Radiation Protection Dosimetry (2012), Vol. 149, No. 4, pp. 438–443 doi:10.1093/rpd/ncr319
Advance Access publication 26 July 2011

STUDY OF NUCLEAR MEDICINE PRACTICES IN PORTUGAL FROM AN INTERNAL DOSIMETRY PERSPECTIVE

J. Bento[1,*], P. Teles[1], M. Neves[1], A. I. Santos[2], G. Cardoso[2], A. Barreto[2], F. Alves[3,4], C. Guerreiro[4], A. Rodrigues[4], J. A. M. Santos[5], C. Capelo[5], R. Parafita[6,7] and B. Martins[6,7]
[1]Instituto Tecnológico e Nuclear, Sacavém, Portugal
[2]Hospital Garcia de Orta, Almada, Portugal
[3]Escola Superior de Tecnologia de Saúde de Coimbra, Coimbra, Portugal
[4]Instituto de Ciências Nucleares Aplicadas à Saúde, Coimbra, Portugal
[5]Centro de Investigação do Instituto Português de Oncologia do Porto Francisco Gentil EPE, Porto, Portugal
[6]Hospital CUF Descobertas, Lisboa, Portugal
[7]Medical Consult, SA, Portugal

*Corresponding author: joana.bento@itn.pt

Received February 25 2011, revised May 31 2011, accepted June 23 2011

Nuclear medicine practices involve the handling of a wide range of pharmaceuticals labelled with different radionuclides, for diagnostic and therapeutic purposes. This work intends to evaluate the potential risks of internal contamination of nuclear medicine staff in several Portuguese nuclear medicine services and to conclude about the requirement of a routine internal monitoring. A methodology proposed by the International Atomic Energy Agency (IAEA), providing a set of criteria to determine the need, or not, for an internal monitoring programme, was applied. The evaluation of the risk of internal contaminations in a given set of working conditions is based on the type and amount of radionuclides being handled, as well as the safety conditions with which they are manipulated. The application of the IAEA criteria showed that 73.1 % of all the workers included in this study should be integrated in a routine monitoring programme for internal contaminations; more specifically, 100 % of workers performing radioimmunoassay techniques should be monitored. This study suggests that a routine monitoring programme for internal exposures should be implemented in Portugal for most nuclear medicine workers.

INTRODUCTION

World population (both occupationally exposed workers and members of the public) exposure to ionising radiation due to medical activities has increased sharply in recent years[(1)]. Among the occupationally exposed workers in these fields, those most affected by this increased exposure to ionising radiation are nuclear medicine workers, who, in their daily activities, need to handle a wide variety of unsealed radioactive sources, including patients, both for diagnostic and therapeutic purposes, resulting in a significant risk of internal radiation exposure. Nuclear medicine practices involve the handling of a wide range of pharmaceuticals, labelled with different types of radionuclides, for diagnostic and therapeutic purposes. From a radiation protection perspective, an accurate assessment of the dose that nuclear medicine workers are subjected to must be performed not only for external exposure, but also for incorporations. Several of the radionuclides handled in nuclear medicine practices entail a specific risk for contaminations, which is dependent not only on their physical and chemical properties, but also on the safety practices implemented in each institution, as well as the type of protection involved in their handling. The continuing progress of nuclear medicine and molecular imaging in Europe and, in particular [Positron Emission Tomography (PET)/Computed Tomography (CT)] as the major imaging modality in current medicine, was presented at the 2010 Annual Congress of European Association of nuclear medicine[(2)]. This entails the need for a more specific assessment of these practices, from a radiological protection point of view.

In Portugal, during the period 1999–2003, the annual external radiation doses received by the staff of nuclear medicine departments from public hospitals were reported by Martins *et al.*[(3)]. Nuclear medicine technologists are one of the most exposed groups of workers and consequently are the most important contributors to the total collective dose of this group. However, other professionals, such as nurses, physicians and physicists are also potentially exposed to internal contamination. From an internal dosimetry perspective, due to the nature of their activities, nuclear medicine workers are pointed out as being more at risk for internal contaminations[(4)]. The radiation protection of nuclear medicine staff, particularly in the handling of beta emitters, in the assessment of the dose to

extremities and in the risks of internal contamination in medical cyclotron personnel involved in synthesis processes, have been reviewed elsewhere[5].

