Chapter 7
Occupational Exposure: With Special Reference to Skin Doses in Hands and Fingers

Adela Carnicer, Mercè Ginjaume, Marta Sans-Merce, Laurent Donadille, Ilona Barth, and Filip Vanhavere

7.1 Introduction

Nuclear medicine (NM) is the medical specialty that is associated with all uses of unsealed radioactive sources for diagnosis and treatment of disease. In diagnostics, technological advances have led to the fast spread of both the conventional and new imaging techniques such as single-photon emission computed tomography (SPECT) and positron-emission tomography (PET). As a consequence, radiopharmaceuticals are increasingly used, thus resulting in a rise of workload in radiopharmacy units and nuclear medicine departments. On the other hand, new therapy procedures with unsealed radionuclides are also gaining increasing importance. Pure beta-emitters or mixed beta-gamma radionuclides are particularly suitable for therapy applications with typically high activities required to fulfill the therapeutic effect.

Radiation protection of workers is an important issue in NM since, firstly, high radionuclide activities are needed, from few tens to several thousands of MBq; secondly, the procedures require the handling of radiopharmaceuticals at contact or very close to the extremities (hands, fingers); and, thirdly, often pure beta-emitters

---

A. Carnicer • M. Ginjaume (✉)
Universitat Politecnica de Catalunya (UPC), Diagonal 647, 08028 Barcelona, Spain
e-mail: merce.ginjaume@upc.edu

M. Sans-Merce
Institut de Radiophysique, University Hospital Center (CHUV), University of Lausanne, Rue du Grand-Pré 1, 1007 Lausanne, Switzerland

L. Donadille
Institut de Radioprotection et de Sûreté Nucléaire (IRSN), 31 Av. de la Division Leclerc, 92260 Fontenay-aux-Roses, France

I. Barth
Bundesamt für Strahlenschutz (BfS), Koepenicker Allee 102-130, 10318 Berlin, Germany

F. Vanhavere
Belgian Nuclear Research Centre (SCK-CEN), Boeretang 200, 02400 Mol, Belgium

S. Mattsson and C. Hoeschen (eds.), *Radiation Protection in Nuclear Medicine*,
DOI 10.1007/978-3-642-31167-3_7, © Springer-Verlag Berlin Heidelberg 2013

and mixed photon/beta-emitters are used. NM workers are thus potentially exposed to external radiation and to internal contamination in case of accidental intake. If adequate protocols are used, in general, contamination leads to negligible exposure to staff. External whole-body exposures for nuclear medicine staff are coming mostly from the patient contribution, in particular in PET procedures, but the annual effective dose is usually low (2–3 mSv for gamma procedures, around 6 mSv for PET). However, the exposure of the extremities during preparation and administration of radiopharmaceuticals can be high. The hands remain often unprotected, and thus, fingertips can receive high doses which are likely to exceed the dose limit for extremities whenever the level of radiation protection is insufficient or the workload is too high.

The works of Vanhavere et al. [1] and Donadille et al. [2] highlighted the fact that the radiation protection of workers in NM presented open issues that were not yet satisfactorily addressed. Thus, from January 2008 up to February 2011, the collaborative project, *Optimization of Radiation Protection of Medical Staff*, ORAMED, was set up and funded within the European Atomic Energy Community’s Seventh Framework Programme (http://www.oramed-fp7.eu) with the aim of overcoming the problems previously identified. In particular, one of the working groups in ORAMED, WP4, aimed at the study of extremity dosimetry within NM. Three main objectives were proposed:

- To address the lack of knowledge on skin dose distribution and maximum skin dose to the hands
- To optimize routine monitoring of extremity dosimetry in order to assess skin dose as close as possible to maximum skin dose
- To set up the conditions and requirements necessary to ensure an acceptable level of radiation protection

This chapter first gives an overview of basic concepts, regulation, and problems associated with occupational monitoring in nuclear medicine. It then presents the methodology and main results of the ORAMED project in the field of extremity dosimetry of nuclear medicine staff. Finally, some recommendations to improve radiation protection in occupational exposure in nuclear medicine are proposed.

7.2 Occupational Monitoring: Basic Concepts, Regulation, and Practical Considerations

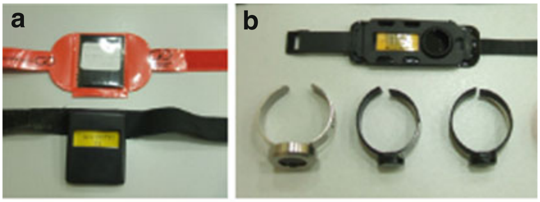
The main objectives of occupational monitoring are to provide a basis for estimation of the actual radiation exposure of workers and to demonstrate compliance with legal requirements. It is also useful to optimize operating procedures, to increase awareness of risk, and to motivate workers to reduce their own exposure. The limitation of dose for occupationally exposed workers to ionizing radiation is regulated by National and International Authorities. Regulations are based on the recommendations of the International Commission of Radiological Protection (ICRP) [3, 4] and the International Commission of Radiation Units and Measurements (ICRU) [5, 6]. In Europe, the Council Directive 96/29/Euratom [7] establishes the basic safety standards for the health protection of the general public and workers against the dangers of ionizing radiation. This directive is based on ICRP Publication 60 [3] and is now under revision [8]. The new version introduces recent scientific findings and recommendations, such as the 2007 recommendations of the ICRP [4].

