signed informed consent. Consent included wearing dosemeters during procedures, providing procedure information, and agreeing to the collection and analysis of routine dosimetry data. Only pseudonymized data will be used for analysis, documentation, reports, or publications, ensuring confidentiality.

Results

New occupational dosimetry data

In total, 69 completed data sets from 6 hospitals have been collected for ^{177}Lu, 65 completed data sets from 6 hospitals for ^{68}Ga and 13 completed data sets from 2 hospitals for ^{131}I. In Table 3, the $H_p(10)$, $H_p(3)$ and $H_p(0.07)$ doses are reported for the 3 isotopes, averaged over all participants. All dose data are normalized to the total isotope-specific activity manipulated (A_{tot}) while wearing the dosemeter sets.

Whole-body and eye lens dosimetry

From Table 3, it can be observed that highest whole-body doses are observed for ^{68}Ga. In general, many whole-body dosemeter sets resulted in measurement values below the DL: 108 out of 148, i.e. 73%. In Fig. 2, the variation in $H_p(10)$ for the different hospitals and for each isotope is demonstrated. For the eye lens doses, again 73% of measurements resulted in values below the DL for left and right eye together. When dose measurements exceeded the DL for at least one eye, it was impossible to determine which side typically had the highest dose. Consequently, the analysis considered the maximum eye

Table 3 Average whole-body dose $H_p(10)$, average maximum eye lens dose $H_p(3)$ and average maximum extremity dose $H_p(0.07)$, normalized to manipulated activity [μSv/GBq] for all 3 isotopes

Isotope	$H_p(10)/A_{tot}$ [μSv/GBq]	Max $H_p(3)/A_{tot}$ [μSv/GBq]	Max $H_p(0.07)/A_{tot}$ [μSv/GBq]
^{68}Ga	58	204	6200
^{177}Lu	< 3	2.6	30
^{131}I	8.6	8.5	260

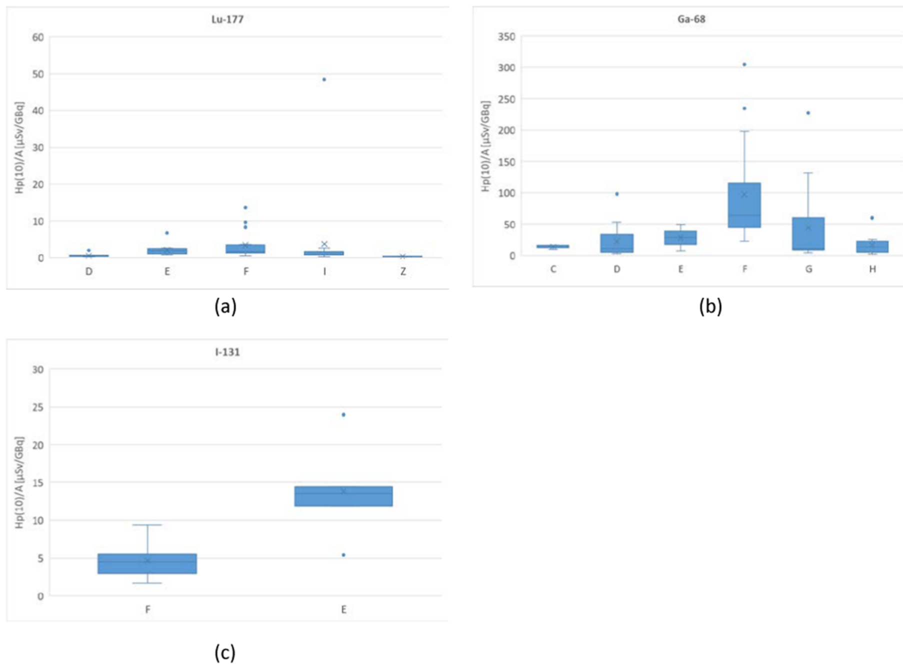

Fig. 2 Variation in $H_p(10)$ per normalized activity at each hospital for ^{177}Lu (**a**), ^{68}Ga (**b**) and ^{131}I (**c**). Boxplots with minimum and maximum, 1st and 3rd quartile, median and average (x) values and outliers (dots)

