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INDIVIDUAL MONITORING FOR INTERNAL EXPOSURE IN EUROPE AND THE INTEGRATION OF DOSIMETRIC DATA

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The European Radiation Dosimetry Group, EURADOS, established a working group consisting of experts whose aim is to assist in the process of harmonisation of individual monitoring as part of the protection of occupationally exposed workers. A catalogue of facilities and internal dosimetric techniques related to individual monitoring in Europe has been completed as a result of this EURADOS study. A questionnaire was sent in 2002 to services requesting information on various topics including type of exposures, techniques used for direct and indirect measurements including calibration and sensitivity data and the methods employed for the assessment of internal doses. Information relating to Quality Control procedures for direct and indirect measurements, Quality Assurance Programmes in the facilities and legal requirements for 'approved dosimetric services' were also considered. A total of 71 completed questionnaires were returned by internal dosimetry facilities in 26 countries. This results in an overview of the actual status of the processes used in internal exposure estimation in Europe. In many ways harmonisation is a reality in internal dose assessments, especially when taking into account the measurements of the activity retained or excreted from the body. However, a future study detailing the estimation of minimum detectable activity in the laboratories is highly recommended. Points to focus on in future harmonisation activities are as follows: the process of calculation of doses from measured activity, establishment of guidelines, similar dosimetric tools and application of the same ICRP recommendations. This would lead to a better and more harmonised approach to the estimation of internal exposures in all European facilities.

INTRODUCTION

Once EURATOM 96/29 Directive[(1)] has been implemented in many European states, coordination of the monitoring procedures of occupational workers becomes an important matter to deal with in a continent without borders and with free movement of workers exposed to radiation in the nuclear facilities of different countries. The aim of the European Radiation Dosimetry (EURADOS) working group on harmonisation of individual monitoring is to promote harmonisation in the field of individual monitoring of occupational exposures throughout Europe[(2)]. A sub-group was formed by experts involved in tasks related to the assessment of doses in either internal or external exposures; the objective to achieve was the integration of dosimetric methods, investigating how the results from personal dosemeters for external radiation and workplace monitoring and from monitoring for internal exposure can be combined into a complete and consistent system of individual monitoring. An important aspect of the study is to investigate how these different methods can be harmonised so that the numerical dose values can be added to result in a total effective dose for the worker.

In contrast to the measurements of dose for external radiation, internal doses cannot be measured directly: they must be inferred from the measurement of quantities such as body activity content, excretion rates or airborne concentrations of radioactive materials. Furthermore, the assessment of exposures due to intake depends critically upon knowledge of the biokinetics of the radionuclides.

Quality assurance in internal dosimetry is also a complex matter; the uncertainty in the measuring process (whole-body counting and bioassay) and in the assumptions often made in order to establish circumstances of the intake result in large uncertainties associated to the estimated radiation dose. There is a considerable concern within regulatory bodies and approved internal dosimetric services about the need for harmonisation on the evaluation of internal exposures. In this way, national and international intercomparisons have been organised for the purpose of checking not only the performance of *in vivo* and *in vitro* laboratories but also the methodology used by services to assess the effective doses taking into account ICRP recommendations and national regulations. The objective is always to validate measurement procedures and dosimetric tools to guarantee the reliability of calculated doses.

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CATALOGUE OF INTERNAL DOSIMETRIC SERVICES IN EUROPE

One of the aims of the EURADOS harmonisation study is the completion of a catalogue of Internal Dosimetric Services and an inventory of methods and techniques used for individual monitoring at the internal dosimetry facilities in the whole of Europe. With the collaboration of a contact-person in each country the 'Eurados 2002 Questionnaire (2) for a catalogue of Internal Dosimetry Techniques used for individual monitoring in European countries' was sent in spring 2002 by e-mail. The information requested (Figure 1) related to various topics: the equipment used for the measurement of internal exposures, calibration and Minimum Detectable Activity (MDA) data, the methods applied for the assessment of internal doses, quality control procedures for direct and indirect measurements, quality assurance programmes in the facilities and legal requirements for being an approved dosimetric service. The statistical information received for each section of the questionnaire gives an overview of the situation of internal dosimetry in Europe in 2001.

The contact-person in each European state was asked to decide the appropriate laboratories to which the questionnaire should be sent, taking into account not only approved internal dosimetric services but also other facilities that perform direct/indirect measurements or dose assessments related to internal exposures of workers. In some countries, the responsibility for carrying out internal dose assessments lies with a qualified expert who may not be responsible for undertaking the measurements.

The 'Eurados Database of European Dosimetric Data' (Appendix) has been generated as a result of this project. It contains all the information collected from the questionnaires obtained from 114 facilities involved in dose assessments for internal and external exposures in 28 European states (Table AP1). The database includes a general information section where each country is registered with the complete list of dosimetric services. The database will be periodically updated, in an effort to improve the amount of information collected and to reflect the actual situation of the dosimetry in Europe.

A European dosimetric network of contact-persons collaborating with EURADOS for harmonisation has been established. The final results obtained from the data analysis of the Internal Dosimetry questionnaires (Q2), are presented here.

Information about individual monitoring of workers at risk to intake of radionuclides in European countries was collected by working group 2. A total of 71 completed questionnaires from 26 countries were received and provided a very useful set of data covering different aspects of the methodology required in the assessment of internal doses. A total of 58 laboratories involved in direct measurements supplied detailed information relating to *in vivo* techniques and procedures; 43 facilities working in indirect measurements of internal exposures forwarded information relating to services using *in vitro* methods and personal air sampler/static air sampler (PAS/SAS) monitoring for the evaluation of individual doses. The countries and number of services collaborating with Eurados in this task are shown in Table 1.

Although no information was collected from France, Finland or Latvia (no answers were received

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Figure 1. Index of EURADOS 2002 Questionnaire (Q2) for a catalogue of internal dosimetric techniques used for individual monitoring in European countries.

Table 1. Countries and internal dosimetric services collaborating with Eurados 2001.

Code	Country	ID Services Eurados*	ID Services Total**
AT	Austria	2	5
BE	Belgium	1	1
BG	Bulgaria	1	3
CH	Switzerland	7	7
CS	Serbia and Montenegro	2	2
CZ	Czech Republic	4	4
DE	Germany	8	25
DK	Denmark	1	1
EE	Estonia	1	1
ES	Spain	9	10
GB	United Kingdom	3	10
GR	Greece	2	2
HR	Croatia	1	1
HU	Hungary	2	4
IE	Ireland	1	1
IT	Italy	8	18
LT	Lithuania	2	2
NL	Netherlands	1	1
NO	Norway	1	1
PL	Poland	1	1
PT	Portugal	1	1
RO	Romania	5	5
SE	Sweden	3	7
SI	Slovenia	3	3
SK	Slovakia	2	2
UA	Ukraine	1	1
Total		73	119

*Internal dosimetric services that answered Eurados Q2 questionnaire per country

**Total number of internal dosimetric services in each country

from services in these countries), the set of 73 laboratories involved in internal dosimetry matters (Annex, Table AN1) is representative of the type of exposures, techniques, performance criteria and regulations associated with different procedures and monitoring programmes used by internal dosimetric services. An important goal achieved as a result of this Eurados Action is the availability of data from facilities in 26 countries, including western, central and eastern Europe working together to reach harmonisation, taking into account the different cultures and accessible tools that apply in each case for intake determinations.

The answers of Eurados Q2 Questionnaire provided, in first instance some general information relating to each internal dosimetric service (name and complete address, and person in charge of the service) thus facilitating contact with those services in a quick and easy fashion. Table 1 gives an indication of the number of services that replied against the number in each country. The Eurados catalogue along with the European databases give a reasonable overview of the status of internal dosimetry in Europe.

TYPE OF INTERNAL EXPOSURES OF EUROPEAN WORKERS

Internal monitoring programmes designed by services were investigated to ascertain the type of occupational exposures received by monitored workers in Europe (Figure 2). The majority of workers monitored for internal exposures work in nuclear power plants (NPPs), research activities and the medical field. Non-nuclear industry, the nuclear fuel cycle

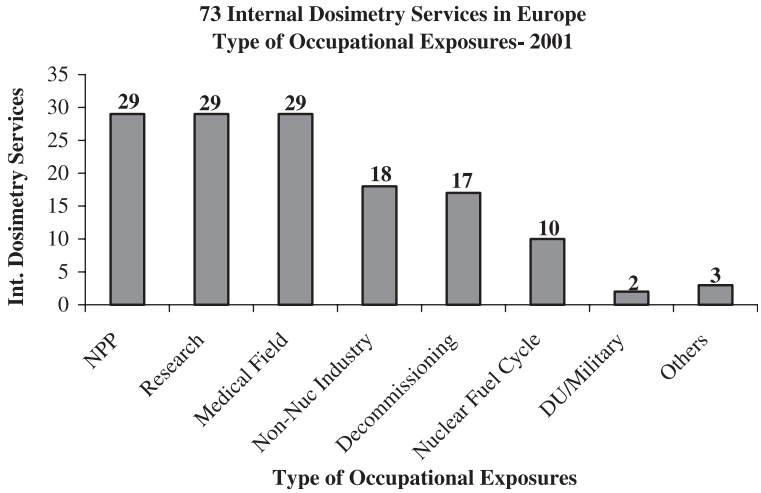

Figure 2. Type of internal exposures associated with the individual monitoring of European workers.

Table 2. Exposed workers monitored in 71 internal dosimetric services of 26 European countries (status 2001).

Assessment of internal exposures	Monitored workers	Measurements performed
Direct methods (WBC, organ counting)	31,800	63,400
Indirect techniques (Bioassay, PAS/SAS)	12,700	67,500

and decommissioning activities are other workplaces where the intake of radionuclides must be evaluated. In 2001 monitoring of workers involved in depleted uranium incidents was also dealt with by some services.

Table 2 gives an overview of the monitored workers and number of measurements performed in 2001 in the 73 laboratories from 26 countries that have collaborated with Eurados in this harmonisation study. The results show that there are more workers included in individual monitoring programmes to assess internal exposures with direct techniques (*in vivo* detection of X-ray and gamma emitters in whole-body counting or organ counting), compared with the number of persons controlled by indirect procedures (Bioassay and PAS/SAS monitoring). In contrast, as it was expected, the number of *in vitro* measurements (assessment of activity of alpha, beta and gamma emitters in excreta samples) together with PAS/SAS monitoring for the assessment of individual doses, is higher than the number of *in vivo* evaluations. This fact is explained by the requirement of more frequent routine monitoring programmes for the annual determination of alpha and beta emitters using indirect techniques, taking into account parameters such as sensitivity of equipments and dose levels to detect, following regulations in force.

TECHNIQUES AND PERFORMANCE CRITERIA FOR THE EVALUATION OF INTERNAL EXPOSURES

Direct techniques

Direct measurements of the radiation emitted by the internally deposited radionuclides are suitable for those isotopes which emit photons of sufficient energy and in sufficient numbers to escape from the body and be measured by an external detector. X-ray and gamma emitters (and to a lesser extent high-energy beta emitters) can be evaluated by direct external measurements using a whole-body counter (WBC) or organ counter, with an easy identification but a not-so-easy quantification of radionuclides, based on the emitted energy spectra.