Monitoring of internal exposure for nuclear medicine workers requires frequent measurements due to the short physical half-lives of most radionuclides used in this field. Baechler et al. [9] describe a protocol used in Switzerland to perform screening measurements of NM workers at the workplace to detect whether potential intake has occurred. The intakes from ingestion and inhalation are usually negligible, provided that adequate protection measures are applied. However, when volatile radionuclides such as iodine are used, it is recommended to monitor the workplace conditions, in particular to control contamination levels in the air.

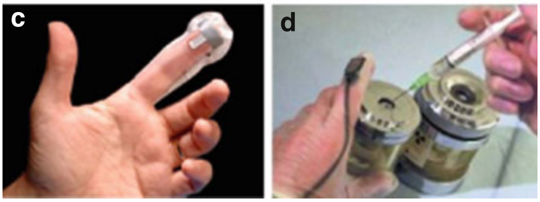
The operational quantity for external individual monitoring (see Chap. 1) is the personal dose equivalent, $H_p(d)$, which is the dose equivalent in ICRU soft tissue [10] at an appropriate depth, d, below a specified point on the human body. For the assessment of effective dose due to external exposure, $H_p(10)$ at a depth $d = 10$ mm is chosen, and for the assessment of skin, hands, and feet equivalent dose, the personal dose equivalent, $H_p(0.07)$, at a depth $d = 0.07$ mm is used. A depth $d = 3$ mm has been proposed for the case of monitoring the dose to the lens of the eye.

Operational quantities are measurable, and instruments for radiation monitoring of external exposure are calibrated in terms of these quantities. In routine monitoring, the values of these operational quantities are usually a conservative estimate of the protection quantities. $H_p(d)$ is usually measured with a whole-body dosemeter, worn on the anterior part of the chest. The individual dose monitoring is performed with a passive dosemeter, mainly with thermoluminescent detectors but also with photographic films and photoluminescence and optically stimulated luminescent detectors. Likewise for internal exposure, the effective dose due to external radiation is usually low. According to the results from the ESOREX project [11], in the medical field, in Europe, for the year 2000, 93% of monitored workers received an annual effective dose below 2 mSv and 99% below 5 mSv. In the training material on radiation protection in PET/CT [12], the IAEA provides some typical annual doses in nuclear medicine: around 1 mSv for radiochemists, below 6 mSv for PET/CT, and below 0.1 mSv for the other staff. Indeed, as mentioned earlier, the largest contribution to whole-body exposures for nuclear medicine staff is mostly due to ^{18}F-injected patients. Radiation exposure from CT during PET–CT procedures, which imply higher patient doses, can be neglected for staff, because of the beam geometry and the fact that technologists are usually outside the irradiation room. This topic is discussed further in Chap. 11.

In cases in which exposure is not homogeneous or is localized on a different part of the body, the whole-body monitoring has to be completed with additional dosemeters worn on the exposed zone. This is the case of workers involved in the preparation, labeling, or injection of radiopharmaceuticals. The monitoring of



Wrist TLD Ring TLD



Electronic extremity dosemeter Electronic extremity dosemeter

Fig. 7.1 Different types of extremity dosemeters

extremities and skin is recommended for workers that might receive an annual equivalent dose higher than 3/10th of the equivalent dose limits for hands and skin, namely, 150 mSv for hands or skin.

The most widely used dosemeters for the extremities are based on thermoluminescent detectors, placed in a holder that can be worn on the base of the finger or on the wrist. They are commonly known as *ring* and *wrist* dosemeters, respectively. Some dosemeters are specifically designed to be worn at the fingertips and also some electronic devices are available [13], but their use is much less frequent, mainly because they hinder the regular work. Figure 7.1 shows an example of the different types of extremity dosemeters.

7.3 Finger Doses for NM Workers

This paragraph provides information on finger doses for NM workers and guidance to monitor them, mainly based on the results of the ORAMED project.

7.3.1 Methodology

In order to determine the dose distribution across the hands and to supply information on reference dose levels for the most frequent NM procedures, an extensive measurement campaign was performed within the ORAMED project. It included 139 workers from 35 NM departments in seven European countries (Belgium, France, Germany, Italy, Slovakia, Spain, and Switzerland) representing the largest number of collected data on extremity dosimetry in NM up to now [14]. The experimental data were complemented with Monte Carlo (MC) simulations to better determine the main

Fig. 7.2 Example of gloves used in the measurement campaign

parameters that influence extremity exposure, the effectiveness of different radiation protection measures and the degree of variability that could be "intrinsically related" to each monitored procedure. Details on the Monte Carlo protocol and results are described by Ferrari et al. [15].