Table 4 Maximum extremity dose, per manipulated activity, [mSv/GBq] in the different hospitals for preparation + dispensing of the ^{68}Ga vial, for administration of the ^{68}Ga syringes and for QC tests

	Max $H_p(0.07)/A_{tot}$ [mSv/GBq					
Task	**Hospital C**	**Hospital D**	**Hospital E**	**Hospital F**	**Hospital G**	**Hospital H**
Prep + Dis	4.2	2.0	8.8	*	3.9	4.2
Admin	1.3	/	3.9	2.7	3.1	5.2
QC	/	37	/	/	45	/

/: No data sets have been recorded containing measurements for the specific task alone

*This specific task is not performed in the respective hospital

lens dose measured without distinguishing between the left or right eye as a conservative estimation. The highest doses are again observed for ^{68}Ga.

Extremity dosimetry

In Table 3, also the average maximum $H_p(0.07)$ extremity doses are reported for the 3 isotopes, normalized to the total activity handled and averaged over the different participants and tasks performed, with highest doses determined once more for ^{68}Ga. A more extensive evaluation is performed separately for ^{68}Ga and ^{177}Lu below. For ^{131}I, only 13 datasets have been evaluated, so it is not included in the detailed analysis.

^{68}Gallium In Table 4, the average maximum extremity doses, normalized to the manipulated activity, are compared across different hospitals for three distinct tasks: preparation + dispensing, administration and QC. Data sets that involve a combination of activi-

ties (such as preparation + dispensing + QC, preparation + dispensing + administration, preparation + dispensing + QC + administration, or dispensing + administration) are excluded from this comparison due to the difficulty in making accurate comparisons. The lower dose values observed at Hospital D for preparation and dispensing can be attributed to their fully automatic elution, preparation, and dispensing procedures. In contrast, other hospitals use an automated system for elution and preparation, but the dispensing is done manually, and shielding is applied to the syringes only after measuring the activity in a radioactivity meter. The administration of ^{68}Ga is always performed manually with shielded syringes. Consequently, the observed variations in extremity doses during administration can be explained by individual differences in how each technologist handles the syringe. All hospitals use Pb shielding for the vial while preparing or dispensing the ^{68}Ga and W shielding for the syringes during dispensing and administration.

For general QC procedures, a small amount of activity (a few μL; 20–100 kBq per QC procedure) is used for various QC tests, such as thin layer chromatography (TLC), pH and half-life analyses. The total activities handled, involving multiple QC procedures over several days, ranged between 60 and 600 MBq. These tests are conducted quickly, but without any shielding. This resulted in extremity dose measurements well above the DL of 50 μSv, with maximum extremity doses per data set ranging between 2.3 and 23 mSv. This explains why the normalized maximum dose values per manipulated activity are much higher compared to other tasks, as the manipulated activities for QC procedures are much smaller.

^{177}Lutetium In Table 5, the average maximum extremity doses, normalized to the manipulated activity, are compared among various hospitals for two specific tasks: preparation + dispensing and dispensing + administration. The elevated extremity doses observed in hospital K can be attributed to the manual preparation and dispensing processes, in contrast to hospital I, where these tasks are fully automated. In hospitals D, E and J, the preparation phase is automated, while the dispensing of syringes is done manually for D and E, and in hospital J it is automated for single patient synthesis and manual for two patients per synthesis. Across all hospitals, the administration of ^{177}Lu is done using either semi-automatic or fully automatic systems, including injection systems, infusion pumps or infusion methods. The dose values from hospital D involve both dispensing and administration, while in the other centers only administration is performed in the data sets included in Table 5. Shielding is used in every hospital: usually Pb and PMMA for vial shielding and W or Pb for syringe shielding.