Internal exposure can arise either from an accident or from the nature of the implemented practices, although it must be stated that this risk is still minimal especially if good practices and the use of proper protection devices are ensured. Due to the unsealed nature of the radioactive sources in nuclear medicine, nuclear medicine activities carry the potential risk of both external and internal contamination. Radiopharmaceutical dispensing procedures, ventilation scanning and decontaminating areas where ^{131}I treatment occurred are identified as the most likely activities causing body surface and internal contamination among nuclear medicine staff. Also, in ventilation studies, radionuclides such as aerosolised ^{99m}Tc or ^{133}Xe, exhaled by the patient can be inhaled by the nuclear medicine staff. Work should be carried out in well-ventilated rooms, with assisted extraction in order to reduce the radiation background in the room atmosphere. The ^{133}Xe contamination in the reusable internal bacteria filter and CO_2 absorber of a ventilation system was reported by Hackett *et al.*[6].

Some cases of internal contaminations have already been identified at hospitals[7]. Individual monitoring procedures of internal exposure for nuclear medicine workers were reported based on practical screening implemented for most radionuclides used in nuclear medicine, including gamma emitters and beta emitters[8]. For radioiodine, a calibrated surface contamination monitor is placed in front of the thyroid to detect whether the activity threshold has been exceeded. For radionuclides with short to very short physical half-lives, such as ^{99m}Tc, ^{11}C, ^{15}O, ^{18}F and ^{68}Ga, screening procedures consist in performing daily measurements of ambient dose rate in front of the abdomen. Other gamma emitters used for imaging (^{67}Ga, ^{111}In and ^{201}Tl) are measured with a scintillation detector located in front of the thorax. For pure beta emitters (^{90}Y and ^{169}Er) as well as beta emitters with gamma rays emission (^{131}I, ^{153}Sm, ^{177}Lu, ^{186}Re and ^{188}Re), the procedure consists in measuring hand contamination immediately after use. In Germany, Sweden and Hungary, the Euratom Council Directive 96/29 of 13 May 1996 concerning the radiation exposure monitoring[9] was legally implemented and internal monitoring programmes are mandatory[10, 11].

There has been a recent awareness for the need to create a systematic methodology to assess internal contamination risks, so that the principles of radiological safety and protection are fully satisfied, not only in nuclear medicine practices, but in a broader sense. In 1999, the International Atomic Energy Agency (IAEA) published a safety guide[4], which aims at providing a set of criteria to be taken into account in order to determine the need, or not, for an internal monitoring programme. Although this publication is not specific to nuclear medicine, recent studies and publications have applied these criteria to assess risk in nuclear medicine practices in some countries[10, 12]. Besides ongoing developments in the dosimetry of incorporated radionuclides (mainly using the MIRD methodology), there have been various efforts to improve the monitoring of workers for potential or real intakes of radionuclides[13].

The UPSR (Unidade de Protecção e Segurança Radiológica of Instituto Tecnológico e Nuclear) with responsibilities in providing expertise in radiological protection and safety in Portugal, as part of the internal dosimetry activities currently being developed in the institution, intends in the present work to quantify the risk for internal contaminations in the nuclear medicine staff of several nuclear medicine key institutions in the country. For this purpose, the criteria suggested by IAEA to indicate whether individual monitoring is necessary or not, were implemented to assess internal incorporation risks in nuclear medicine staff in Portugal. These criteria have shown to be adequate and easier to apply when comparing with other methods[14].

Although there are currently about 30 nuclear medicine centres in activity in the country, in this study, for practical reasons, the authors have worked with only a selected few key institutions from the cities of Lisbon, Porto and Coimbra. These key institutions constitute the most relevant in Portugal, since they are representative in terms of procedures performed and number of patients examined/treated, are referenced by their infrastructures and have training and education-related activities. Therefore, they can be said to constitute a good sample of the overall nuclear medicine practices implemented in the country.