In vivo detection offers the advantage of a rapid estimate of activity in the whole body or in an organ of the body at the time of the measurement. The direct techniques are characterised, in the first instance, by spectrometry features such as resolution, efficiency and sensitivity; other factors to take into account are the counting geometry, the control of the background, the calibration method, uncertainties associated with assessments and quality assurance. The objective is to guarantee the capability of *in vivo* techniques to detect and to evaluate the intakes of the radionuclides of interest.

The Eurados study for the harmonisation of individual monitoring represents an important source of information which indicates the status of direct determinations of internal contaminations in Europe. The collected information gives an overview of the type and characteristics of *in vivo* detection systems used by the laboratories, the materials and dimensions of shielding rooms, the counting geometries applied, calibration phantoms and methods, procedures for assessment of activities (software, counting time, detection efficiency) and the MDAs (sensitivity of the *in vivo* detection systems) of more relevant radionuclides in each geometry.

Figure 3 shows the analysis of the Eurados data relating to direct techniques. The main type of measurements used for individual monitoring of internal exposures are whole-body counting (*in vivo* detection of gamma emitters 100–3000 keV in total-body), thyroid counting (assessment of ^{125}I and ^{131}I) and monitoring of actinides in lungs. Other types of *in vivo* detection have been implemented in some facilities: determination of actinides in bone or liver, *in vivo* detection of beta emitters, assessment of contaminants in wound or hand counting. The selection of the appropriate technique for individual monitoring must take into account the type of occupational exposure and the actual risk of intake of specific radionuclides at the workplace.

As expected whole-body counting, thyroid monitoring and lung counting are commonly used for *in vivo* measurements, reflecting the type of workers controlled for intake of radionuclides.

Whole-body counting

The determination of gamma emitters in a whole-body counting geometry is most frequently used by the participants of this study. Technical information was obtained on approximately 62 WBCs from 52 European laboratories, providing an overview of the status of direct determination of fission and activation products in the body and other radionuclides in the range 100–3000 keV.

The group of WBCs counters considered in this study includes 5 mobile units, 30 detection systems inside shielded rooms and 28 equipments with no

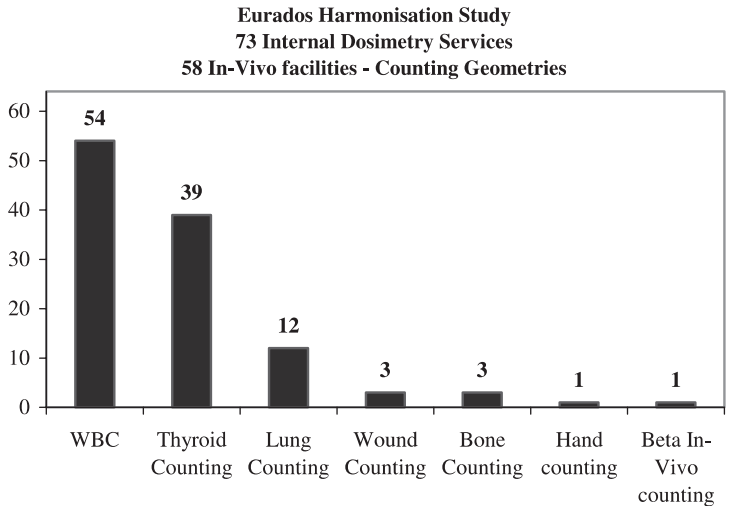

Figure 3. Type of direct techniques applied for the individual monitoring of European workers.

shielding room. After the Chernobyl accident, mobile units became an important direct technique to be used in the case of radiological accidents as well as in routine monitoring. The data collected from this sample of European facilities is illustrative of the different procedures and available methods related to the *in vivo* determination of gamma emitters in total-body.

Shielding room. The interest of performing direct measurement using detectors inside a shielded room is the background reduction, mainly with the objective of decreasing the limits of detection, to reduce counting time, to minimise the uncertainty associated with the measurement (counting statistic and variation of background), and to moderate peaks that can cause interference during the analysis of spectra. The background in the energy range of interest (10–3000 keV) arises from several sources: environmental background, radionuclides in the body and background generated by shielding, equipment and detector materials. Without shielding, the cosmic radiation contributes in the spectrum in the form of a continuum with very few photopeaks, but other photopeaks originating from natural radioactivity are also present. With effective shielding, the background component that is more significant is the radionuclides within the shielded enclosure.

ICRU 69[3] establishes that a counting room ($2.25 \times 1.5 \times 1.80$ m^3) consisting of 15 cm thick steel, and with an inner graded lining of 4 mm of Pb, 3 mm of Sn and 0.4 mm Cu provides a measured attenuation factor for external gamma radiation of 100 in the energy range for transmitted photons of 150–2000 keV. Steel is the recommended material for the outer shield of a counting room and lead is the more convenient material for the inner shield; cadmium can be used as an alternative to tin and iron is sometimes an alternative to copper.

As already stated, 30 of the 62 WBCs included in the Eurados study are operative in a shielded room. Most of the facilities (23 WBC) use steel for the outer shield, with the thickness of walls varying from 10 to 21 cm, and an average value of 16 cm of steel for the counting room; other laboratories prefer concrete (70 or 30 cm) or iron (8 or 15 cm). Lead is the more common material used as inner shield, with thickness varying from 1 to 10 mm, the general choice being 3 or 5 mm of Pb; the other elements used as graded-lining are Cu and Cd.

Counting geometry for whole-body counting. The counting geometry selected by an *in vivo* facility for direct measurements takes into account the physical characteristics and biokinetic behaviour of the radionuclides to be detected, the application of measured results and available space and resources. The main application of the laboratories included in this harmonisation study is individual monitoring and evaluation of internal doses for radiation protection purposes; the objective to achieve is to perform measurements with a configuration that makes maximum efficiency and sensitivity available.

Different detector–subject arrangements are possible in the case of total-body determination of gamma emitters; the most common counting geometries place the person on a bed or in a special chair. The analysis of the resulting spectrum will provide

the activity of radionuclides detected in the whole body, assuming homogeneously distribution of radioisotopes. In the case of total-body single-detector measurements, the recommended (ICRU 69) types of monitoring are chair geometry, arc geometry and bed or stretcher geometry (stationary or scanning). If the *in vivo* system is a multidetector, the recommended counting geometries are stationary stretcher geometry, stationary arc geometry and line scanning stretcher geometry. With reference to quick body monitoring, a vertical array of detectors is used in some cases, with the subject standing up for a short time; this represents a quick, screening technique rather than an *in vivo* method for quantitative measurements that requires high accuracy.

Analyses of the configurations used in the 62 WBC performing total-body evaluations of gamma emitters show that not only bed or chair geometries, but also the standing-up position are employed (Table 3). Bed geometry seems to be the most widely used configuration for the whole-body determination of high-energy gamma emitters, with almost half of the facilities preferring it; 14 laboratories utilise scanning or moving-bed arrangements, and 2 the stretcher geometry.

Whole-body counting detector system. NaI(Tl) or Ge detectors are the counting systems commonly used for whole-body counting. The selection of a detector for *in vivo* measurements depends upon its application. The radionuclides to be detected, features of the detector (resolution, intrinsic efficiency, stability), background response and cost are factors that must be considered. For high-energy photons, thick detectors are typically used to optimise the probability of a photoelectric interaction in the detector.

A majority (53%) of the European laboratories who participated in the Eurados project use NaI(Tl) detectors for *in vivo* total-body monitoring of radionuclides. A total of 15 facilities have single-detectors systems, 8 facilities use 2-detectors systems and 10 WBC use an array of 4 NaI(Tl) detectors (Table 4).

A large number, 21 facilities, have installed high purity germanium (HPGe) detectors, with 13 laboratories selecting single-detector systems and 8 WBC installing multidetectors systems with different arrays: 2-detectors, 3-detectors, 4-detectors and 6-detectors (Table 5). The remaining four *in vivo* facilities (Table 6) perform their measurements using both scintillation detectors (NaI(Tl)) and semiconductor detectors (HPGe).

Table 3. Counting geometries applied in WBC for the evaluation of gamma emitters in total body.

Whole-body counting	No. of WBC
Bed geometry	29
Chair geometry	15
Standing-up geometry	10
Arc geometry	1
Simple Box geometry	1

Whole-body counting calibration phantoms. An important matter of interest is the calibration procedure of the detection systems for the assessment of the activity of gamma emitters ($E >$ 200 keV) deposited in total-body. The methods and tools used by the 62 WBC facilities collected in the Eurados harmonisation study have been analysed. *In vivo* calibration requires phantoms as human simulators with assumed radionuclide distributions. Phantoms must be anthropometric (same measurement characteristics as a human), but in the case of high-energy photon emitters, they do not have to be anthropomorphic (Table 7). The calibration phantoms recommended for the direct measurement of internal exposures are described in ICRU 48[4].

The bottle phantom, the brick phantom fabricated by the Research Institute of St Petersbourg during the last 10 y with active rods containing isotopes for calibration, and the BOMAB phantom consisting of 10 pieces of polyethylene simulating the ICRP standard man with the set of radionuclides homogeneously distributed in the phantom are the preferred phantoms in facilities with WBC for the calibration of NaI(Tl) and HPGe detectors. Other types available are the torso phantom and the RMC transfer phantom. The massonite phantom has been selected in some Spanish WBCs, but they are in the process of changing to the BOMAB phantom for calibration purposes.

The phantoms used for the calibration of *in vivo* detection systems must simulate the behaviour and interaction of the ionising radiations in the body. Phantoms should be constructed with materials that provide equivalent photon transmission properties of the different human tissues. The attenuation properties of water are very close to soft tissue and, along with special plastic materials to contain the water, an anthropometric phantom can be constructed. Most WBCs are calibrated with phantoms consisting of plastic containers filled with standardised radioactive water-based solutions (bottle phantoms and BOMAB phantoms constructed with polyethylene cylinders).

Whole-body counting calibration source. ^{137}Cs and ^{60}Co are the elements more commonly employed by European *in vivo* facilities for calibration purposes. Laboratories prefer a mixture of radionuclides for calibration, where ^{152}Eu and ^{133}Ba seem to be widely

Table 4. Selected data of European facilities using NaI(Tl) for whole-body counting evaluations.