Table 5 Maximum extremity dose, per manipulated activity, [μSv/GBq] in the different hospitals for preparation + dispensing of the ^{177}Lu vial and for administration of the ^{177}Lu syringes

	Max $H_p(0.07)/A_{tot}$ [mSv/GBq					
Task	**Hospital D**	**Hospital E**	**Hospital F**	**Hospital I**	**Hospital J**	**Hospital K**
Prep + Dis	/	0.050	*	0.011	0.008	0.045
(Dis) + Admin	0.031	0.092	0.040	0.009	0.006	/

/: No data sets have been recorded containing measurements for the specific task alone

*This specific task is not performed in the respective hospital

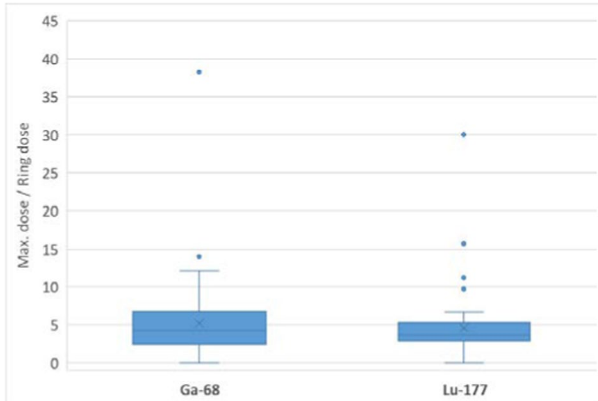

Fig. 3 Ratio between maximum dose and dose measured at the base of the middle finger for ^{68}Ga and ^{177}Lu

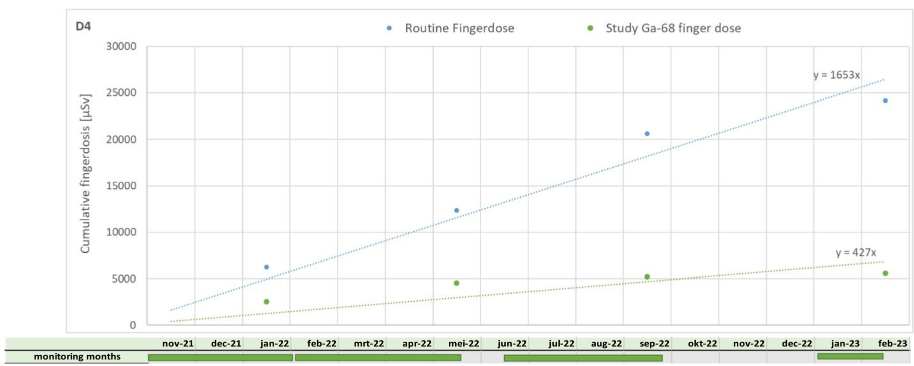

Fig. 4 Monthly cumulative routine ring doses and ^{68}Ga-specific fingerdose data for the monitoring periods (green bars) of participant D4

Ratio of maximum dose to ring dose Approximately 75% of maximum extremity doses for ^{68}Ga are measured on the fingertips of the thumb, index or middle finger of the non-dominant hand, while 25% are on the thumb or index finger of the dominant hand. For ^{177}Lu, maximum dose positions are more equally distributed between both hands' fingertips. It should be noticed that for ^{177}Lu, the variation in measured dose ranges across both hands is rather small. In many cases, if the maximum dose was observed on the dominant hand, the dose values on the non-dominant hand were in the same range as well. The average ratio between the maximum dose and the dose at the base of the middle finger (possible routine ring dosemeter position) is around 5 for both^{68}Ga and ^{177}Lu (Fig. 3), and therefore consistent with current recommendations to apply a correction factor [10].