For the measurement campaign, a common protocol was established to be able to compare and evaluate the data from the different hospitals. In particular, it was agreed to use thin detectors (effective thickness below 10 mg cm^{-2}) for positron and beta-emitters [16]. The operational personal dose equivalent $H_p(0.07)$ was measured at 11 positions on each hand (Fig. 7.2), considering both the usually highest exposed areas (fingertips and fingernails) and the most practical and frequently used positions for routine monitoring (wrist and bases of the fingers). The most frequently employed radionuclides were considered, i.e., ^{99m}Tc and ^{18}F for diagnostic applications and ^{90}Y for therapy. Measurements were performed separately for each radionuclide and independently for preparation and administration. For each worker, a set of 4–5 measurements were taken, except for therapy, where this was not always achievable.

For the analysis, the measured doses were normalized to the activity defined according to the following criteria:

- For preparation:
  - For ^{99m}Tc, the activity withdrawn from the elution vial to prepare the radiopharmaceutical (this is less than the total eluted activity)
  - For ^{18}F, the activity in the mono or multidose vial
  - For ^{90}Y, the activity used for the preparation of the radiopharmaceutical
- For administration:
  - The total activity in the injection syringe

Then, the mean normalized dose in each monitored position was calculated for each worker and for each procedure. From these data, the distribution of the maximum normalized dose in the monitored workers is obtained $\langle H_p(0.07)_{max}/A \rangle$.

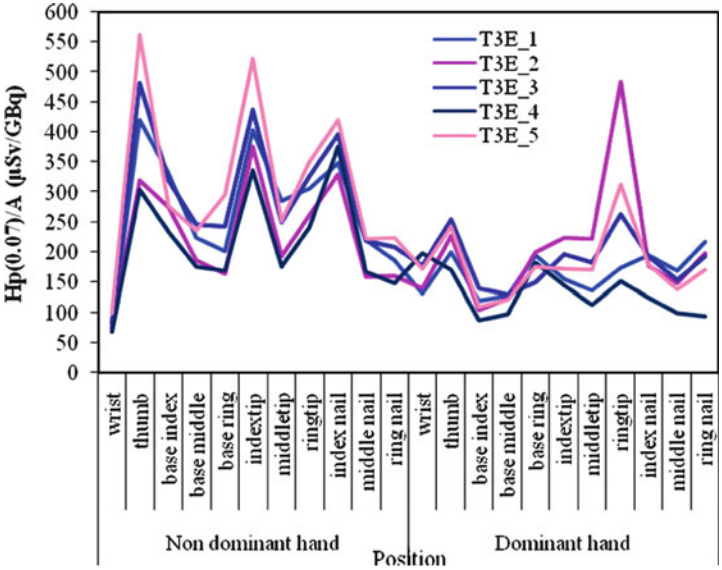


Fig. 7.3 Hand dose distribution for worker T3E, for preparation of ^{18}F. Each curve corresponds to individual sets of 20 TL readings

7.3.2 Results and Discussion

7.3.2.1 Hand Dose Distribution

As an example, Fig. 7.3 shows the normalized hand dose distribution during ^{18}F preparation. The worker is anonymously labeled T3E. The graph presents the set of five measurements of this worker; the uncertainty associated to each individual measurement ($k = 1$) is of the order of 15%. Although hand dose distribution varies between workers and techniques, general trends could be observed.

The tips of the fingers of both hands, especially the index and thumb, were identified to be the highest exposed positions. There is general agreement on this issue [17–21]. The least exposed positions were found to be the wrists, followed by the bases of the fingers. A clear trend was observed for the nondominant hand to be more exposed than the dominant hand, in particular for radionuclide preparation. However, this trend was strongly linked to individual working habits. In the literature, there is no consensus on which hand is the most exposed. The influence of individual working habits on the most exposed hand and position has also been pointed out in several works [17, 19, 20]. ICRP 106 [22], based on a thorough literature review, reports that the fingertips (especially index and thumb) of the dominant hand are the most exposed. For therapy, spatial dose inhomogeneity is usually much more pronounced, but generally also the same positions as for diagnostics were the most exposed. In most cases, the index tip of the nondominant hand is the most exposed specific position [23].

Table 7.1 Mean, median, maximum, and minimum values of $\langle H_\mathrm{p}(0.07)_\mathrm{max}/A \rangle$ of all monitored workers per procedure (*A* stands for administration and *P* for preparation) (adapted from Sans-Merce et al. [14])

	Maximum doses from all workers (mSv/GBq)			
	Mean	Median	Minimum	Maximum
P—^{99m}Tc	0.4	0.25	0.03	2.1
A—^{99m}Tc	0.2	0.12	0.01	0.9
P—^{18}F	1.2	0.83	0.1	4.4
A—^{18}F	0.9	0.64	0.1	4.1
P—^{90}Y Zevalin	11	9.5	1.2	44
A—^{90}Y Zevalin	5	2.9	1.0	12

7.3.2.2 Maximum Skin Dose to the Hands

Table 7.1 presents the range, median, and mean of $\langle H_\mathrm{p}(0.07)_\mathrm{max}/A \rangle$ overall monitored workers, classified per procedure. It is shown that preparation of radiopharmaceuticals involves higher finger doses per unit activity than administration because the procedures take longer time and there are more steps requiring manipulations of the vials and/or syringes with higher activities, some of them without a shield. Therapy procedures involve generally higher mean normalized skin dose to the hands than diagnostics. Within diagnostics, ^{18}F involves higher skin doses per unit activity than ^{99m}Tc because of the different dose rates at contact. Considering typical workloads, preparation of ^{18}F was found to be the most critical of the studied procedures, which is in agreement with other authors' findings [17, 18].