Ref.	Shield room	Geometry description	Detector system	Calibration phantom	Blank	Tc (s)	MDA ^{137}Cs (Bq)	MDA ^{60}Co (Bq)
Be-SC	Yes	Tilted chair geometry	1 NaI(Tl)	BOMAB phantom	^{40}K	2000	3	7
	Yes	Tilted chair geometry	1 NaI(Tl)	Torso phantom	^{40}K	3000		
Cz-NR	Yes	Chair geometry	1 NaI(Tl)	70 × 1 litre PE bottles		2000	80	60
Ch-BA	Yes	Scan on couch	2 NaI(Tl)	IGOR brick phantom	Person	1440	25	27
Ch-BK	No	Standing-up geometry	2 NaI(Tl)	IGOR brick phantom	Phantom + ^{40}K	600		800
Cs-NS	Yes	Arc geometry	1 NaI (Tl)	70 litre water solution of radioisotope of interest	Phantom + ^{40}K Person	1800		
De-FJ	Mobile	Standing-up geometry	2 NaI(Tl)	RMC-II phantom; brick phantom	Person	60	250	
	Mobile	Children lying in a half-tube above detector	1 NaI(Tl)	Bottle phantom; brick phantom	Person	60	150	
	Mobile	Person lying above the detectors	2 NaI(Tl)	Brick phantom	Person	60	100	
De-KT	Yes	Stretcher geometry: 4 detectors setup in pairs, above and below the bed	4 NaI(Tl)	Bottle phantom; LLNL phantom	Phantom	300	59	55
De-UE	No	Bed geometry	4 NaI(Tl)	Bottle phantom	Phantom + ^{40}K	1200	54	50
Es-AL	No	Standing-up geometry	4 NaI(Tl)	Massonite phantom	Phantom + ^{40}K	120	622*	720*
Es-AL	No	Scanning bed geometry	1 NaI(Tl)	Massonite phantom	Phantom + ^{40}K	480	100*	115*
Es-AS	No	Standing-up geometry	4 NaI(Tl)	Massonite phantom	Phantom + ^{40}K	120	540*	650*
Es-AS	No	Scanning bed geometry	1 NaI(Tl)	Massonite phantom	Phantom + ^{40}K	480	105*	110*
Es-CI	Yes	Reclined-chair geometry	1 NaI(Tl)	BOMAB phantom	Phantom	1200	60	60
Es-CO	No	Standing-up geometry	4 NaI(Tl)	Massonite phantom	Phantom + ^{40}K	120	375*	450*
Es-CO	No	Scanning bed geometry	1 NaI(Tl)	Massonite phantom	Phantom + ^{40}K	480	85*	85*
Es-TE	Mobile	Standing-up geometry	4 NaI(Tl)	Massonite phantom	Phantom + ^{40}K	120	520*	604*
Es-TE	Mobile	Scanning bed geometry	4 NaI(Tl)	Massonite phantom	Phantom + ^{40}K	480	180*	190*
Es-TR	No	Standing-up geometry	4 NaI(Tl)	Massonite phantom	Phantom + ^{40}K	120	625*	750*
Es-VA	No	Standing-up geometry	4 NaI(Tl)	Massonite phantom	Phantom + ^{40}K	120	515*	650*
Es-VA	No	Scanning bed geometry	1 NaI(Tl)	Massonite phantom	Phantom + ^{40}K	480	90*	100*
Es-ZO	No	Scanning bed geometry	1 NaI(Tl)	Massonite phantom	Phantom + ^{40}K	480	115*	105*

Table 4. Continued

Ref.	Shield room	Geometry description	Detector system	Calibration phantom	Blank	Tc (s)	MDA ^{137}Cs (Bq)	MDA ^{60}Co (Bq)
Es-GA	No	Scanning bed geometry	1 NaI(Tl)	Massonite phantom	Phantom + ^{40}K	480	280*	263*
Hr-NM	No	Scanning bed geometry	1 NaI(Tl)	RMC phantom	Person	480	200	150
Hu-AE	Yes	Scanning bed geometry (end-stop)	1-2 NaI(Tl)	BOMAB phantom Bottle phantom	Phantom	1300	100	80
Ie-SV	No	Moving couch	2 NaI(Tl)	RMC-II phantom	Phantom + ^{40}K	1200	72	64
It-EN	Yes	Tilting chair geometry	1 NaI(Tl)	BOMAB phantom	Person	1200	70	50
It-IS	No	T. CH or contact lungs	1 NaI(Tl)	BOMAB & Alderson	Person	1800	28	6
Lt-IP	Yes	Bed scanning geometry	1 NaI (Tl)	Thorax phantom	Person	1800	22	41
Nl-RE	Yes	Bed geometry	4 NaI(Tl)	Bottles phantom	Person	600	125	120
No-IE	No	Sitting in a chair	1 NaI(Tl)	IRINA phantom	Person	600	769	1700
Ro-CN	No	Standing-up geometry	2 NaI(Tl)	RMC-II phantom	Person	600	30	31
Ro-IC	No	Chair geometry	1 NaI(Tl)	BOMAB phantom	Phantom + ^{40}K	600	178	300
Si-KR	No	Standing-up geometry	2 NaI(Tl)	Torso phantom	2800 Bq of ^{40}K	70	600	400
Si-MC	No	Bed geometry	1 NaI(Tl)	RMC-II phantom		600	145	150
Sk-BO	Yes	WB, GIT, thyroid, lung	1 NaI(Tl)	RMC-II phantom	Phantom	60	210	150
Ua-RM	No	Chair geometry	2 NaI(Tl)	Human body tissue shape filled split peas	Phantom	600	374	384

*Values reported as lower limit of detection

Table 5. Selected data of European facilities using HPGe for whole body counting evaluations.

Ref.	Shield room	Geometry description	Detector system	Calibration phantom	Blank	Tc (s)	MDA ^{137}Cs (Bq)	MDA ^{60}Co (Bq)
At-AR	Yes	Bed geometry, scanning	2 HPGe	Bottle phantom	Person	1000	190	140
At-GR	No	Bed geometry	1 HPGe	Bottle phantom	Person	1000	230	200
Cz-DU	Yes	Detector over the end of sternum in default distance from bed; scan in five positions	1 HPGe	BOMAB phantom	Person	1000	77	46
Cz-RP	Yes	Sitting position in front of the detector	1 HPGe (110%)	IGOR brick phantom, BOMAB phantom, modified BOMAB	Empty chamber	1200	50	40
Cz-TE	Yes	Chair geometry	1 HPGe	BOMAB phantom	Person	600	200	200
	Yes	Scanning bed geometry	1 HPGe	BOMAB phantom	Person	3000	90	85
Ch-PS	Yes	Chair geometry	1 HPGe	IGOR brick phantom	Phantom + ^{40}K	420	45	60
De-BS	Yes	Whole-body scan	2 HPGe	IGOR brick phantom	Phantom + ^{40}K	1200	50	40
De-FJ	Yes	Stretcher geometry, with four detectors in pairs, above and below the bed	4 HPGe	Bottle phantom, brick phantom	Person	600	35	27
De-LU	Yes	Lying (couch) geometry	4 HPGe	Water phantom		600	30	20
De-SH	Yes	Bed geometry	6 HPGe	Bottle Phantom, brick phantom	Person	900	86	97
Dk-RI	Yes	Chair geometry	1 HPGe	25 litres canister	Empty chamber	3600	100	80
Gb-AW	No	Chair geometry	4 HPGe	32 Point sources	Person	1200	125	125
Hu-AE	Yes	Scanning bed geometry (end-stop)	1 HPGe	Bottle phantom, BOMAB phantom	Phantom	1300	300	230
Hu-RR	Yes	Scanning or fixed position (lung thyroid)	2 HPGe	Plastic bottle (1 litre) phantom	Phantom	1500	70	50
It-CA	Yes		1 HPGe	BOMAB phantom	Person	1000	102	78
It-EF	Yes		1 HPGe	BOMAB phantom (15 sections)		1200	50	60
Lt-IP	Yes	Mobile Unit, bed scanning geometry	1 HPGe (25%)	Thorax phantom	Person	1800	38	57
Pt-TN	No	WB, thyroid, lung, GIT	1 HPGe	RMC-II phantom	No	2400	290	233
Se-HU	Yes	Simple box geometry	1 HPGe	IRINA phantom		600	150	75
Se-RI	Yes	Chair geometry	1 HPGe (43%)	Solid tissue equivalent phantom		500	200	200
Si-MC	No	Whole body, thyroid, lung, GIT, empty bed	2 HPGe	RMC-II simulation of ANSI standard phantom		600	450	400
Sk-BA	Yes	Bed geometry	1 HPGe	BOMAB phantom	Phantom	1000	60	45
Sk-BO	No	Whole body (1), Lung (2)	1 HPGe	BOMAB phantom	Phantom			
	(1) Scanning bed geometry					1200	433	279
	(2) Lung/fixed geometry					1200	159	113

Table 6. MDA of European facilities using NaI + HPGe for whole-body counting determinations.

Ref.	Shield room	Geometry description	Detector system	Calibration phantom	Blank	Tc (s)	MDA ^{137}Cs (Bq)	MDA ^{60}Co (Bq)
Bg-KO	Yes	Moving bed and vertical moving detector	1 NaI(Tl) + 3 HPGe	Polythene modules	Person	600	326	340
Gr-GA	No	Moving bed geometry	1 NaI(Tl) + 1 HPGe	RMC-II phantom, Bottle phantom	Empty bed	1460	30	
Se-OK	Yes	Chair geometry	2 HPGe + 1 NaI(Tl)	Solid tissue equivalent phantom	Phantom	600	31	38
Ua-RM	Yes	Six detectors in line along human body under bed	1 NaI(Tl) + 1 HPGe	Human body tissue shape filled split peas	Phantom	600	24	28

Table 7. Calibration phantoms used for the WBC evaluations in European *in vivo* facilities.

Calibration phantoms whole-body counting	No. of WBC
Bottle phantom	14
BOMAB phantom	13
Brick phantom	12
RMC phantom	7
Torso phantom	5
Massonite phantom	10
Others	4

Table 8. Type of blank used for MDA calculations in whole-body measurements.

	Person	Phantom + ^{40}K	Phantom	Background
No. of facilities	19	14	15	3

used due to their multiline emissions. Mixed nuclide sources commonly prepared also contain ^{109}Cd, ^{139}Ce, ^{203}Hg, ^{113}Sn and ^{88}Y; with other radionuclides as ^{134}Cs, ^{141}Ce, ^{85}Sr, ^{65}Zn, ^{54}Mn or ^{235}U being used in a few instances.

The calibration of WBCs is performed with a radiation source that emits photons with energies covering the operative range of the detection system. In order to obtain a good fit in the calibration efficiency curve, particularly the low-energy contribution, ^{57}Co and ^{241}Am are the preferred radionuclides, due to their very-low-energy gamma emissions.

Fifteen per cent of the WBCs included in the Eurados study decided to perform the total-body calibration of the *in vivo* system with ^{40}K in the source (applying to both scintillators and semiconductors). This is important to note, especially in the case of calibration for the ^{60}Co evaluation with NaI(Tl) detectors (interference of ^{40}K body emissions).

MDA for whole-body counting. Eurados Q2 questionnaire contained a section dedicated to the assessment of Minimum Detectable Activity (MDA) for ^{137}Cs and ^{60}Co, as an indicator of the sensitivity of the *in vivo* detection system in whole-body counting geometry; information of counting time, efficiency and the blank used for MDA estimation (Table 8) was collected from the 62 WBC.

Counting times, in routine whole-body counting, are spread out over a very wide range, 60–3600 s. A total of 13 WBC utilise a time of 600 s, with a further 13 facilities using 1000–1200 s. Finally, for quick counting, 60–70 or 120 s are the options selected.

Table 4 shows some selected data related to the MDA in force in facilities using NaI(Tl) detectors for the *in vivo* detection of gamma emitters in total-body. Table 5 presents the more relevant data associated to the laboratories operating with semiconductors (HPGe) for the direct determination of radionuclides in whole-body; MDA values in Bq for ^{137}Cs and ^{60}Co are also given. Table 6 shows the data of four facilities operating with a mixture of detectors (NaI(Tl) and HPGe) for whole-body counting evaluations; MDA values are also presented.