Contribution to the total occupational extremity doses

The cumulative extremity dose values measured at the base of the middle finger of the non-dominant hand for ^{68}Ga and ^{177}Lu during this study were compared to routine monthly ring dosemeter values for the same periods. As an example, Fig. 4 shows cumulative doses for participant D4, comparing routine ring doses and ^{68}Ga-specific doses, monitored during ^{68}Ga administration. The green bars represent the monitoring periods in the study and the total dose at the base of the middle finger of the non-dominant hand of each such period has been shown in a cumulative way. Similarly, the routine monthly ring doses are summed within each monitoring period and also shown in Fig. 4 in a cumulative way. The routine ring doses for months when no study-dosemeter sets have been used (for example D4, this is oct–dec 2022), are omitted. The ratio of the slopes of the cumulative ring dose curves indicates that 26% of the total routine dose comes from the administration of ^{68}Ga. Next, the workload of each participant was assessed in terms of total activity for each handled isotope. For some centers, detailed personal monthly data for each isotope were available, while others provided typical yearly workloads (e.g., number of patients x activity per syringe) and the total number of staff handling the isotopes. For participant D4, 2% of the yearly activity involved ^{68}Ga, 80% involved ^{99m}Tc, 17% involved ^{18}F and 0.7% involved ^{123}I. Since 26% of D4's total routine finger dose came from ^{68}Ga-injections, despite only 2% of the handled activity being ^{68}Ga, it was concluded that ^{68}Ga administration results in 13 times more extremity dose compared to the manipulated activity from other isotopes. Tables 6, 7, 8 and 9 summarize this analysis for all NM staff (with minimum 2 dosemeter sets per isotope) involved in ^{68}Ga administrations, ^{68}Ga synthesis, ^{177}Lu administrations and ^{177}Lu preparations, respectively.

Table 6 Contribution of the ^{68}Ga finger dose compared to the total finger dose from all isotopes for participants administering ^{68}Ga

^{68}Ga administrations	**G4**	**F9**	**F10**	**F5**	**F8**	**D3**	**D4**
^{68}Ga finger dose/routine finger dose [%]	54	29	31	25	63	8	26
Activity ^{68}Ga/total yearly activity [%]	1.3	0.4	0.4	0.4	0.4	0.7	2
^{68}Ga dose fraction compared to other isotopes	**40**	**71**	**78**	**64**	**155**	**12**	**13**

The bold lines, represent the final data that is used for the conclusions of this analysis. The data in the lines above is the data used to obtain the data in the bold lines

Table 7 Contribution of the ^{68}Ga finger dose compared to the total finger dose from all isotopes for participants synthesizing^{68}Ga

^{68}Gasynthesis	**G1**	**G2**	**G3**	**G5**	**D1**	**C1**
^{68}Ga finger dose/routine finger dose [%]	41	43	23	23	54	50
Activity ^{68}Ga/total yearly activity [%]	1.4	13	0.8	0.4	2	2.3
^{68}Ga dose fraction compared to other isotopes	**29**	**3**	**28**	**53**	**26**	**22**

The bold lines, represent the final data that is used for the conclusions of this analysis. The data in the lines above is the data used to obtain the data in the bold lines

Table 8 Contribution of the ^{177}Lu finger dose compared to the total finger dose from all isotopes for participants administering ^{177}Lu

^{177}Lu administrations	**F2**	**F11**
^{177}Lu finger dose/routine finger dose [%]	83	24
Activity ^{177}Lu/total yearly activity [%]	3.0	3.0
^{177}Lu dose fraction compared to other isotopes	**25**	**7**

The bold lines, represent the final data that is used for the conclusions of this analysis. The data in the lines above is the data used to obtain the data in the bold lines

Table 9 Contribution of the ^{177}Lu finger dose compared to the total finger dose from all isotopes for participants preparing ^{177}Lu

^{177}Lu preparations	**D1**	**D2**	**I3**	**I5**	**K1**
^{177}Lu finger dose/routine finger dose [%]	25	22	10	5	99
Activity ^{177}Lu/total yearly activity [%]	90	88	40	41	66
^{177}Lu dose fraction compared to other isotopes	**0.3**	**0.3**	**0.3**	**0.1**	**1.5**

The bold lines, represent the final data that is used for the conclusions of this analysis. The data in the lines above is the data used to obtain the data in the bold lines

Table 10 Extrapolated annual doses ($H_p(10)$, $H_p(3)$, $H_p(0.07)$) for NM staff performing ^{68}Ga administrations

Participants	**Annual activity (A)** [GBq]	**<$H_p(10)$/A>** [μSv/GBq]	**Annual $H_p(10)$** [mSv]	**<$H_p(3)$/A>** [μSv/GBq]	**Annual $H_p(3)$** [mSv]	**<$H_p(0.07)$/A>** [μSv/GBq]	**Annual $H_p(0.07)$** [mSv]
D3	24	39	0.9	39	0.9	2239	53
D4	34	17	0.6	17	0.6	1325	45
G4	8	72	0.6	622	5.0	3178	25
F9	18	75	1.4	73	1.3	1879	35
F10	18	152	2.8	105	1.9	1782	33
F5	18	53	1.0	51	0.9	2419	45
F8	18	69	1.3	61	1.1	4215	78