In Tables 7.2 and 7.3, ORAMED results are compared to earlier published data for diagnostics and therapy, respectively. For each referenced study, the tables show the number of monitored workers, the number of measurements per worker, and the values of $\langle H_\mathrm{p}(0.07)_\mathrm{max}/A \rangle$ (minimum, median, mean, and maximum). For diagnostics, the value (maximum or mean) and position [fingertips (tips) or base of fingers (ring)] of the reported doses are also provided. For therapy, all tabulated data correspond to maximum doses measured in the tip of the fingers. Rimpler et al. [24] data are given with and without outliers. Outliers correspond to cases in which radiation protection means were not standard, either because shielding was not used or because semiautomatic devices were used. Likewise, in Rimpler et al. [25], the authors reported some high doses which were considered outliers and were therefore not included in the calculation of the mean and median.

Unfortunately, not all available works could be included in the comparison because of major differences in the measurement methodologies (type of detectors, radionuclides, procedures, etc.) or in the expression of the results (e.g., doses not normalized to the manipulated activity) or because many details were omitted. Even after the selection of studies, comparison must be performed with care since, generally, some parameters differ to a certain extent from work to work. In spite of the large range of data, there is good agreement on the relative exposure for the considered procedures and on the position of the maximum exposure, the tips of the fingers.

Table 7.2 Comparison of values of hand skin dose in NM diagnostics in several published works (adapted from Carnicer et al. [23])

Procedure	References	N workers	Measurements/ worker	Value (position)	$\langle H_\mathrm{p}(0.07)_\mathrm{max}/A\rangle$ (µSv/GBq)			
					Min	Median	Mean	Max
^{99m}Tc administration	Carnicer et al. [23]	32	4–5	Max (tip)	10	120	230	950
	Tandon et al. [37][a,c]	54	1–2	Mean (ring)	5	46	175	999
	Covens et al. [36][a,b]	5	n.s.	Max (tip)	40	49	50	60
^{99m}Tc preparation	Carnicer et al. [23]	36	4–5	Max (tip)	30	250	430	2,060
	Tandon et al. [37][a]	54	1–2	Mean (ring)	2	46	113	361
	Wrzesién et al. [35]	13	3–4[a]	Max (tip)	30	–	260	2,000
	Covens et al. [36][a,b]	2	n.s.	Max (tip)	20	65	65	110
	Leide-Svegborn [38][b]	3	3–7	Max (tip)	20	29	57	121
^{18}F administration	Carnicer et al. [23]	30	4–5	Max (tip)	140	640	930	4,110
	Tandon et al. [37][a]	3	1–2	Mean (ring)	155	218	232	324
	Covens et al. [36][a,b]	5	n.s.	Max (tip)	210	320	321	530
	Covens et al. [18][b]	8	5[a]	Max (tip)	200	280	350	750
	Covens et al. [18][b,d]	8	2–3[a]	Max (tip)	3.5	10	11	30
^{18}F preparation	Carnicer et al. [23]	30	4–5	Max (tip)	100	830	1,200	4,430
	Tandon et al. [37][a]	3	1–2	Mean (ring)	65	87	83	98
	Covens et al. [36][a,b]	2	n.s.	Max (tip)	290	570	570	850
	Covens et al. [18][b]	2	25[a]	Max (tip)	90	320	500	1,300
	Covens et al. [18][b,d]	2	10[a]	Max (tip)	4.5	9	10	18

n.s. Not specified

[a] Values not directly reported

[b] Approximate values (taken from graphs)

[c] Normalized by the eluted activity plus activity manipulated during radiopharmacy work

[d] Automated dispensing and injection system (Posyjet)

Table 7.3 Comparison of values of hand skin dose in NM therapy in several published works

Procedure	References	N workers	N measurements	$\langle H_p(0.07)_{max}/A \rangle$ (mSv/GBq) Min	Median	Mean	Max[a]
^{90}Y-Zevalin® preparation	Rimpler et al. [24]	15	1–5	1.2	9.5	11	44
	Rimpler et al. [24][b]	20	1–5	0.3	8.9	39	570
	Rimpler et al. [25]	11	n.s.	2	5.4	–	13(600)
	Geworski et al. [39]	7	n.s.	1.4	–	4.0	8.1
	Cremonesi et al. [40][c]	n.s.	15	0.1	1.5	1.9	28
^{90}Y-Zevalin® administration	Rimpler et al. [24]	19	1–5	1.0	2.9	4.8	12
	Rimpler et al. [24][b]	22	1–5	0.3	3.4	9.0	78
	Rimpler et al. [25]	14	n.s.	0.7	1.0	–	7(27)
	Geworski et al. [39]	8	n.s.	0.4	–	3.3	10.6

For all works, measurements are taken at the maximum (finger tip)

n.s. Not specified

[a] Values in parenthesis are outliers and are not considered in the mean or median calculation

[b] Data including outliers

[c] Values not directly reported

7.3.2.3 Parameters of Influence on Skin Dose to the Hands

Although experimental doses presented high variability, the ORAMED database was sufficient to analyze the main parameters of influence in the measured doses, with appropriate statistical weight [23]. The MC simulation sensitivity study [15] revealed that short source displacements (of up to some few cm), orientation, and volume changes (of up to 3 ml) can increase the maximum dose by a factor from 3 to 5 depending on the source. However, the large range of doses measured for similar techniques means that there is still room for reduction of the largest measured doses.