METHODOLOGY

In order to evaluate the internal contamination risks involved in nuclear medicine practices in Portugal, the authors have applied the criteria defined by the IAEA[4]. These criteria are based on the estimation of a 'decision factor' d, as described in the following expression:

$$d_i = \frac{A_i e(g)_i f_{(\mathrm{fs})i} f_{(\mathrm{hs})i} f_{(\mathrm{ps})i}}{0.001} \qquad (1)$$

where, for each radionuclide i, A_i is the average annual activity handled by the worker, $e(g)_i$ is the dose coefficient for inhalation of 5-μm aerosols by workers (given in Sv Bq^{-1}), $f_{(\mathrm{fs})i}$ is a physical form safety factor based on the physical and chemical

properties of the handled material, $f_{(hs)i}$ is a handling safety weighing factor, which accounts for the operations taken to handle radionuclide '*i*', $f_{(ps)i}$ is a protection safety weighing factor, which accounts for the safety precautions taken while handling radionuclide '*i*' and 0.001 is a conversion factor from sievert to millisievert. In the majority of cases, f_{fs} should be 0.01, therefore Equation 1 reduces to

$$d_i = 10 A_i e(g)_i f_{(hs)i} f_{(ps)i} \quad (2)$$

The final decision factor D for all radionuclides handled in the workplace is given by:

$$D = \sum_i d_i \quad (3)$$

According to the IAEA publication, the estimation of this decision factor should serve as a means to determine whether a given worker should be monitored for internal incorporations (if $D > 1$ mSv) or not (if $D < 1$ mSv).

Considering more than one radionuclide present in the workplace, monitoring of separated radionuclides decision is based on the following criteria:

(1) all radionuclides with $d_i > 1$ should be monitored;
(2) if $D > 1$, radionuclides with $d_i > 0.3$ should be monitored and monitoring of radionuclides with $d_i < 0.1$ is unnecessary.

It should be noted that this criterion applies to all types of practices involving some kind of risk for internal contamination, and not only for nuclear medicine practices. This must be taken into account when assigning values to the weighing factors to be used for the estimation of the decision factor. The safety weighing factors, as proposed by the IAEA safety guide, are, as such, very general, and a more adapted set of weighing factors, specifically dedicated to nuclear medicine practices was proposed by Navarro[15]. Moreover, personal protection measures as masks and gloves are not considered in this methodology but, if they are employed, their efficacy should be assessed.

In order to apply this methodology in all the nuclear medicine institutions involved, for each institution, a systematic analysis of the procedures performed was undertaken. The main guidelines driving the analysis are the following:

(1) Procedures involving the handling of a given radionuclide were identified.
(2) For each procedure identified, a careful analysis of the handling conditions and protection measures was carried out, leading to the definition of a set of handling and protection safety factors between 0.01 and 10.
(3) The annual activity handled by each worker performing the identified procedures was estimated.
(4) Decision factors (d) were calculated for each operation for each worker as well as the final decision factor (D) for each worker.
(5) The analysis was undertaken in full anonymity, i.e. the identity of the workers was not disclosed.
(6) The results for each institution were then compiled and communicated to the institution in the form of a report.

Four institutions are part of this study and most of them possess both diagnostic and therapeutic procedures. Also, three institutions perform PET scans and one institution implements radioimmunoassay (RIA) techniques with ^{125}I. The procedures implemented by these centres were analysed based on the criteria defined in the IAEA guidelines to evaluate the need for internal monitoring. Moreover, the results were used to identify the operations more prone to the occurrence of internal contaminations.

In Table 1 are reported the main radiopharmacy and manipulation procedures identified as well their associated handling safety factors. The identified operations are classified as elution, labelling, dose fractionation, dose administration (injection and capsules), ventilation studies, quality control (both radiopharmaceutical and imaging equipment), clinical studies involving the gamma camera and the PET scanner, radioactive waste management and RIA techniques. Table 2 presents the standard protection safety factors assigned to operations performed in a glove box, fume hood and open bench.

Both standard safety factors reported in Tables 1 and 2 are defined based on the IAEA criteria[4], on the values reported by Navarro[15] and operational experience of the technicians and medical physicists

Table 1. Standard handling safety factors based on the nature of the operation[4,15].

Operation	Handling safety factor (f_{hs})
Elution	1
Labelling	1
Dose fractionation	1
Dose administration (injection)	1
Dose administration (capsules)	0.01
Ventilation studies	1
Equipment quality control	0.01
Studies with gamma camera and PET scanner	0.01
Radioactive waste management	0.01
RIA techniques	10

The values can vary depending on the operation execution conditions.

Table 2. Standard protection safety factors based on the protection measures employed[4,15].

Protection measure	Protection safety factor (f_{ps})
Glove box	0.01
Fume hood	0.1
Open bench	1

The values can vary depending on the operation execution conditions.

Table 3. Dose coefficients for inhalation of 5-μm aerosols by workers (Sv Bq^{-1}) for the handled radionuclides in the participating institutions[16].