Table 11 Extrapolated annual doses ($H_p(10)$, $H_p(3)$, $H_p(0.07)$) for NM staff performing ^{68}Ga synthesis

Participants	**Annual activity (A)** [GBq]	**<$H_p(10)$/A>** [μSv/GBq]	**Annual $H_p(10)$** [mSv]	**<$H_p(3)$/A>** [μSv/GBq]	**Annual $H_p(3)$** [mSv]	**<$H_p(0.07)$/A>** [μSv/GBq]	**Annual $H_p(0.07)$** [mSv]
G1	77	13	1.0	78	6.0	5841	449
G2	156	10	1.5	19	3.0	3879	607
G3	75	6	0.5	36	2.7	1072	81
G5 (QC)	4	131	0.6	2923	12.5	44674	190
D1	111	6	0.7	6	0.7	1411	156
C1	44	13	0.6	13	0.6	6922	306

Table 12 Extrapolated annual doses ($H_p(10)$, $H_p(3)$, $H_p(0.07)$) for NM staff performing ^{177}Lu administrations

Participants	**Annual activity (A)** [GBq]	**<$H_p(10)$/A>** [μSv/GBq]	**Annual $H_p(10)$** [mSv]	**<$H_p(3)$/A>** [μSv/GBq]	**Annual $H_p(3)$** [mSv]	**<$H_p(0.07)$/A>** [μSv/GBq]	**Annual $H_p(0.07)$** [mSv]
F2	155	1.6	0.25	1.6	0.25	19	2.9
F11	155	1.0	0.15	1.1	0.17	11	1.7

Table 13 Extrapolated annual doses ($H_p(10)$, $H_p(3)$, $H_p(0.07)$) for NM staff performing ^{177}Lu synthesis

Participants	Annual activity (A) [GBq]	< $H_p(10)$/A > [μSv/GBq]	Annual $H_p(10)$ [mSv]	< $H_p(3)$/A > [μSv/GBq]	Annual $H_p(3)$ [mSv]	< $H_p(0.07)$/A > [μSv/GBq]	Annual $H_p(0.07)$ [mSv]
D1	1348	0.4	0.5	0.4	0.5	33	44
D2	1077	0.4	0.5	0.5	0.5	34	37
I3	262	0.7	0.2	0.7	0.2	2.9	1
I5	262	0.6	0.2	0.6	0.2	5.7	1
K1	1620	0.3	0.4	0.3	0.4	45	72

Extrapolation to annual doses

Tables 10, 11, 12, and 13 show the extrapolated yearly doses for NM staff, including whole-body dose [$H_p(10)$], maximum eye lens dose [$H_p(3)$] and maximum extremity dose [$H_p(0.07)$], for the synthesis or administration of ^{68}Ga and ^{177}Lu radiopharmaceuticals separately. These values can be compared against the annual occupational dose limits: 20 mSv/year for $H_p(10)$ and $H_p(3)$ and 500 mSv/year for $H_p(0.07)$ [20].

For ^{177}Lu, annual doses are below 0.5 mSv for both whole-body and eye lens doses during radiopharmaceutical synthesis and administration. Yearly maximum extremity doses stay below 100 mSv for synthesis and only several mSv for administration. For ^{68}Ga, annual $H_p(10)$ can reach nearly 3 mSv, and $H_p(3)$ can reach 5–6 mSv. For participant G5, who only performs QC of ^{68}Ga pharmaceuticals, an annual eye lens dose of 12 mSv is estimated. Yearly extremity doses stay below 100 mSv for ^{68}Ga administration but can reach up to 600 mSv for synthesis and dispensing.