The sensitivity of the detector system has been given for ^{137}Cs and ^{60}Co where the MDA represents the detection limit of the system expressed in terms of the activity. For *in vivo* equipment in a whole-body application, a specific blank is used to obtain background counts. The MDA is calculated here using as background a measured blank person or a phantom simulating the human body and containing an expected amount of ^{40}K. The Eurados study does not take into account how facilities obtain the MDA data (ISO, ANSI, NUREG, etc.). Facilities were required to supply information relating to the

parameters that affect the sensitivity of the system (type and number of detectors, shielding, counting geometry, efficiency, type of blank and counting time) together with the MDA values for ^{137}Cs and ^{60}Co, in order to compare the data. It is worth noting here the publication ICRU 69, contains a comparison of MDAs achieved by different WBCs (NaI(Tl) and HPGe).

It was quite difficult to extrapolate strong conclusions from the comparison of MDA values reported by laboratories collaborating with Eurados in the harmonisation project. The information collected was separated into different groups depending on the type of detectors (Tables 4–6) and parameters such as counting time, number of detectors, type of blank as well as the counting geometry used in each case. It was found that similar sets of these parameters corresponded to different MDA values, thereby leading to the conclusion that there is a need for harmonisation in methods and procedures. This finding is especially applicable to HPGe detectors where it was expected that under similar measurement conditions longer counting times resulted in lower MDA. However, this was not the finding in the Eurados study (Table 5).

Considering the percentages of the number of occurrences of a given value of MDA in a specific interval over the total number of available values, some information can be drawn regarding the spread of the collected MDA values. Figure 4 shows the percentage values that have been reported. A 100 Bq interval has been chosen for both radionuclides up to 1000 Bq. As can be seen, results related to NaI(Tl) WBC types are more widely distributed than those related to HPGe. Approximately 60% of the MDA values for HPGe WBC are present in the first MDA interval (0,100) Bq, for both radionuclides as compared with 40% of those related to NaI(Tl) types. The higher MDA values are only associated with NaI(Tl) type WBC (values >500 Bq). For the HPGe type WBC the distribution of occurrences is narrow for ^{60}Co in respect to ^{137}Cs.

The lowest MDA reported was 3 Bq of ^{137}Cs and 7 Bq of ^{60}Co of a WBC using 1 NaI(Tl) detector (200 mm diameter, 100 mm thickness) in a shielding room (steel walls with wood, Pb and brass); the tilted chair geometry was applied, for a counting time of 2000 s. Calibration was undertaken with a BOMAB phantom, using a Blank with ^{40}K for MDA calculations.

The optimisation of MDA values seems to be achieved using a mixture of detectors, NaI(Tl) and HPGe, in shielding room using a bed geometry. Two countries reported that they used this configuration, with a counting time of 600 s, obtaining MDA values of 20–30 Bq for ^{137}Cs and ^{60}Co, respectively. Good results are also reported for 4 WBCs using NaI(Tl) detectors and a counting time of 1200 s, agreeing in values of 60–70 Bq for ^{137}Cs for and 50-60 Bq for ^{60}Co, obtained with different sets of calibration/counting data. Quick counters using NaI(Tl) detectors, with a measurement time of 60 s reported MDA values in the range of 100–250 Bq for ^{137}Cs and ^{60}Co.

As was expected, in general, the use of HPGe detectors requires longer counting times to achieve the same MDA values as using NaI(Tl) detectors. Seventy-five per cent of the *in vivo* facilities using semiconductor detection systems selected counting times in the range of 600–1200 s. Three laboratories using HPGe detectors and a measurement time of 1200s reported quite similar MDAs to the NaI(Tl) values. One facility using 1 HPGe detector in a

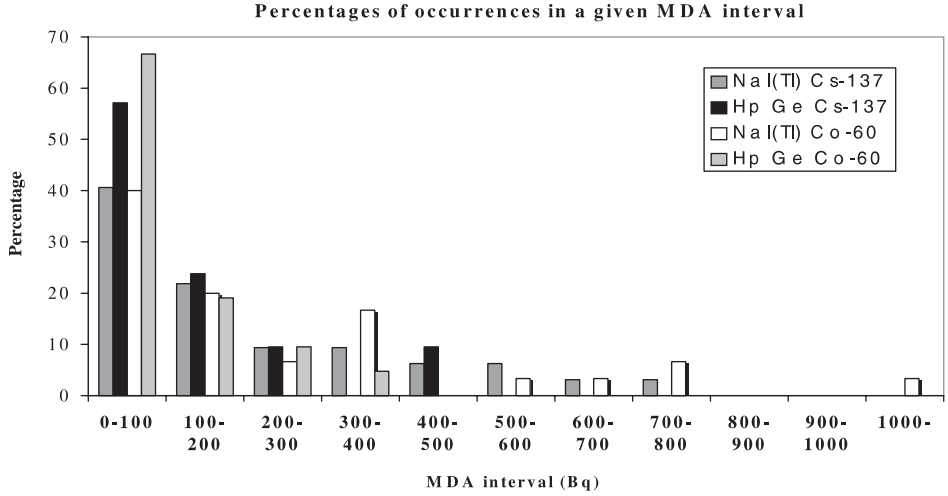

Figure 4. Percentage of occurrences in a given MDA interval (WBC measurements).

shielding room, employing a chair geometry and obtaining 100 and 80 Bq for MDA values have the measurement time of 3600 s. As a final conclusion for HPGe detector system used for whole-body determinations, it is worth noting that there is a lack of agreement in the results of MDA in that similar sets of parameters resulted in different MDA values. It is recommended that this be further studied with a more detailed investigation of MDA calculations of European *in vivo* facilities.

Thyroid counting

Other types of *in vivo* measurement counting are required when considering intakes of radionuclides that are deposited in some particular organs. This happens, for example, when internal exposures to radioiodine occurs and it is retained in the thyroid gland. Counting geometry for thyroid monitoring consists of one or more detectors of a suitable size placed close to the surface of the neck over the thyroid area, with the subject either in a supine or sitting position. A collimator or shield is recommended to minimise interference from radionuclides in other parts of the body.

The Eurados harmonisation study includes 44 thyroid counters at some 38 *in vivo* facilities. This represents an illustrative sample of thyroid monitoring in Europe with the information collected showing that both, NaI(Tl) and HPGe detectors are used for the evaluation of the activity of ^{131}I and ^{125}I deposited in thyroid. ^{131}I is a gamma emitter with an easily identifiable spectrum and characteristic photopeak of 364.5 keV; the assessment of ^{125}I can be done from the analysis of the X-ray typical emissions ~27.1 keV and/or using the low-energy gamma photopeak of 35.5 keV.

Calibration for thyroid monitoring requires a special phantom that simulates the size and shape of this organ, and which must be realistic in the attenuation of the overlying tissue-equivalent material. A variety of phantoms are reported in ICRU 69 publication by Kramer *et al.*[5].

In vivo assessment of ^{131}I in thyroid. The most frequently used measurement system for the *in vivo* determination of ^{131}I in thyroid is one NaI(Tl) detector (Table 9). A few services have installed one HPGe detector or multidetector systems. All the determinations are carried out from the analysis of the 364.5 keV photopeak in the gamma spectrum. A thyroid detector distance of 10–15 cm is used in 50% of the *in vivo* counters. The remainder are divided into those that apply close distances of 1–5 cm, and a small number who prefer long distances of 20–30 cm.

With reference to calibration phantoms a great variety are chosen, as shown in Table 9. The assessment of the activity of ^{131}I in the thyroid is carried for counting times varying from 10 to 1800 s with 500–600 s being typical in 16 of the 42 respondents. The MDA is obtained from the measurement on a blank phantom (50% of the laboratories performing thyroid monitoring) or a blank person. In both cases MDAs in the range 4–800 Bq of ^{131}I in thyroid are achieved. Three facilities using one HPGe detector at close distances ($\leq$10 cm) for counting times of 600–1000 s reported the lowest value of MDA, ~5 Bq of ^{131}I in thyroid. A future study of the harmonisation of MDA is also recommended, which considers more fully the procedure for calculating the limit of detection for ^{131}I in thyroid monitoring in European *in vivo* laboratories.

In vivo assessment of ^{125}I in thyroid. Table 10 shows selected data related to the direct measurement of ^{125}I in the thyroid in 13 European *in vivo* facilities. The X rays (~27 keV) and very-low gamma detection (35 keV) is carried out using semiconductors (HPGe and LEGe) detection systems (six laboratories) and also scintillators (NaI(Tl)). The detection device is placed over the neck, close to the thyroid area, with thyroid-detector distances ranging from 2 to 15 cm. The most frequently used distances are found to be 10–15 cm. The lowest MDAs reported correspond to 2–6 Bq of ^{125}I in the thyroid, where the detection of 27 keV emission by germanium detectors and one Na(Tl) detector is recorded and different counting times (300, 600 and 1200 s) are used.

As with the comparison for MDA values in WBC measurements, a comparison of the percentages of the number of occurrences of a given value of MDA in a specific interval over the total number of available values can provide some indication of the spread of the data collected. In Figure 5 those values are reported for the two monitored radioisotopes.

Figure 5 shows the distribution of MDA values for the two radioisotopes are very similar. In the case of ^{125}I, due to the small number of data, one value at 360 Bq represents 10% of the distribution. In the case of ^{131}I one-third (31%) of the distribution of values is >160 Bq.

Lung counting

Lung counting is the type of *in vivo* measurement recommended for radionuclides with long residence times in the lung, such as uranium oxides, plutonium and ^{241}Am oxides. An optimisation study of counting efficiency is required to achieve the sensitivity of the detection system for the measurement of low-energy photons emitters that are of interest in occupational exposures; it has been reported that detection efficiency is higher if the subject is

Table 9. European services performing thyroid monitoring for ^{131}I determination.