Radionuclide	$e(g)_{inh}$ (Sv Bq^{-1})
^{99m}Tc	2.0×10^{-11}
^{111}In	3.1×10^{-10}
^{67}Ga	2.8×10^{-10}
^{68}Ga	8.1×10^{-11}
^{123}I	1.1×10^{-10}
^{125}I	7.3×10^{-9}
^{131}I	1.1×10^{-8}
^{18}F	8.9×10^{-11}
^{89}Sr	1.4×10^{-9}
^{90}Y	1.6×10^{-9}
^{153}Sm	6.8×10^{-10}
^{201}Tl	7.6×10^{-11}

from the participating institutions. In some cases from this study, these factors had to be adapted since the protection conditions of some performed procedures did not fit entirely into any of the options. These exceptional protection measures include an automatic dose fractionator and nuclear medicine dedicated fume hood. These adaptations were done to ensure a correct relationship between the factor values and the risk of incorporation.

The dose coefficients used in the decision factor calculations derived from the biokinetic models of the International Commission on Radiological Protection—ICRP 68[16]. Table 3 presents the handled radionuclides in the participating institutions as well as the dose coefficients for each radionuclide for inhalation of 5-μm activity median aerodynamic diameter aerosol by workers, chosen based on the chemical form in which it is used in nuclear medicine and RIA procedures.

In all institutions, the annual handled activity was identified by worker and by operation, since the handling conditions of a certain radionuclide vary from the preparation of the radiopharmaceutical to its administration to the patient and, consequently, the safety factors also vary. In some institutions, there was a record of the manipulated activity per worker ensuring an accurate value and in other institutions the annual handled activity was estimated based on the mean activity per operation and the estimation of the annual frequency of such operation.

RESULTS AND DISCUSSION

Table 4 lists all the procedures performed at the nuclear medicine departments and RIA departments of the participating institutions. The handling (f_{hs}) and protection (f_{ps}) factors values assigned to each procedure depend on the execution circumstances of the operations performed in each institution, and are thus given in the form of an interval, from the minimum to the maximum value applied.

As a result, depending on the annual handled activities and on all the factors described above, intervals for decision factor values (d) for each operation have been obtained, which consist of the interval that goes from the minimum (d_{min}) to the maximum (d_{max}) value of d estimated. To note that the results are presented in a generalistic way, meaning that the decision factor intervals obtained are to be read as the interval found in the overall of the institutions studied. In the cases where there was no interval but only one value, the actual estimated value is given.

Almost all workers perform more than one operation, which means that the estimated d values obtained must be summed for each worker in order to obtain the final decision factor D. Then, summing the d values for each worker in order to obtain the final D, it was found that 71.9 % of all workers from nuclear medicine services from all the participating institutions should be integrated in a routine monitoring programme for internal contaminations ($D > 1$ mSv). Regarding the RIA workers, 100 % of the workers should be monitored, as they all perform the four RIA operations described in Table 4 (D=2.436).

However, it should be noted that the decision factor value related to a certain operation, although having units of mSv, do not represent the dose effectively received by the worker when performing such operation. It represents a potential committed effective dose that can occur from the exercise of that operation. As such and from Equation 2, the larger amount of activity manipulated by the worker ($>A$), the greater risk of the operation ($>f_{hs}$) and when less protective measures are applied ($>f_{ps}$), the greater incorporation likelihood.

Table 4 shows that the operations leading to larger decision factors are those where ^{99m}Tc is handled, having been estimated a decision factor of 157.472 mSv for a given worker who administrates ^{99m}Tc doses. These greater values are mainly related to the higher execution frequency of operations

Table 4. Safety factor assigned to the procedures performed at the nuclear medicine services of the participating institutions and minimum and maximum decision factor found.