Discussion

Although well-characterized and sensitive detectors have been used to monitor occupational doses in NM departments, the whole-body and eye lens doses we measured for the specific isotopes under study often remained below the DL (50 μSv), even with monthly monitoring for ^{68}Ga or over several treatment cycles for ^{177}Lu and ^{131}I. From the collected routine dosimetry data we could observe that the total monthly whole-body doses (considering all the isotopes handled by the respective participant) were typically higher than the DL applied in this study. The variation in extremity doses between hospitals for the same radionuclide can largely be explained by the specific tasks performed and the working procedures applied within those tasks. Based on our results, we can confirm that the use of automatic synthesis and dispensing significantly reduces the dose to personnel. There is a large variation in academic background of the staff that collaborated in the measurements, depending on the hospitals. For ^{177}Lu, the synthesis, labeling and QC are mainly done by NM technologists (hospitals D, E, I and K), only in hospital J this is done by a radiopharmacist. For the administration of ^{177}Lu, physicians are involved in hospitals E, F and I, while in hospitals D and J this is also done by NM technologists. In hospital D, also 1 medical physicist was involved in the preparation, QC and administration of ^{177}Lu. For ^{68}Ga, the synthesis, labeling and QC were performed by NM technologists in hospitals D and E, while it was done by lab technicians in hospitals C, G and H. In hospital D again 1 medical physicist participated. The ^{68}Ga injections were performed by NM technologists (hospitals C and D), by lab technicians (hospital G), by nurses (hospital F) or by physicians (hospitals E and H). The number of participants per category are too low to make a sound conclusion on what is the effect of the staff's academic background on the obtained dose data.

In the review paper by Kollaard et al., five studies were identified that reported fingertip doses for ^{177}Lu ranging from 1 to 44 μSv/GBq [18]. These findings are consistent with the average maximum fingertip dose observed in this study, which is 30 μSv/GBq, with a range of 5.5–92.4 μSv/GBq. For the unpacking and administration of ^{131}I pills, documented fingertip doses vary between 50 and 7040 μSv/GBq [21]. This extensive range encompasses the average maximum fingertip dose of 260 μSv/GBq, with a specific range of 20–743 μSv/GBq reported in this study. Additionally, a recent study by Wrzesien et al. conducted a small-scale measurement campaign to evaluate fingertip doses in a NM department involved in the preparation and administration of ^{68}Ga-DOTA-TATE [22]. The results from Wrzesien's study were comparable to those in this study, with the highest average fingertip dose being approximately 4 mSv/GBq for elution and labeling of ^{68}Ga, 40 mSv/GBq for dispensing, and 1.3 mSv/GBq for technologists administering the doses.

On average, ^{68}Ga activities monitored in this study result in about 40 times higher finger doses per manipulated activity compared to other isotopes, with variations ranging from 3 to 155 times. Most participants handle less than 2% of their total activity coming from ^{68}Ga, with the majority coming from ^{99m}Tc and ^{18}F. An exception in this study is participant G2, who handles a higher workload for ^{68}Ga, while only 25% for ^{99m}Tc, ~ 20% for ^{82}Rb and ^{131}I, and 10% for ^{90}Y.

For ^{177}Lu administrations, extremity doses are 7–25 times higher than those coming from other isotopes, but this analysis includes only 2 participants, i.e. F2 and F11 who primarily handle ^{99m}Tc and ^{18}F (~ 90%). Participants preparing and dispensing ^{177}Lu mainly work with this radionuclide, contributing 40–90% of their handled activity, but only 5–25% of their routine finger dose, indicating that ^{177}Lu preparation contributes less to the finger dose than other isotope preparations.

Generalizing these results is difficult due to the variability in isotope handling practices and personal habits. The use of different detectors between this study and routine practice adds uncertainty, particularly for beta-particle exposure from ^{68}Ga, as for this study detectors are used with an improved response for beta-particles. Moreover, routine ring dosemeters might sometimes be forgotten or affected by contamination, complicating its dose determination. A study limitation is the often-limited dose data from only 2 datasets per participant, hindering long-term isotope contribution assessment. More datasets per participant would strengthen the analysis, but practical constraints made this difficult. The burden of using multiple dosemeters and detailed activity recording, along with low frequency of ^{177}Lu therapy, further limited the available data.

As observed in many other studies, maximum finger doses are reached on the fingertips. For ^{68}Ga this maximum dose is mostly observed on the non-dominant hand, while for ^{177}Lu the working practice results in a more equal distribution in dose values across both hands and the different positions. Additionally, we could confirm that the use of the ring dosemeter with a correction factor of 5 is recommended to estimate the maximum dose to the fingertips.