Shielding was found to be the most important parameter affecting skin dose levels, both for diagnostics and especially for therapy. This result is in agreement with the conclusions of ICRP Publication 106 [22] and with other authors' findings [26–29]. Even though the use of shields slows down the whole procedure, increases the difficulty of visualizing the required volume, and offers less comfort, especially for heavy and thick shields, it provides a protection which mostly cannot be replaced by increasing working speed. The influence of shielding on the dose, estimated in the ORAMED measurement campaign, is shown in Table 7.4. For each procedure, the range, median, mean, and relative standard deviation of the mean of $\langle H_p(0.07)_{max}/A \rangle$ are shown, both for workers using shield and those not using a shield.

For preparation of ^{99m}Tc, it was shown that the influence of the shield on the dose is statistically more significant in the case of the vial than in the case of the

Table 7.4 Range, median, mean and relative standard deviation of mean, $S_{\langle H_p(0.07)_{\max}/A\rangle}$ ($k = 1$), of $\langle H_p(0.07)_{\max}/A\rangle$ values for all workers in function of the use or lack of use of shield

			$\langle H_p(0.07)_{\max}/A\rangle$ (µSv/GBq)					
Procedures	Shield	Number of workers	Range	Median	Mean	±	$S_{\langle H_p(0.07)_{\max}/A\rangle}$	Shielding efficiency[a]
^{99m}Tc preparation	Yes	32	30–940	200	310	±	13%	4.3
	No	4	620–2,060	1,290	1,320	±	23%	
^{99m}Tc administration	Yes	24	20–940	90	190	±	27%	1.8
	No	7	140–640	350	340	±	21%	
^{18}F preparation	Yes	18	100–2,930	555	770	±	21%	2.3
	No	12	390–4,430	1,430	1,800	±	22%	
^{18}F administration	Yes	29	110–3,670	630	830	±	18%	5.0
	No	1	4,110–4,110	4,110	4,110	±	0%	
^{90} Y-Zevalin® preparation	Yes	20	0.2–570	7.6	37	±	77%	–
	No	0	–	–	–	±	–	
^{90} Y-Zevalin® administration	Yes	21	0.3–78	2.9	7.4	±	48%	3.1
	No	1	23–23	23	23	±	0%	

Values are rounded

[a] Mean $\langle H_p(0.07)_{\max}/A\rangle$ for unshielded data group divided by mean $\langle H_p(0.07)_{\max}/A\rangle$ for shielded data group

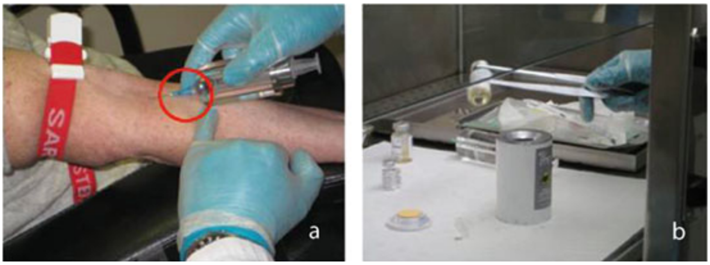


Fig. 7.4 (**a**) Example of bad practices: some fingers are non-properly shielded. (**b**) Example of good practice: tweezers are used to shake the unshielded vial; the procedure is performed in a shielded box

syringe ($p < 0.003$; $p < 0.180$). For the other diagnostic procedures, all workers used shielded vials, and this could not be analyzed. For ^{90}Y-Zevalin, shields are, in general, systematically used (apart from a few outliers), so it is difficult to quantify their influence with the available data. Table 7.4 shows that the use of shields provided a reduction of a factor from 2 to 5 for diagnostic procedures. This reduction factor is much lower than what is calculated using MC calculations for static situations because, in practice, there are always steps during which the shield is not used or situations where part of the hand is not properly shielded. However, MC simulations were found to be very useful to decide which was the adequate shielding for each procedure.

Together with shielding, the literature review shows that the use of automatic devices to avoid worker manipulation is potentially a very efficient mean of dose reduction [18, 29]. Jansson et al. [29], for example, have reported a finger dose reduction of a factor of 5 when using an automatic injection robot with respect to manual injection for ^{18}FDG. However, some works reported some problems associated with the use of automatic devices [26, 29, 30]. Nevertheless, in spite of related problems, most authors agreed on recommending automatic devices for dispensing and injecting, provided that appropriate training was given.

In the ORAMED study, only a weak trend was observed for experience to entail lower doses for diagnostic procedures, but it was not statistically significant. Some studies [31] have shown the positive influence of experience, but it is clear that other issues are more relevant. When analyzing individual cases of high maximum doses, good working habits were found to be more important than experience.