Ref.	Detector system	Diameter (mm)	Thickness (mm)	*d* (cm)	Phantom	Tc (s)	Blank	MDA (Bq)
At-AR	1 HPGe	53.5	54.0	10	IAEA thyroid phantom	500	Background	20
At-Gr	1 HPGe	54.4	62.8	12	Thyroid neck phantom	1000	Person	43
Be-SC	1 HPGe	50.0	20.0	2	Lucite cylinder	600	Phantom	4
Cz-DU	1 NaI(Tl)	51.2	51.2	0	Neck phantom	300	Person	20
Cz-NR	1 NaI(Tl)	25.0	25.0	3.5–5	PE bottle with special wax	60	Phantom	150
Cz-RP	1 NaI(Tl)			5	Solution (2 ml of volume) in ampoule placed in neck phantom	600	Person	35
Cz-TE	1 NaI(Tl)	51.0	51.0	8	IAEA/ANSI phantom	600	Phantom	100
Ch-BK	1 NaI(Tl)	38.0	12.0	10	Polythene neck phantom 950 kg m^{-3}, 14 cm diameter, 16 cm high	600	Phantom	400
Ch-BK	1 NaI(Tl)	110.0	25.0	10	Polythene neck phantom 950 kg m^{-3}, 14 cm diameter, 16 cm high	600	Phantom	550
Ch-PS	1 NaI(Tl)	25.4	25.4	10	Polythene neck phantom 950 kg m^{-3}, 14 cm diameter, 16 cm high	100	Phantom	800
Ch-RA	1 NaI(Tl)	44.0	51.0	10	Polythene neck phantom 950 kg m^{-3}, 14 cm diameter, 16 cm high	900	Phantom	150
De-FJ	1 HPGe	67.0	63.0	9	Modified IAEA phantom	600	Person	6
De-GA	1 NaI(Tl)	2 inch	2 inch	5	Neck phantom	600	Phantom	34
De-UE	1 NaI(Tl)	38.1	25.4	5	Plexiglass neck phantom		Phantom	12
Es-CI	1 NaI(Tl) + collimator	203.0	102.0	30	Amersham thyroid phantom (Mock iodine) inLLNL phantom	1200	Person	23
Es-TE	4 NaI(Tl)	100 × 100	75	10	Mock ^{131}I thyroid in a massonite phantom	120	Phantom	215*
Es-TE	4 NaI(Tl) + collimator	100 × 100	71	10	Mock ^{131}I thyroid in a massonite phantom	480	Phantom	20*
Es-TR	1 NaI(Tl)	100 × 100	71	10	Mock ^{131}I thyroid in a massonite phantom	120	Phantom	260*
Es-ZO	1 NaI(Tl)	200	100	10	Mock ^{131}I thyroid in a massonite phantom	480	Phantom	15*
Es-CO	4 NaI(Tl)	100 × 100	75	10	Mock ^{131}I thyroid in a massonite phantom	120	Phantom	175*
Es-CO	1 NaI(Tl)	200	100	10	Mock ^{131}I thyroid in a massonite phantom	480	Phantom	10*
Es-AS	4 NaI(Tl)	100 × 100	75	10	Mock ^{131}I thyroid in a massonite phantom	120	Phantom	245*
Es-AS	1 NaI(Tl)	200	100	10	Mock ^{131}I thyroid in a massonite phantom	480	Phantom	12*
Es-VA	4 NaI(Tl)	100 × 100	75	10	Mock ^{131}I thyroid in a massonite phantom	120	Phantom	200*
Es-VA	1 NaI(Tl)	200	100	10	Mock ^{131}I thyroid in a massonite phantom	480	Phantom	10*
Es-AL	4 NaI(Tl)	100 × 100	75	10	Mock ^{131}I thyroid in a massonite phantom	120	Phantom	260*
Es-AL	1 NaI(Tl)	200	100	10	Mock ^{131}I thyroid in a massonite phantom	480	Phantom	12*
Es-GA	1 NaI(Tl)	125	75	10	Mock ^{131}I thyroid in a massonite phantom	480	Phantom	20*

Table 9. Continued

Ref.	Detector system	Diameter (mm)	Thickness (mm)	*d* (cm)	Phantom	Tc (s)	Blank	MDA (Bq)
Hu-AE	1 NaI(Tl)	40	40		IAEA-ANSI neck phantom	500	Phantom	100
Hu-RR	1 HPGe	50	55	1	Plexiglass phantom	600	Phantom	30
Ie-SV	1 NaI(Tl)	400× 125	75.0		Transfer phantom RMC II	1200		
It-AG	Inorganic scintillator	50.0	50.0	20	Thyroid phantom	900	Phantom	80
	Inorganic scintillator	50.0	50.0	5	Thyroid phantom	300	Phantom	30
It-CA	1 HPGe	60.5	60.5	1	BOMAB Phantom	1000	Phantom	5
It-EF	1 HPGe	58.9	67.3	5	BOMAB phantom (15 sections)	1200		90
It-IS	1 NaI (Tl)	203.2	101.6		ALDERSON phantom	600	Person	200
It-ON	1 NaI (Tl)	50.0	50.0	20	IAEA-ANSI thyroid	360	Phantom	90
It-EN	1 NaI(Tl)	203.0	102.0		ANSI neck phantom	600	Person	30
Lt-IP	1 NaI(Tl) + 1 HPGe	76 × 127 × 400		4	Thorax phantom	1800	Person	46
No-IE	1 NaI(Tl)	76.2	76.2	10	IRINA	600	Phantom	
Pl-RP	1 NaI(Tl)	76.0	76.0	15	RSD type RS-542	1000	Person	30
Pl-RP	1 NaI (Tl)	76.0	76.0	10, 15	RSD type RS-542	1000	Person	70, 90
Ro-IC	1 NaI(Tl)	40.0	50.0	10	Tissue equivalent thyroid phantom		Phantom	26
Se-OK	1 NaI(Tl)	38.1	50.8	5	Cylindrical phantom	600	Phantom	250
Se-Ri	1 HPGe	60.0	54.0	14	Thyroid phantom	500		400
Si-KR	1 NaI(Tl)	38.0	13.0	5				
Sk-BO	1 NaI(Tl)	45.0	50.0	15	IAEA-ANSI neck calibration phantom	600	Phantom	170

*Values reported as lower limit of detection

Table 10. European services performing thyroid monitoring for ^{125}I determination.

Ref.	Detector system	Diameter (mm)	Thickness (mm)	Window	*d* (cm)	Phantom	Tc (s)	Blank	*E* (keV)	MDA (Bq)
At-AR	1 HPGe	53.5	54	Be	10	IAEA thyroid phantom	500	Background	35	130
At-Gr	1 HPGe	54.4	63	Be (0,5 mm)	12	Thyroid neck phantom	1000	Person	35	360
Cz-RP	1 NaI(Tl)	62.8			5	Solution (2 ml of volume) in ampoule placed in neck phantom	600	Person	27–36	25
Ch-PS	1 NaI(Tl)	25.4	25	Be (0.2 mm)	10	Polythene neck phantom 950 kg m^{-3}, 14 cm diameter, 16 cm high	100	Phantom		100
Ch-RA	1 NaI(Tl)	44	51		10	Swiss phantom polythene neck phantom 950 kg m^{-3}, 14 cm diameter, 16 cm high	900	Phantom		60
De-BS	2 LEGe	50.5	10	C-Epoxy (0.5 mm)	12	Thyroid neck phantom	600	Phantom	27.4	5
De-FJ	1 HPGe	67	63	C-Epoxy	9	Modified IAEA phantom	600	Person	27	5
De-KT	1 NaI(Tl)	25	50		1	Thyroid neck phantom	600	Phantom	27–36	2
Es-CI	1 LEGe	70	25	C-Epoxy (0.5 mm)	15	Thyroid simulator with ^{125}I source, in LLNL phantom	1200	Person	27.4	6
It-EN	1 HPGe	76	25	C-Epoxy	2	ANSI neck phantom	300	Person	27.7	2
Hu-AE	1 NaI(Tl)	40	6.3	Al		IAEA-ANSI neck phantom	500	Phantom	28	90
Hu-RR	1 HPGe	50	55	Be (0.5 mm)	1	Plexiglass phantom	600	Phantom		30
Pl-RP	1 NaI (Tl)	76.0	76.0		10	RSD type RS-542	1000	Person		40
	1 NaI (Tl)	50.0	12	Al	10, 15	RSD type RS-542	1000	Person	26–36	20, 30
Se-HU	1 NaI (Tl)					Calibration with ^{125}Eu	300			75

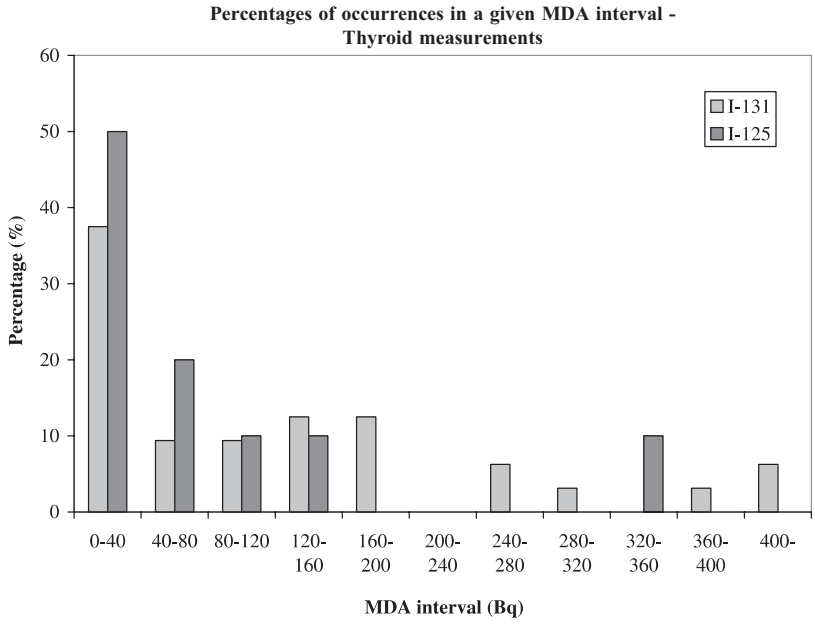

Figure 5. Percentage of occurrences in a given MDA interval (thyroid monitoring).

measured in a sitting rather than a supine position as described by Palmer[6].

A total of 12 laboratories collaborated with Eurados in providing information related to parameters and methods applied in lung monitoring; a selected data of services and procedures are presented in Tables 11 and 12. Some *in vivo* facilities like French internal dosimetric services, are not included in the study (no answers of questionnaires) representing an important gap of information in the overview of this type of monitoring in Europe.

In vivo measurements of radionuclides in lung typically involve the detection of X rays and/or photons with energies <200 keV; Phoswich detectors (excellent detection efficiency, worse resolution comparing with germanium detectors) have been traditionally used to evaluate radionuclides emitting photons in this range of energy. In case of multiple radionuclide exposure, the excellent resolution of germanium systems is the better recommendation. The majority of the laboratories involved in the Eurados harmonisation study use germanium detectors for lung monitoring; the detection systems consist of different arrays of detectors of different sizes. Two cases of Phoswich and another of NaI(Tl) are presented here as an alternative technique of semiconductors (Table 11).

Anatomically realistic phantoms should be used for lung calibration with the detectors being located close to the surface of the body. The differential attenuation in muscle, adipose tissue, lung and bone must be accurately simulated using anthropometric phantoms such as the LLNL (Lawrence Livermore National Laboratory) phantom or the JAERI (Japanese Atomic Energy Research Institute) phantom; all the phantoms available for lung monitoring are described in ICRU Report 48 (1992). When measuring low-energy photon emitters (<100 keV) deposited in lungs, the thickness of the overlying tissue (chest wall thickness or CWT) becomes an important parameter to take into account in the *in vivo* calibration (counting efficiency) and in activity calculations. Therefore, calibration for low-energy photon measurements in lungs requires the use of phantoms with various overlying tissue substitute plates. The efficiency as a function of CWT is then evaluated by an exponential function obtained from experimental data after the measurements of the realistic torso phantom.

Table 12 shows those European laboratories that use LLNL and Alderson phantoms for lung calibration. Sets of overlying chest plates of 50% muscle and 50% fat are employed to obtain the efficiency function depending on CWT (other facilities did not supply this information). The assessment of the activity of radionuclides in lungs is carried out from *in vivo* measurements of ^{241}Am, ^{235}U, ^{234}Th/^{238}U, ^{239}Pu and ^{232}Th.