The evaluation of annual occupational doses, calculated by multiplying individual maximum doses per manipulated activity with estimated yearly activity, shows that for ^{177}Lu, these annual extremity doses remain well below the specific annual dose limits and even below the recommended monitoring limit (i.e. 1/3rd of the annual dose limit). However, more care is needed for ^{68}Ga synthesis and dispensing, as some participants' extrapolated annual $H_p(0.07)$ values exceeded the 500mSv annual limit. Considering that ^{68}Ga typically represents only a small part of the total workload, a non-negligeable contribution from other isotopes should also be added to this annual extremity dose. Additionally, the annual eye lens dose approaches the recommended monitoring limit of 6 mSv and specific attention should be paid to eye lens doses during QC of ^{68}Ga radiopharmaceuticals. It should also be noted that all measurement values below the DL have been set to 50 μSv, meaning that mainly for whole-body doses and eye lens doses, these extrapolated yearly doses can be considered as conservative estimations.

Conclusion

This study's measurement campaigns across various European countries have provided new and extensive occupational dosimetry data for NM staff handling ^{68}Ga and ^{177}Lu radiopharmaceuticals and to a lesser extent also for ^{131}I radiopharmaceuticals. For staff working in radiopharmacy hot labs, the preparation, labeling and dispensing of ^{177}Lu contribute less to the total finger dose compared to other isotopes. A conservative estimation of annual occupational doses indicates that the manipulation of ^{177}Lu has a limited impact on reaching the annual dose limits for whole-body, eye lens and extremity doses.

However, careful monitoring of hand and finger exposure is essential for all radiopharmaceuticals. The contribution of ^{68}Ga radiopharmaceuticals to finger doses is significantly higher compared to other isotopes, particularly during elution, synthesis and dispensing. There is a risk of reaching the annual dose limit for these activities. It is also recommended to monitor the eye lens dose during these procedures, at least for a specific period, to ensure accurate dose estimation and individual risk assessment.

Author contributions

LS has made substantial contribution to the conception and design of the work, the analysis and interpretation of the data and has drafted and revised the manuscript. EA, LB, NC, YD, FDM, ALM, RM, CT, SVdB, HZ, VS all contributed to the organization and collection of data in the participating centers. They all revised the manuscript. WS prepared and read all the dosemeter sets for the measurements in the participating centers. FV has made substantial contribution to the analysis of the data and revised the manuscript.

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Availability of data and materials

The datasets used and/or analysed during the current study are available from the corresponding author on reasonable request.

Declarations

Ethics approval and consent to participate

This study was performed in line with the principles of the Declaration of Helsinki. Approval was granted by the local Medical ethics committees. Every participant received an information letter and signed an informed consent before participation. Only pseudonymised data will be used for analysis of the data and in any documentation, reports or publication about the study.

Consent for publication
Not applicable, no individual person data submitted in the paper.

Competing interests
The authors declare that they have no competing interests" in this section.