All practices avoiding direct contact whenever possible, enlarging distances to the sources, and speeding up procedures can be considered as good practices. Most bad working habits involved direct source contact. Often staff are not aware that near the bottom of a shielded syringe, the dose rate is very high. One example is given in Fig. 7.4a. Using tweezers is a very effective means of dose reduction when vials or syringes have to be held without a shield (Fig. 7.4b) and also during connecting and separating the syringe to or from needles or butterflies.

Table 7.5 Range, median, and mean values of the ratios between the maximum dose and the dose at the base of the index, base of the ring, and tip of the index fingers calculated for the nondominant (adapted from Carnicer et al. [23] and Sans-Merce et al. [14])

		Maximum dose/dose at other positions			
		Wrist	Base index	Base ring	Index tip
Diagnostics	Range	3–93	2–38	2–60	1–12
	Median	16	4	7	2
	Mean	20	6	10	2
^{90}Y-Zevalin	Range	3–94	2–47	1–87	1–17
	Median	14	7	9	2
	Mean	21	7	15	3

7.3.2.4 Routine Extremity Monitoring

Measurement and simulation results were used for setting up the basis of an appropriate routine monitoring of $H_p(0.07)$ for NM workers. As regards detector technical requirements, Carnicer et al. [16] demonstrate that for ^{99m}Tc measurements, thick standard TLDs (up to 100 mg cm^{-2}) are appropriate, whereas for ^{18}F and ^{90}Y, thin TLDs (up to 10 mg cm^{-2}) are recommended to avoid potential underestimations (up to 50%) because of the beta radiation, as has also been shown in previous studies [32–34].

Dose distribution data were used to find out the best monitoring position. The ratios between the highest dose and the dose at the most common monitoring positions were calculated and are summarized in Table 9.5. It is shown that even with the exclusion of outliers, the distribution of ratios is very wide (from 2 to around 90 for the wrist and from 1 to around 50 for the base of the index).

Mebhah et al. [20] also reported similar ranges, from 5 to 56 for the base and the tip of the middle finger (for diagnostics). This variability responds to the fact that the dose distribution is strongly operator and technique dependent. Thus, taking into consideration the large variations observed, ideally, the best solution for extremity monitoring would be to adapt it to each worker, in other words, to determine, during a trial period, the most appropriate monitoring position for that worker or at least to find out the most exposed hand. If this is not possible, based on the results of the ORAMED project, it is recommended to wear the dosemeter on the index tip of the nondominant hand. However, as there are very few dosimetric systems designed to be situated at this position and since it can cause discomfort, a more practical solution is to wear a ring dosemeter placed on the base of the index finger of the nondominant hand, with the detector facing the palm of the hand. This recommended position is different from other positions proposed in other works such as ICRP 106 [22].

For the recommended monitoring position (base of the index finger), a factor of 6 must be applied to estimate the maximum dose (Table 7.5). Similar correction values were reported by Jankowski et al. [21] and Wrzesien et al. [35]. Other authors [22, 36] published lower ratios, typically from slightly greater than 1 to larger than 4. ICRP 106 [22] recommends for the estimation of $H_p(0.07)$ a dosemeter placed on the base of the middle finger with the element positioned on the palm side. For this position, ICRP recommends a factor of 3 to obtain an estimate of the dose to the tip and of 6 if the dosemeter faces the back of the hand. ORAMED results show that this correction might be too low in many cases. Finally, it should be noted that there is broad agreement that, in nuclear medicine, the ring dosemeter should be preferred to the wrist dosemeter, which underestimates the maximum dose by a factor of 20 [14, 21].

7.4 Recommendations

From the analysis of ORAMED results [14] and other published works on extremity dosimetry in nuclear medicine, nine recommendations are proposed to improve radiation protection of nuclear medicine staff:

1. Extremity monitoring is essential in nuclear medicine. The choice of TLD and TLD position is important for an accurate dose assessment. Thin-layer TLDs (below 10 mg cm^{-2}) are most appropriate when beta-emitters are used.
2. To determine the position for routine monitoring, the most exposed position on the hand for each worker should be found by individual measurements for a short trial period. If for practical reasons, these measurements are not possible, the base of the index finger of the nondominant hand with the sensitive part of the dosemeter placed towards the inside of the hand is the recommended position for routine extremity monitoring in nuclear medicine.
3. To estimate the maximum dose, the reading of the dosemeter worn at the base of the index finger of the nondominant hand should be corrected by a factor of 6.
4. Shielding of vials and syringes is essential. This is a precondition, but not a guarantee for low exposure, since not all parts (e.g., bottom of the syringe) are shielded during use.
5. The minimum acceptable thickness of shielding for a syringe is 2 mm of tungsten for ^{99m}Tc and 5 mm of tungsten for ^{18}F. For ^{90}Y, 10 mm of PMMA completely shields beta radiation, but shielding of 5 mm of tungsten provides better protection, as it cuts down bremsstrahlung radiation.
6. The minimum acceptable shielding required for a vial is 3 mm of lead for ^{99m}Tc and 3 cm of lead for ^{18}F. For ^{90}Y, acceptable shielding is obtained with 10 mm of PMMA with an external layer of a few mm of lead.
7. Any device or tool increasing the distance (e.g., forceps, automatic injector) between the hands/fingers and the source is very effective for dose reduction.
8. Training and education in good practices (e.g., procedure planning, repeating procedures using nonradioactive sources, estimation of doses to be received) are more relevant parameters than the worker's experience level.
9. Working fast is not sufficient; the use of shields or increasing the distance are more effective than working quickly.