Counting times for lung monitoring vary from 1200 to 3000 s; the MDAs that have been reported refer to a CWT of ~2.5 cm for a blank person. Some agreement seems to be achieved in

Table 11. *In vivo* detection of radionuclides in European facilities performing lung monitoring (1).

Ref.	Shielded room	Detector system	Diameter (mm)	Thickness (mm)	Window	Geometry	CWT estimation
At-AR	300 mm concrete, 10 mm steel, 40 mm lead	2 HPGe	54, 56	54, 58	Be	Bed	Estimate from height and weight
Be-SC	2.25 × 1.5 × 1.8 m^3; steel, wood, Pb, Sn, Fe	2 HPGe	50	20	C-Epoxy	Chair	Sumerling (NRPB) formula
Cz-NR	2.5 × 2.0 × 2.0 m^3; old steel walls 21 cm thick	2 LEGe	51	20, 15	C-Epoxy (0.5 mm)		
De-KT	4.2 × 2.25 × 2.25 m^3; 150 mm Fe, 3 mm Pb, 1.5 mm Sn + 0.5 mm Cu	2 Phoswich	200	1 NaI; 50 CsI	Be (1 mm)	Bed	LLNL chest phantom
De-SH	1.5 × 2.2 × 2.0 m^3; 120 mm steel, 10 mm Pb, 5 mm Cu	6 HPGe	52	20	Be (0.5 mm)		Estimate from height and weight
Es-CI	2.43 × 2.43 × 1.97 m^3; 130 mm steel, 5 mm Pb, 0.7 mm Cd, 0.7 mm Cu	4 LEGe	70	25	C-Epoxy	Reclined chair	Sumerling (NRPB) formula
Gb-AW	No shielded room	4 HPGe	80	25	C-Epoxy	Chair	Ultrasonic measurements
Hu-AE	2.2 × 2.0 × 160 m^3; 200 mm old steel, 4 mm old Pb, 1 mm Cu	1 NaI(Tl)	150	100	Al (0.5 mm)	Stretcher	
Hu-RR	2.2 × 1.6 m^2; 150 mm Fe, 2 mm Cu	2 Planar Ge	70	30	C-Epoxy	Bed	
It-IS	2.7 × 2.2 × 2.4 m^3;	1 NaI(Tl)	203	101.6		T. CH	
It-EN	700 mm concrete, 200 mm Fe, 3 mm Pb, 2 mm Cu, 3 mm plastic	4 LEGe	76	25	C-Epoxy	Stretcher	
Ua-RM	2.4 × 2.2 × 2.0 m^3; wall thickness 200 mm steel	2 Phoswich	150	2 NaI; 40 CsI	Al (0.1 mm)	Bed	2.5 cm

Table 12. *In vivo* detection of radionuclides in European facilities performing lung monitoring (2).

Ref.	Detector system	Calibration Phantom	Overlay plates	Radionuclide	*E* (keV)	Tc (s)	Blank	CWT (cm)	MDA (Bq)
At-AR	2 HPGe	IAEA		^{241}Am	59.5	2000	Background		26.0
				^{238}U	352	2000	Background		14.0
				^{232}Th	238	2000	Background		8.0
Be-SC	2 HPGe	LLNL	All	^{241}Am	59.5	3000	Person	From 1 to5	From 6 to 9
De-KT	2 Phoswich	LLNL	50% muscle 50% fat	^{241}Am	59.5	2000	Person	2.5	4.9
De-SH	6 HPGe	LLNL	50% muscle	^{235}U	185.7	2400	Person	2.4	3.8
			50% fat	^{241}Am	59.5	2400	Person	2.4	3.6
Es-CI	4 LEGe	LLNL	50% muscle	^{241}Am	59.5	2700	Person	2.6	6.8
			50% fat	^{235}U	185.7	2700	Person	2.6	3.0
				^{234}Th/^{238}U	63.2	2700	Person	2.6	40.0
Gb-RW				^{241}Am	59.5				8.0
Gb-AW	4 HPGe	LLNL	50% muscle	^{235}U	185.7	1800	Person	3.0	4.0
			50% fat	^{234}Th/^{238}U	63.2	1800	Person	3.0	30.0
				^{241}Am	59.5	1800	Person	3.0	4.0
It-IS	1 NaI(Tl)	Alderson		^{241}Am	59.5	1800	Person	2.2	8.0
It-EN	4 LEGe	Alderson	50% muscle	^{241}Am	59.5	1200	Person	2.5	7.0
			50% fat	^{239}Pu	16.7	1200	Person	2.5	2200.0
				^{234}Th/^{238}U	63.2	1200	Person	2.5	40.0
Ua-RM	2 Phoswich			^{241}Am	59.5	1800	Person	2.5	6.0

MDA estimation of ^{241}Am in lungs, with values generally lying in the range 4–8 Bq. Lowest values of MDA correspond to *in vivo* determination of 3–5 Bq ^{235}U in the lungs. An aliquot of 40–45 Bq of ^{234}Th is the MDA obtained by laboratories for the assessment of ^{238}U in the lungs, assuming equilibrium conditions.

As conclusion of the lung monitoring study, further investigations about how services estimate MDA is recommended as a continuation of this harmonisation action supported by Eurados.

Other in vivo counting (skeletal, wound and beta/ Bremsstrahlung measurements)

Some *in vivo* facilities confirmed their ability to perform other types of *in vivo* measurements such as the determination of the activity in the skeleton, hand counting and wound monitoring and *in vivo* beta counting. A summary of these techniques is presented below.

In case of bone-seeking radionuclides emitting low-energy photons (^{210}Pb or ^{241}Am), the *in vivo* measurement of the activity deposited in bone is usually performed in a isolated region of the body like the skull or the knee. The assessment of total activity retained in the skeleton is calculated from the estimation of the fractional activity deposited in the region viewed by the detector. Calibration phantoms are available for *in vivo* measurement of low-energy emitters in the skull and knee.

Measurement of the radionuclides in a wound is recommended in the case of accidental contamination, to quantify and localise the activity remaining in the wound site. Small or collimated detectors should be used to determine the activity distribution in the wound.

Beta emitting radionuclides can be measured either by Bremsstrahlung photon emission or through direct detection of the beta particles. Only beta emitters with high enough energy could be detected by gamma spectrometry. Bremsstrahlung monitors can be designed as whole-body or partial-body counters placed above and below the body. Phoswich detectors, thin NaI(Tl), planar HPGe and/or HPGe in combination with plastic scintillators can also be employed. ^{90}Sr, and its progeny ^{90}Y, is a typical pure-beta emitter, being suitable for Bremsstrahlung counting. ICRU 69 establishes the range 800–1500 Bq as lower limit of *in vivo* detection of ^{90}Sr/^{90}Y in whole-body.

Indirect techniques

A radiochemical analytical laboratory is required for indirect measurements on biological samples. Radiochemical analysis detects low levels of activity in the samples, providing a sensitive method for the measurement of internal exposures in many cases. From a routine monitoring point of view, urine measurements are normally chosen to determine the rate of loss of radioactive material from the body; the assessment of intake and dose is carried out by using an adequate biokinetic model.

The quality assurance of in-vitro laboratories in Europe is mainly coordinated by PROCORRAD Association funded in 1995 by CEA (Commissariat de l'Energie Atomique, France), ABNF (Association des Biologistes de l'Industrie Nucléaire Française) and COGEMA (Compagnie Générale des Matières Nucléaires). Radiotoxicological intercomparison exercises are carried out every year. Other intercomparison exercises have been organised by BfS (Bundesamt für Strahlenschutz) and IAEA.

Analytical procedures and equipment for indirect measurements vary among bioassay laboratories. Publication ISO12790[7] establishes the performance criteria recommended for analytical determinations of radioactivity burdens in biological samples; *in vitro* facilities need of specific equipments and appropriate sample preparation, to carry out chemical processing and radionuclide quantification. With reference to the sensitivity of the techniques, for analysis involving radiochemical separations and radioactivity counting processes of a radionuclide in a biological sample, the chemical recoveries and counting efficiencies can be taken into account separately or they may be incorporated to the calibration factor for MDA calculations.

A total of 43 European laboratories have collaborated with Eurados, supplying information about procedures and techniques related to the analysis of excreta for the assessment of internal exposures. The collection of urine and faecal samples from workers with a risk of intake of radionuclides is usually carried out for radiation protection purposes. Occasionally other types of samples such as breath, nasal fluid, blood, hair or finger nails are also analysed.

Indirect measurements performed by facilities have also been examined (Figure 6), with the focus being on the type of radionuclide being evaluated (actinides, beta and gamma emitters) and the technique to apply (bioassay determinations or PAS/SAS monitoring). A total of 26 laboratories are involved in the detection of pure-beta emitters in excreta (^{3}H, ^{90}Sr/^{90}Y, ^{14}C, etc.). Information relating to *in vitro* measurements of actinides was provided by 19 laboratories, 17 European facilities of the Eurados group perform measurements for gamma emitters in excreta, and a small set of services is involved in PAS/SAS monitoring. The most relevant information received is presented in more detail below.

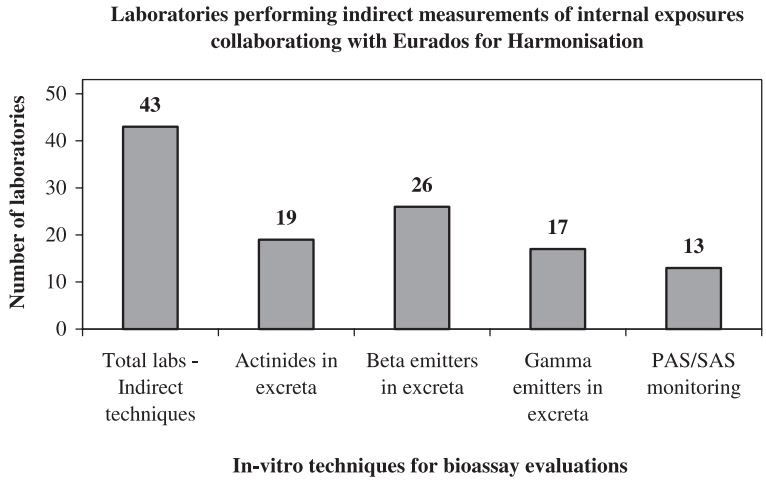

Figure 6. Type of indirect techniques applied for the individual monitoring of European workers.

Indirect measurements of actinides

Table 13 shows the capability of laboratories to perform indirect measurements for the determination of actinides in excreta. Alpha spectrometry is the technique most commonly used by services (14 of the 19 laboratories included in the study), and the ICP/MS measurements (a expensive technique with excellent sensitivity) are available in three facilities. Alternative indirect determinations are carried out using Fluorimetry, phosphorescence laser-induced or KPA for uranium measurements, liquid scintillation counting (LSC) (application to alpha emitters), LABSOC and Waterscintillator, and gamma spectrometry.