Operation	$[f_{hs,min}, f_{hs,max}]$	$[f_{ps,min}, f_{ps,max}]$	$[d_{min}, d_{max}]$ (mSv)
Elution ^{99m}Tc	[0.01, 1]	0.01	[0.007, 3.896]
Labelling			
^{68}Ga	0.01	0.05	0.016
^{111}In	1	0.01	0.087
^{99m}Tc	[0.1, 1]	0.01	[0.026, 2.850]
^{90}Y	0.01	0.05	0.007
Dose fractionation			
^{67}Ga	[0.01, 1]	[0.01, 0.05]	[0.002, 0.085]
^{68}Ga	0.01	0.05	0.005
^{89}Sr	0.01	0.05	0.013
^{90}Y	0.01	0.05	0.033
^{123}I	[0.01, 1]	[0.01, 0.05]	[0.003, 0.086]
^{131}I	[0.01, 1]	[0.01, 0.05]	[0.024, 0.080]
^{111}In	[0.1, 1]	0.01	[0.002, 0.079]
^{153}Sm	0.01	0.05	0.019
^{99m}Tc	[0.01, 1]	[0.01, 0.05]	[0.090, 1.995]
^{18}F	[0.01, 1]	[0.01, 0.05]	[0.089, 0.940]
^{201}Tl	1	0.01	0.141
^{99m}Tc	[0.01, 1]	[0.1, 1]	[0.753, 157.472]
Dose administration			
^{67}Ga	[0.01, 1]	[0.01, 0.05]	[0.001, 8.736]
^{123}I	[0.01, 1]	[0.01, 0.05]	[0.710, 4.520]
^{111}In	[0.1, 1]	1	[0.181, 8.647]
^{131}I	[0.01, 1]	[0.1, 1]	[1.278, 2.12]
^{90}Y	0.01	0.1	0.022
^{153}Sm	0.01	0.1	0.013
^{68}Ga	0.01	0.05	0.009
^{89}Sr	0.01	0.1	0.009
^{201}Tl	1	1	28.964
^{18}F	[0.01, 1]	[0.01, 0.05]	[0.539, 9.405]
Pulmonary ventilation	1	1	0.156
Quality control ^{99m}Tc	0.01	1	[0.0003, 0.246]
Equipment quality control	0.01	1	0.053
Studies using gamma camera and PET scanner	0.01	0.01	[0.020, 0.025]
Radioactive waste management	0.01	1	0.002
RIA			
17 hydroprogesterone	10	1	0.696
Free testosterone	10	1	0.795
Renine	10	1	0.921
Aldosterone	10	1	0.322

involving ^{99m}Tc on the remaining radionuclides, leading to a larger amount of activity present in the workplace when comparing with the other radionuclides. It should be noted however, that ^{99m}Tc is a very short-lived radionuclide. The results also show that dose administration, in general for all radionuclides, is the operation that presents higher decision factors comparing to labelling and dose fractionation.

CONCLUSION

This study suggests that, according to the IAEA criteria, a routine monitoring programme for internal exposures should be implemented in Portugal for most nuclear medicine workers. The application of IAEA criteria showed that the risk of internal contaminations in the course of such activities exists based on the aforementioned methodology.

It should be noted, however, that the IAEA guide does not specifically mention the periodicity of the monitoring to be implemented. This should depend greatly on the radionuclide and its physical–chemical form, resident time in the body, increased uptake organs, radiotoxicity and physical half-life. If a short-lived isotope, such as ^{11}C (half-life 20.38 min) is accidentally inhaled, it will probably not be possible to assess the intake and, consequently, the dose.

The periodic monitoring, thus, will not detect any trace of this isotope. The same concept applies to others radionuclides, such as ^{18}F (half-life 109 min) or ^{68}Ga (half-life 68 min). Even for longer lived radionuclides, such as ^{99m}Tc (half-life 6 h), the probability of detecting any accidental internal contamination during a routine evaluation will be minimal. However, long-lived isotopes, especially the ones that can be fixed by specific critical organs are clearly more significant. Isotopes such as ^{131}I (half-life 8 days), which is a thyroid seeker, or ^{177}Lu (half-life 6.9 days) and ^{90}Y (half-life 64 hours), which are bone marrow seekers, can imply a much more demanding procedure if a periodic monitoring is to be established.

The type of periodic monitoring would, by these reasons, be much more related to detecting longer lived radionuclide manipulation, rather than by the short or very short-lived, low radiotoxicity ones. However, the specificities of the different measuring techniques available for internal monitoring (minimum detectable activity, methodology, etc.) may also play an important role in the monitoring programme optimization. All these aspects should be taken into account when implementing a routine monitoring programme.

As a consequence, depending on the radionuclides handled as well as their *in vivo* behaviour, if the IAEA criteria were to be taken into account, these workers should be monitored by *in vivo* methods, such as whole-body counters or dedicated organ counters and/or *in vitro* techniques, such as biological samples (urine and faeces) or air samples.