Training material and guidelines related to the optimization of radiation protection in nuclear medicine can be downloaded for free from http://www.oramed-fp7.eu/. In addition, the website provides the instructions to receive an easy tool to estimate hand dose distribution for typical nuclear medicine procedures upon acceptance of freeware license agreement.

References

1. Vanhavere F, Carinou E, Donadille L, Ginjaume M, Jankowski J, Rimpler A, Sans Merce M (2008) An overview on extremity dosimetry in medical applications. Radiat Prot Dosim 129(1–3):350–355
2. Donadille L, Carinou E, Ginjaume M, Jankowski J, Rimpler A, Sans-Merce M, Vanhavere F (2008) An overview of the use of extremity dosemeters in some European countries for medical applications. Radiat Prot Dosim 131(1):62–66
3. International Commission on Radiological Protection (1991) Recommendations of the international commission on radiological protection. ICRP publication 60. Ann ICRP 21(1–3)
4. International Commission on Radiological Protection (2007) The 2007 recommendations of the international commission on radiological protection. ICRP publication 103. Ann ICRP 37(2–4)
5. International Commission on Radiation Units and Measurements (1992) Measurements of dose equivalents from external photon and electron radiations, ICRU report 47. International Commission on Radiation Units and Measurements, Bethesda, Maryland
6. International Commission on Radiation Units and Measurements (1993) “Quantities and units in radiation protection dosimetry”, ICRU report 51. International Commission on Radiation Units and Measurements, Bethesda, Maryland
7. European Commission (1996) Council directive 96/29/EURATOM of 13 May 1996 laying down basic safety standards for the protection of the health of workers and the general public against the dangers arising from ionizing radiations. Off J Eur Commun 39L:159
8. European Commission (2011) Proposal for a COUNCIL DIRECTIVE laying down basic safety standards for protection against the dangers arising from exposure to ionising radiation. Draft presented under Article 31 Euratom Treaty for the opinion of the European Economic and Social Committee. http://ec.europa.eu/energy/nuclear/radiation_protection/doc/com_2011_0593.pdf
9. Baechler S, Stritt N, Bochud FO (2011) Individual monitoring of internal exposure for nuclear medicine workers in Switzerland. Radiat Prot Dosim 144(1–4):464–467
10. International Commission on Radiation Units and Measurements (1989) Tissue substitutes in radiation dosimetry and measurement. ICRU report 44. International Commission on Radiation Units and Measurements, Bethesda, Maryland
11. Frasch G, Petrova K (2007) Dose trends in occupational radiation exposure in Europe results from the ESOREX project. Radiat Prot Dosim 125(1–4):121–126
12. International Atomic Energy Agency. IAEA training material on radiation protection in PET/CT. Lecture 8 on staff and public doses. http://rpop.iaea.org
13. Whitby M, Martin C (2003) Investigation using an advanced extremity gamma instrumentation system of options for shielding the hand during the preparation and injection of radiopharmaceuticals. J Radiol Prot 23:79–96
14. Sans-Merce M, Ruiz N, Barth I, Carnicer A, Donadille L, Ferrari P, Fulop M, Ginjaume M, Gualdrini G, Krim S, Mariotti F, Ortega X, Rimpler A, Vanhavere F, Baechler S (2011) Recommendations to reduce hand exposure for standard nuclear medicine procedures. Radiat Meas 46(11):1330–1333