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References

1. Carnicer A, Sans Merce M, Baechler S, Barth I, Donadille L, Ferrari P, et al. Hand exposure in diagnostic nuclear medicine with ^{18}F- and ^{99m}Tc-labelled radiopharmaceuticals—results of the ORAMED project. Radiat Meas. 2011;46:1277–82.
2. Fioroni F, Grassi E, Giorgia C, Rubagotti S, Piccagli V, Filici A, et al. Skin dose saving of the staff in ^{90}Y/^{177}Lu peptide receptor radionuclidetherapy with the automatic dose dispenser. Nucl Med Commun. 2016;37:1046–52.
3. Geworski L, Zöphel K, Rimpler A, Barth I, Lassmann M, Sandrock D, et al. Radiation exposure in (90) Y-Zevalin therapy: results of a prospective multicentre trial. Nuklearmedizin. 2006;45:82–6.
4. Leide-Svegborn S. External radiation exposure of personnel in nuclear medicine from^{18}F, ^{99m}TC and ^{131}I with special reference to fingers, eyes and thyroid. Radiat Prot Dosim. 2012;149:196–206.
5. Rimpler A, Barth I, Ferrari P, Barchler S, Carnicer A, Donadille K, et al. Extremity exposure in nuclear medicine therapy with ^{90}Y-labelled substances—results of the ORAMED project. Radiat Meas. 2011;46:1283–6.
6. Saether HK, Davidson T-M, Widmark A, Wøhni T. Measurements of finger doses in X-ray guided surgery, nuclear medicine and research. Radiat Prot Dosim. 2005;113:392–5.
7. Whitby M, Martin CJ. A multi-centre study of dispensing methods and hand doses in UK hospital radiopharmacies. Nucl Med Commun. 2005;26:49–60.
8. Wrzesien´ M, Olszewski J, Jankowski J. Hand exposure to ionising radiation of nuclear medicine workers. Radiat Prot Dosim. 2008;130:325–30.
9. Annex E. Radiation exposure of hands in radiopharmacies: monitoring of doses and optimisation of protection. ICRP Publication 106. Ann. ICRP 38 (1–197).
10. ISO. Radiological protection—procedures for monitoring the dose to the lens of the eye, the Skin and the Extremities (International Organization for Standardization), 2015.
11. Vanhavere F et al. Optimization of radiation protection of medical staff. EURADOS Report2012–02. 2012. https://doi.org/10.12768/yc01-0d55.
12. Dwivedi DK, Snehlata DAK, Lochab SP, Kumar R, Naswa N, et al. Radiation exposure to nuclear medicine personnel handling positron emitters from Ge-68/Ga-68 generator. Indian J Nucl Med. 2011;26(2):86–90.
13. Riveira-Martin M, Struelens L, Schoonjans W, Sanchez-Diaz I, Iglesias JM, Davilla OF, et al. Occupational doses during management of therapeutic (Lu-177-DOTATATE) and diagnostic (Ga-68-DOTATOC) radiopharmaceuticals for theranostics. Physica Med. 2022;104:S42.
14. Bakker WH, Breeman WAP, Kwekkeboom DJ, De Jong LC, Krenning EP. Practical aspects of peptide receptor radionuclide therapy with[^{177}Lu]-[DOTA, Tyr]octreotate. QJ Nucl Med Mol Imaging. 2006;50:265–71.
15. Demir M, Abuqbeitah M, Uslu-Besli L, Yildirim O, Yeyin N, Cavdar I, et al. Evaluation of radiation safety in ^{177}Lu-PSMA therapy and development of outpatient treatment protocol. J Radiol Prot. 2016;36:269.
16. Riveira-Martin M, Struelens L, Iglesias JM, Schoonjans W, Tabuenca O, Nogueiras JM, et al. Radiation exposure assessment of nuclear medicine staff administering [^{177}Lu] Lu-DOTA-TATE with active and passive dosimetry. EJNMMI Phys. 2023;10:70.
17. Sghedoni R, Grassi E, Fioroni F, Asti M, Piccagli V, Versari A, et al. Personnel exposure in labelling and administration of ^{177}Lu-DOTA-D-Phe1-Tyr3-octreotide. Nucl Med Commun. 2011;32:947–53.
18. Kollaard R, Zorz A, Dabin J, Covens P, Cooke J, Crabbé M, et al. Review of extremity dosimetry in nuclear medicine. J Radiol Prot. 2021;41(4):60–87.
19. Van Hoey O, Hasan M, Struelens L, Schoonjans W, Dabin J, Castillo Seoane D, et al. Evaluation of different types of lithium fluoride thermoluminescent detectors for ring dosimetry in nuclear medicine. Radiat Meas. 2022;159(2–4): 106866.
20. ICRP. The international commission on radiological protection. The 2007 recommendations of the international commission on radiological protection. ICRP Publication 103. Ann. ICRP 37 (2–4) 2007.

21. Wrzesien M, Olszewski J. Hand exposure of nuclear medicine workers during administration of radioiodine. Radiat Prot Dosim. 2012;151:147–52.
22. Wrzesien M, Albiniak Ł. Personal dose equivalent $H_p(0.07)$ during 68Ga-DOTA-TATE production procedures. Radiat Environ Biophys. 2023;62(1):117–29.

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