This study also identifies the operations in nuclear medicine entailing higher risks of contamination—handling of ^{99m}Tc in general and dose administration. The inclusion of additional protection measures during these operations would reduce the decision factors values and, consequently, could reduce the risks of incorporation. The same applies to RIA techniques; performing the same RIA procedure in a fume hood rather than in open bench would reduce significantly the decision factors.

ACKNOWLEDGEMENTS

The authors would like to thank Dr Humberto Ventura from Hospital Garcia de Orta for his collaboration in this study and to all physicians, technicians and physicists from the participating institutions who received authors and contributed to this work.

FUNDING

The authors would like to thank Fundação para a Ciência e Tecnologia for Joana Bento's grant (SFRH/BI/33656/2009).

REFERENCES

1. UNSCEAR (United Nations Scientific Committee on the Effects of Atomic Energy). *Report on sources and effects of ionizing radiation*. Annex A: medical radiation exposures (2008). ISBN: 978 92 1 142274.
2. Carrió, I. *Current research in nuclear medicine and molecular imaging: highlights of the 23rd Annual EANM Congress*. Eur. J. Nucl. Med. Imaging **38**, 378–399 (2011).
3. Martins, B., Alves, J. G., Abrantes, J. N. and Roda, A. *Occupational exposure in nuclear medicine in Portugal in the 1999–2003 period*. Radiat. Prot. Dosim. **125**(1–4), 130–134 (2007).
4. International Atomic Energy Agency. *Assessment of occupational exposure due to intake of radionuclides*. Safety Guide No. RS-G-1.2. IAEA (1999).
5. Salvatori, M. and Luchignani, G. *Radiation exposure, protection and risk from nuclear medicine procedures*. Eur. J. Nucl. Med. Mol. Imaging **37**, 1225–1234 (2010).
6. Hackett, M., Collins, J. and Wierzbinski, R. *^{133}Xe contamination found in internal bacteria filter of xenon ventilation system*. J. Nucl. Med. Technol. **31**, 170–172 (2003).
7. Ośko, J., Golnik, N. and Pliszczyński, T. *Cases of post-accident contamination with iodine ^{131}I registered in the Institute of Atomic Energy POLATOM in Świerk, Poland*. Radiat. Prot. Dosim. doi:10.1093/rpd/ncq422 (2010).
8. Baechler, S., Stitt, N. and Bochud, F. O. *Individual monitoring of internal exposure for nuclear medicine workers in Switzerland*. Radiat. Prot. Dosim. (2010). doi:10.1093/rpd/ncq350
9. European Communities. *96/29/EURATOM Directive, 13th 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 radiation* (1996).
10. Kerekes, A., Kicsy, G. and Pellet, S. *Individual monitoring for internal exposure of workers: regulation and practice in Hungary*. Radiat. Prot. Dosim. **125**(1–4), 33–36 (2007).
11. Lopez, M. A., van Dijk, J. W. E., Castellani, C. M., Currivan, L., Falks, R., Olko, P. and Wernli, C. *Individual monitoring for internal exposures in Europe: conclusion of an EURADOS action*. Radiat. Prot. Dosim. **118**(2), 176–181 (2006).
12. Dantas, B. M., Lucena, E. A. and Dantas, A. L. A. *Internal exposure in nuclear medicine: application of IAEA criteria to determine the need for internal monitoring*. Braz. Arch. Biol. Tech. **51**, 103–107 (2008).
13. Henrichs, K. *Application of ISO standard 27048: dose assessment for the monitoring of workers for internal radiation exposure*. Radiat. Prot. Dosim. (2010). doi:10.1093/rpd/ncq568
14. Macías, M. T., Navarro, T., Lavara, A., Robredo, L. M., Sierra, I. and Lopez, M. A. *Guidance on individual monitoring programmes for radioisotopic techniques in molecular and cellular biology*. Radiat. Prot. Dosim. **105**(1–4), 355–359 (2003).
15. Navarro, T. *Training course Medidas de contaminación radiactiva en instalaciones radiactivas de medicina, investigación y docência—Tema 8: medidas de contaminacion personal interna*. Instituto de Investigaciones Biomédicas Alberto Sols CSIC (2009).
16. International Commission on Radiological Protection. *Dose coefficients for intakes of radionuclides by workers*. Publication No. 68, Elsevier Science, Oxford (1994).