15. Ferrari P, Sans-Merce M, Carnicer A, Donadille L, Fulop M, Ginjaume M, Gualdrini G, Mariotti F, Ruiz N (2011) Main results of the Monte Carlo studies carried out for nuclear medicine practices within the ORAMED project. Radiat Meas 46(11):1287–1290
16. Carnicer A, Ginjaume M, Duch MA, Vanhavere F, Sans-Merce M, Baechler S, Barth I, Donadille L, Ferrari P, Fulop M, Gualdrini G, Krim S, Mariotti F, Ortega X, Rimpler A, Ruiz N, Olko P (2011) The use of different types of thermoluminescent dosemeters to measure extremity doses in nuclear medicine. Radiat Meas 46(12):1835–1838
17. Vanhavere F, Berus D, Buls N, Covens P (2006) The use of extremity dosemeters in a hospital environment. Radiat Prot Dosim 118(2):190–195
18. Covens P, Berus D, Vanhavere F, Caveliers V (2010) The introduction of automated dispensing and injection during PET procedures: a step in the optimization of extremity doses and whole-body doses of nuclear medicine staff. Radiat Prot Dosim 140(3):250–258
19. Martin C, Whitby M (2003) Application of ALARP to extremity doses for hospital workers. J Radiol Prot 23:405–421
20. Mebhah D, Djeffal S, Badreddine A, Medjahed M (1993) Extremity dosimetry in nuclear medicine services using thermoluminescent detectors. Radiat Prot Dosim 47(1/4):439–443
21. Jankowski J, Olszewski J, Kluska K (2003) Distribution of equivalent doses to skin of the hands of nuclear medicine personnel. Radiat Prot Dosim 106(2):177–180
22. International Commission on Radiological Protection (2008) Radiation dose to patients from radiopharmaceuticals—addendum 3 to ICRP publication 53. ICRP publication 106. Ann ICRP 38 (1–2) (Annex E: Radiation exposure of hands in radiopharmacies: monitoring of doses and optimisation of protection. International Commission on Radiological Protection)
23. Carnicer A, Sans-Merce M, Baechler S, Barth I, Donadille L, Ferrari P, Fulop M, Ginjaume M, Gualdrini G, Krim S, Mariotti M, Ortega X, Rimpler A, Ruiz N, Vanhavere F (2011) Hand exposure in diagnostic nuclear medicine with ^{18}F and ^{99m}Tc-labelled radiopharmaceuticals—results of the ORAMED project. Radiat Meas 46(11):1277–1282
24. Rimpler A, Barth I, Ferrari P, Baechler S, Carnicer A, Donadille L, Fulop M, Ginjaume M, Mariotti M, Sans-Merce M, Gualdrini G, Krim S, Ortega X, Ruiz N, Vanhavere F (2011) Extremity exposure in nuclear medicine therapy with ^{90}Y-labelled substances -results of the ORAMED project. Radiat Meas 46(11):1283–1286
25. Rimpler A, Barth I, Baum R, Senftleben S, Geworski L (2008) Beta radiation exposure of staff during and after therapies with ^{90}Y-labelled substances. Radiat Prot Dosim 131(1):73–79
26. Montgomery A, Anstee D, Martin C, Hilditch T (1999) Reductions in finger doses for radiopharmaceutical dispensing afforded by a syringe shield in an automatic dose dispenser. Nucl Med Commun 20:189–194
27. Tsopelas C, Collins P, Blefari C (2003) A simple and effective technique to reduce staff exposure during the preparation of radiopharmaceuticals. J Nucl Med Technol 31:37–40
28. Whitby M, Martin C (2005) A multi-centre study of dispensing methods and hand doses in UK hospital radiopharmacies. Nucl Med Commun 26:49–60
29. Jansson B, Olsson S, Olsson B, Jönsson L (2011) Reduction of the absorbed dose to technologists fingers from PET-radionuclides using an automatic injection robot. EANM Annual Congress of the European association of nuclear medicine
30. Allen S, Mackenzie A, Stark G, Inwards G, Lazarus C, Bachelor S (1997) Comparison of radiation safety aspects between robotic and manual systems for the preparation of radiopharmaceuticals. Nucl Med Commun Abstract 18: 295
31. Hilditch T, Elliot A, Anstee D (1990) Fifteen years of radiological protection experience in a regional radiopharmacy. Health Phys 59(1):109–116
32. Carinou E, Donadille L, Ginjaume M, Jankowski J, Rimpler A, Sans-Merce M, Vanhavere F, Denoziere M, Daures J, Bordy J, Itie C, Covens P (2008) Intercomparison on measurements of the quantity personal dose equivalent, $H_p(0.07)$, by extremity ring dosimeters in medical fields. Radiat Meas 43:565–570
33. Ginjaume M, Perez S, Duch M, Ortega X (2008) Comparison of TLD-100 and MCP-Ns for use as an extremity dosemeter for PET nuclear medicine staff. Radiat Meas 43(2–6):607–610

34. Brasik N, Stadtmann H, Kindl P (2007) The right choice: extremity dosemeter for different radiation fields. Radiat Prot Dosim 125(1–4):331–334
35. Wrzesien M, Olszewski J, Jankowski J (2008) Hand exposure to ionising radiation of Nuclear medicine workers. Radiat Prot Dosim 130(3):325–330
36. Covens P, Berus D, Buls N, Clerinx P, Vanhavere F (2007) Personal dose monitoring in hospitals: global assessment, critical applications and future needs. Radiat Prot Dosim 124(3):250–259
37. Tandon P, Venkatesh M, Bhatt B (2007) Extremity dosimetry for radiation workers handling radionuclides in nuclear medicine departments in India. Health Phys 92(2):112–118
38. Leide-Svegborn S (2010) Radiation exposure of patients and personnel from a PET/CT procedure with (18)F-FDG. Radiat Prot Dosim 139(1–3):208–213
39. Geworski L, Zöphel K, Rimpler A, Barth I, Lassmann M, Sandrock D, Zander A, Halm T, Hänscheid H, Hofmann M, Reiners C, Munz D (2006) Radiation exposure in ^{90}Y-Zevalin therapy: results of a prospective multicentre trial. Nuklearmedizin 45(2):82–86
40. Cremonesi M, Ferrari M, Paganelli G, Rossi A, Chinol M, Bartolomei M, Prisco G, Tosi G (2006) Radiation protection in radionuclide therapies with ^{90}Y-conjugates: risks and safety. Eur J Nucl Med Mol Imag 33:1321–1327