A total of 12 laboratories perform indirect evaluation of actinides in both urine and faeces; six services only do urine analysis and one facility only supplied information for the determination of actinides in faeces. One facility measures radionuclides in blood and in other body tissues. Detailed information about sample preparation and measurement procedures is presented in Table 14. Reported MDAs permit comparisons to be made with the sensitivity of the different methods used for the evaluation of actinides in excreta. MDAs obtained by services for urine analysis of 24 h samples, are mostly included in the interval 0.1–0.5 mBq d^{-1}, with the counting time varying from 220,000 to 430,0000 s; other reported MDA are in the range 0.1 (500,000 s)–0.5 (250,000 s) mBq l^{-1} of actinides in urine.

Alpha spectrometry is a sensitive technique requiring a long counting time for the determination of alpha emitters in excreta. No detailed information has been supplied by the three facilities that perform measurements with ICP/MS technique, although it is known that much shorter times are necessary to evaluate radionuclides such as ^{238}U, ^{235}U and ^{232}Th in urine.

An analysis of the data supplied by European facilities performing indirect measurements of actinides in biological samples shows harmonisation in the technique selected for bioassay determinations, with alpha spectrometry using passivated implanted planar silicon (PIPS) detectors being routinely used and in one service a silicon surface barrier. There is also agreement among laboratories relating to the volume of the collected sample for urine and faeces (24 h samples), with normalisation by creatinine content in urine in two facilities. Three-day faecal samples or single-voiding are also alternative to the 24 h collection. With reference to the preparation of the source for measurement, electrodeposition is the procedure selected by most of the laboratories, although there is some lack of information related to the radiochemical actinides separation method applied (extraction chromatography or ion exchange chromatography in some cases). MDA values close to 0.1 mBq d^{-1} are recommended for the determination of actinides in urine.

Pure beta emitters in vitro determinations

A total of 26 radiobioassay laboratories participated in the Eurados action supplying information about *in vitro* determinations of beta emitters in biological samples. LSC (19 facilities) and proportional counters (6 laboratories) are the techniques selected by internal dosimetric services. The more typical radionuclides considered in this type of determinations are ^{3}H and ^{90}Sr; other radioisotopes also evaluated are ^{14}C, ^{32}P, ^{35}S, ^{89}Sr, ^{90}Y, ^{125}I and ^{45}Ca.

Table 13. *In vitro* detection of actinides in European laboratories: techniques and type of sample.

Ref.	Measurement techniques	Urine samples	Urine sample volume	Faecal sample	Faecal aliquots
At-AR	Alpha spectrometry	24 h	Full sample, except for 100 ml	Full voiding	2 g dry ash
Be-SC	Alpha spectrometry	36 or 24 h	All	1–4 d	One-tenth of the sample
Cz-RP	Alpha spectrometry, fluorimetry, gamma spectrometry	24 h not normalised on creatinine	From 0.3 litre up to whole volume	24 h	Routinely the whole sample (1/1)
Ch-PS	Alpha spectrometry	24 h	0.25 litre	24 h	Whole sample ash split into two aliquots
Ch-RA	Alpha spectrometry	24 h	Whole sample (0.5–1.0 litre)	Faecal ash	Whole collected sample
De-FJ	Alpha spectrometry, fluorimetry, ICP-MS	24 h, volume mean value = 1.62 litre	All	24 h	1/3
De-FR	Alpha spectrometry, ICP-MS	24 h, 1.0–2.01; HNO_3 conservation	Alpha spectrometry: complete sample; ICP-MS: 5 ml	24 h	Whole sample
De-SH	Alpha spectrometry, ICP-MS	24 h		24 h	
Es-CI	Alpha spectrometry, KPA(U)	24 h	Whole sample/ corrected for by creatinine, measurement	3 d	
Es-EN	Phosphorescence laser induced	Time, volume	3 ml		
Gb-AW	Alpha spectrometry	Provided at work, normally requires 5–10 d to produce required volume	1 litre, normalised to 24 h using creatinine content	Single voiding	1/5 or 1/10 dependent upon sample size
Gb-RW			1.5 litres (U); 6 litres (Th); 1.5 litres (Pu)	24 h	
Gr-GA	Alpha spectrometry	24 h	24 h. Urine collection ($\sim$1 litre)		
Hr-NM	Gamma spectrometry	24 h urine + creatinine	0.75		
It-EN	Alpha spectrometry	2 litres during the weekend	1000 ml for urine		One-half of the sample
Lt-RP	Alpha spectrometry	24 h	The whole volume of sample		
Ro-RB	Liquid scintillation technique	24 h	0.150		
Se-HU	LABSOC and water Scintillator	24 h	2 litres		
Sk-BO	Dual alpha spectrometry			24 h	The whole volume of 24 h sample

Table 15 gives information on the few services that perform indirect measurements of strontium in faeces; Table 16 presents the sample procedure and radionuclides analysed for the determination of beta activity in urine. Table 17 includes all the information collected of source preparation, measurement procedure and MDA values associated with the evaluation of beta-emitters in excreta.

The information collected from European services that carry out indirect measurements of pure beta-emitters in excreta shows harmonisation in the technique selected for *in vitro* determinations, with LSC being widely used. Proportional counters are also available in some services for beta analysis. With reference to the volume of the collected sample, laboratories agree in the case of measurement of ^{90}Sr in urine (24 h samples), but there is no such harmonisation for the determination of ^{3}H in urine, with volumes varying from 10 ml to 1 litre. The procedures related to the preparation of the source for measurement (radiochemical separation and so on) vary considerably among laboratories. The

Table 14. Indirect techniques and MDA associated with the determination of actinides in excreta.

Ref.	Technique	Procedure	Detector system	Efficiency	Tc (s)	Tbckg (s)	MDA
At-AR	Alpha spectrometry	NdF3 microprecipitation	PIPS 450 mm^2	29%	80,000	250,000	1 mBq
Be-SC	Alpha spectrometry	Electrodeposition	From 450 to 600 mm^2	±39%	250,000	750,000	0.1 mBq per 24 h
Cz-RP	Alpha spectrometry	Electrodeposition	PIPS, 1200 mm^2	0.3	n^*84,000	840,000	0.2/1 mBq-depending on the Tc
	Fluorimetry (U)				$n = 2/8$		0.05 μg d^{-1}
	Gamma spectrometry	Aliquot of faeces	HPGe web	0.68	100,000	350,000	10 mBq per 24 h
Ch-PS	Alpha spectrometry	Electrodeposition	450 mm^2 partially depleted solid-state silicon detectors	31%	250,000	250,000	0.5 mBq l^{-1}
Ch-RA	Alpha spectrometry	Exchange chromatography; AGIXZ, U/TEVA, TRU Eichrom resin	PIPS 450 mm^2	25%	500,000	840,000	0.1 mBq l^{-1}
De-FJ	Alpha spectrometry	Electrodeposition	IPE/IPC/PIPS, $d = 20$ mm	0.26	≥79,200	≥79,200	Typically 0.1 mBq
De-FR	Alpha spectrometry	Liquid–liquid extraction, electrolysis	PIPS detector, Canberra; 900 mm^2	31%	150,000	220,000	0.5 mBq
De-SH	Alpha spectrometry						1 mBq
Es-CI	Alpha spectrometry	Electrodeposition	PIPS 450 mm^2	29%	300,000	300,000	0.1–0.5 mBq per sample
	KPA (U)	KPA					0.05 ug l^{-1}
Es-EN	Phosphorescence laser-induced						0.1 ppB U
Gb-AW	Alpha spectrometry-U	Electrodeposition	Surface barrier 450 mm^2	30%	432,000	>432,000	0.5 mBq d^{-1} total-U
	Alpha spectrometry-Pu	Electrodeposition	Surface barrier 450 mm^2	30%	432,000	>432,000	0.2 mBq d^{-1} Pu in urine, 1.0 mBq d^{-1} Pu in faeces
Gb-RW	Uranium in urine						0.002 Bq d^{-1} (^{234}U, ^{238}U and ^{235}U)
	Thorium in urine						0.0002 Bq (^{232}Th, ^{228}Th)
	Pu in urine						0.0002 Bq d^{-1} (^{238}Pu and $^{239+240}Pu$)
	Pu in faeces						0.002 Bq d^{-1} (^{238}Pu and $^{239+240}Pu$)
Gr-GA	Alpha spectrometry	Electrodeposition (NIST ^{229}Th and ^{232}U tracers)	PIPS (CANBERRA) 600 mm^2	23.16%	>432,000	432,000	50 ng l^{-1} Unat
Hr-NM		Preconcentration of 24 h urine with nitric acid		1%, 180 keV	72,000; 80,000	400,000	80 ng (1 Bq) l^{-1}

Table 14. Continued

Ref.	Technique	Procedure	Detector system	Efficiency	Tc (s)	Tbckg (s)	MDA
It-EN	Alpha spectrometry	Chemical preparation (addiction of a tracer, extraction chromatography, electrodeposition)	PIPS detector; diameter 25 mm	0.33 cps Bq^{-1}	600,000	600,000	0.15 mBq l^{-1} for urine, 0.3 mBq l^{-1} for faeces
Lt-RP	Alpha spectrometry	Electrodeposition on stainless steel planschetts, 18 mm diameter	Tennelec alpha spectrometer	0.324 ± 0.016	Up to 8 d	381,620	0.017 Bq l^{-1} (^{234}U, ^{238}U) 0.01 Bq l^{-1} (^{235}U)
Ro-RB	LSC	Co-precipitation of radionuclides (U,^{241}Am) from 0.150 litre urine with calcium phosphate. The precipitate was solved in HCl 2 N and scintillation liquid was added (recovery 85%)			3600–18,000	18,000	0.7 Bq l^{-1} (27 μg l^{-1} urine)
Se-HU	Alpha spectrometry		PIPS 24 mm	0.20	200,000	400,000	1 Bq l^{-1}
Sk-BO	Alpha spectrometry	Radiochemical Pu separation	Passivated ion implanted silicon junction detector	29%	345,600	432,000	0.2 mBq

Table 15. *In vitro* detection of beta emitters in European laboratories: faecal samples.

Ref.	Techniques	Radionuclides	Faecal sample	Faecal aliquot
At-AR	LSC, proportional counting		Full voiding	2 g dry ash
Cz-TE	LSC, proportional counter	^{90}Sr	24 h samples, minimum of 3 d	Whole sample
De-FJ	LSC	^{90}Sr, ^{89}Sr	24 h samples	1/3
Es-CI	LSC	^{90}Sr	3 d samples	

study of sensitivity of beta analysis (Table 17) shows a wide range of MDA values depending on the radionuclide and the counting time used for the measurement. The determination of tritium in urine with LSC provides MDAs in the interval of 25–250 Bq l^{-1}; lowest MDA reported is 1.2 Bq l^{-1} for a counting time of 100,000 s.

Gamma spectrometry

Information about indirect measurements of gamma emitters in biological samples was collected from 17 bioassay facilities. Tables 18 and 19 report all the data supplied by services, showing harmonisation in the technique selected for bioassay determinations, HPGe detectors being used most frequently in some 14 facilities. Ge(Li) and NaI(Tl) detectors are also employed for gamma measurement techniques. There is agreement between facilities on the volume of urine and faeces being collected, 24-h samples with MDA $\leq$1 Bq for ^{137}Cs, ^{60}Co and ^{131}I. Differences are found in the preparation of the source (in some cases no preparation at all), and in the counting time selected by facilities with resulting MDAs varying from 0.01 to 1 Bq for typical gamma emitters.

PAS/SAS monitoring

A difficulty that arises in the measurement of air samples is the interpretation of the results of concentration of radionuclides in the air, at the location of the sampler, and not necessarily in the breathing zone of the worker. A Personal Air Sampler (PAS) is used to collect a sample representative of the activity concentration in the air inhaled by the worker; this allows an estimate of intake of some typical radionuclides. It is important to know or to make realistic assumptions about the particle size distributions in the inhaled material. ICRP78[8] recommends for a routine monitoring programme with PAS, the detection of annual intakes that in total give rise to committed effective doses greater than one-tenth of the annual dose limit.

Static Air Sampler (SAS) are commonly used to monitor workplace conditions, but can underestimate concentrations in air in the breathing zone of the worker (ICRP 78). SAS devices can also provide useful information on radionuclide composition, and on particle size if used with a size analyser such as a cascade impactor.

A total of 13 European laboratories provided data related to this type of monitoring. UK services agreed to share with Eurados the information supplied to OMINEX Project[9]. Some alpha, beta or gamma-emitters can be evaluated by PAS/SAS measurements, particularly ^{131}I and also uranium, thorium and plutonium isotopes. The results are not always used for individual dose evaluation.

SAS devices are used in eight facilities of the Eurados Group, with five services supplying information about the application of PAS. Tables 20 and 21 show the more relevant features associated to this indirect technique. Different MDA values are obtained in each laboratory depending on the radionuclide and type of monitoring selected.

Assessment of internal doses

The assessment of internal doses following the activity measurements requires a set of dosimetric steps. These include the use of biokinetic models, retention and excretion functions and dose factors. The parameters and tools are established and updated in ICRP publications. In recent years, new recommendations have appeared relating to the evaluation of internal exposures through the use of the ICRP 66 lung model[10], the new annual dose limits (ICRP 60)[11] and the dose factors defined in ICRP 68[12]. All of these have been summarised in ICPR 78 which is for individual monitoring.

ICRP developed a more realistic human respiratory tract model (Publication 66) and has established new dose coefficients, which have been adopted in the revised EURATOM directive. In the assessment of internal doses from the activities of radionuclides obtained after individual monitoring, a set of parameter values must be defined in order to evaluate the intake and the committed effective dose, in each internal exposure; more relevant are the time of intake, the route of intake, AMAD (particle size), radionuclide and chemical form and type of absorption.

Table 16. *In vitro* detection of beta emitters in European laboratories: urine samples.

Ref.	Measurement techniques	Radionuclides in urine	Urine samples	Urine volume
At-AR	LSC, proportional counting	^{3}H, ^{14}C, ^{32}P, ^{35}S, ^{125}I, ^{90}Sr	^{3}H,^{14}C,^{32}P,^{35}S,^{125}I: spot urine ^{90}Sr: 24 h sample	^{3}H, ^{14}C, ^{32}P, ^{35}S, ^{125}I: 2 ml ^{90}Sr: 24 h, 100 ml
Be-SC	LSC ^{3}H (internal standarisation)	^{3}H	24 h samples	3 × 1 ml
Ch-MB	LSC	^{3}H	Weekly urine samples	0.001 litre
Ch-PS	LSC	(1)^{3}H, ^{14}C, ^{32}P, ^{33}P, ^{35}S, ^{45}Ca (2) ^{90}Sr, ^{89}Sr	24 h samples	(1) 2 ml (2) 0.5 litre
Ch-RA	Proportional counting	^{90}Sr	24 h samples. 0.5–1.0 1 litre	0.5 litre
Ch-RA	Direct LSC/Tricarb	^{3}H, ^{14}C, ^{32}P, ^{33}P, ^{35}S, ^{45}Ca	20 ml	0.004 litre
Ch-RC	LSC	^{3}H	One sample per month	0.001 litre
Ch-SU	LSC	^{3}H, ^{14}C, ^{32}P, ^{33}P, ^{35}S, ^{45}Ca	Routine measurements: 20 ml urine samples monthly/quarterly	2 × 1 ml
Cz-RP	LSC, low-level proportionalcounter	^{3}H, ^{90}Sr	^{3}H: volume ^{90}Sr: 24 h samples	^{3}H: 0.004/0.01 litre ^{90}Sr: 0.2 litre/whole portion
Cz-TE	LSC, proportional counter	^{3}H, ^{90}Sr	^{3}H: minimum 10 ml ^{90}Sr: 24 h sample	^{3}H: 0.003 litre ^{90}Sr: whole sample
De-FJ	LSC		^{3}H: spot sample Others: 24 h Mean volume: 1.62 litres	^{90}Sr, ^{89}Sr = 1/3 ^{14}C, ^{32}P, ^{33}P, ^{35}S, ^{99}Tc: 1–5 ml
De-FR	LSC	^{3}H, ^{90}Sr	24 h sample; 1.0–2.01 litres; HNO_3–conservation	^{3}H: 5 ml; ^{90}Sr 500 ml
Dk-RI	LSC	^{3}H	One sample every month ~100 ml	
Es-CI	LSC	^{3}H, ^{14}C, ^{32}P, ^{35}S, ^{90}Sr	Time	Variable
Es-TR	LSC	^{3}H	All urine on 12 h in the night	1 ml
Gb-AW	^{3}H in urine	^{3}H	Weekly samples of 150 ml	0.5 ml
Gb-RW		^{3}H, $^{90}Sr/^{90}Y$		Volume = 1.5 litre
Hr-NM	Beta counting	^{90}Sr	24 h samples + creatinine	0.25 litre
Hu-RR	LSC	^{3}H, ^{14}C	Volume: minimum 1 litre	0.02 litre
Ie-SV		^{32}P, ^{89}Sr	24 h samples	20 cm^3
Lt-RP	Gross beta counter, LSC by Tri-Carb 2770 TR/SL	Gross beta, ^{3}H, $^{90}Sr/^{90}Y$	24 h samples	The whole volume of sample
Nl-RE	LSC	^{3}H	0.1 litre; no normalisation	0.002 litre
No-IE	LSC	^{3}H	Weekly samples during shut down periods, beyond that monthly samples	0.7 ml
Ro-CN	LSC	^{3}H, ^{14}C	Monthly sample (50 ml)	1 ml
Ro-PR	Beta activity measurements with G-M in anticoincidence or plastic detectors	^{90}Sr	24 h samples or creatinine method (minimum three excretions)	Whole quantity
Se-RI	LSC	^{3}H	Single sample	1–20 ml depending on the activity of the sample
Sk-BO	LSC, multi-low-level counting	^{3}H, ^{90}Sr	^{3}H: single sample, ~50 ml ^{90}Sr: 24-h sample	^{3}H: 1 or 20 ml (distillation) ^{90}Sr: 25 ml

Table 17. Indirect techniques and MDA associated with the determination of beta emitters in excreta.

Ref.	Technique	Source preparation	Counting efficency	Counting time	MDA
At-AR	LSC	(^{3}H, ^{14}C, ^{125}I), Sr oxalate	30%	3600 s	0.05 Bq
Be-SC	LSC		25 or 35% depending on the counter	2 × 100 min	0.04 Bq l^{-1}
Cz-RP	LSC ^{3}H		0.16	18,000 s	9 Bq l^{-1}
	^{90}Y β measurement	^{90}Sr oxalate method	0.3	3 × 21,600 s	0.05 Bq per sample
Cz-TE	LSC	Add cocktail and mix	0.2	1200 s	≤100 Bq l^{-1}
	proportional counter	Radiochemical separation	0.52	to reach MDA	0.2 Bq l^{-1}
Ch-MB	LSC	No	15–25 depending on the colour and concentration of the sample	120 s	
Ch-PS	LSC	Extraction chromatography, cocktail preparation	^{3}H: 25% ^{90}Sr: 100%	^{3}H: 2400 s ^{90}Sr: 36,000 s	^{3}H: 400 Bq l^{-1}; ^{90}Sr: 0.05 Bq l^{-1}
Ch-RA	Proportional counting	Exchange chromatography + Y-oxalate precipitation	50%	2 d	20 mBq l^{-1}
		4 ml urine + 18 ml Optiphase Hisafe 2	^{3}H: 0.25; ^{32}P: 0.85 ^{14}C and others: 0.65	3600 s	^{3}H: 50 Bq l^{-1} Others: 25 Bq l^{-1}
Ch-RC	LSC	1 ml urine in 10 ml LSC-cocktail	40%	600 s	
Ch-SU	LSC	1 ml urine + 10 ml scintillation cocktail, two vials per sample	^{3}H: 46%, ^{14}C: 76%, ^{32}P: 88% ^{33}P/^{45}Ca: 74%, ^{35}S: 72%	600 s	^{3}H: 170 Bq l^{-1} ^{14}C: 116 Bq l^{-1} ^{32}P: 95 Bq l^{-1} ^{33}P/^{45}Ca: 118 Bq l^{-1} ^{35}S: 122 Bq l^{-1}
De-FJ	LSC	^{90}Sr–^{89}Sr: mounting of $SrCO_3$ ($Y_2(C_2O_4)_3$)	Typically 0.36	60,000 s	Typically 5 × 10^{-3} Bq
De-FR	LSC; ^{3}H	Filtration, 10 ml cocktail	20%	18,000 s	25 Bq l^{-1}
	LSC; ^{90}Sr	Sulphate precipitation, chromatographic precipitation and carbonate precipitation, Cerenkov measurement	58%	7200 s	0.1 Bq l^{-1}
Dk-RI	LSC	Active charcoal, distillation	70%	1800 s	1000 Bq l^{-1}
Es-CI	LSC	^{90}Sr: chemical separation + liquid scintillation cocktail	Variable: depends on quench	3600 s	Variable
Es-TR	LSC	^{3}H source (1 ml)	0.0382 Bq per cpm	900 s	5 × 10^{-2} Bq g^{-1}
Gb-AW	^{3}H in urine	Sample in liquid scintillation cocktail	~30%	900 s	0.25 Bq ml^{-1}
Gb-RW	^{3}H in urine ^{90}Sr/^{90}Y urine				^{3}H: 100 Bq l^{-1} monthly 0.4 Bq d^{-1}
Hr-NM		Calcium oxalate precipitate	49%	6000 s	0.4 Bq l^{-1}
Hu-RR	LSC	Distillation of urine	0.6	3000 s	0.5 Bq per sample

Table 17. Continued

Ref.	Technique	Source preparation	Counting efficency	Counting time	MDA
Lt-RP	Gross beta counting	Evaporation to dryness, ashing at 400°C, gross beta counting of ash	0.18	1200 s	0.13 Bq per sample
	^{3}H: LSC	Double distillation of urine, mixing with cocktail Insta Fluor LLT, counting by LSC	0.18	6000 s	2.6 Bq l^{-1}
	^{90}Sr /^{90}Y analysis	Evaporation to dryness, ashing at 400°C, separation of ^{90}Y with extraction by HDEHP, Cerenkov counting in water media by LSC	0.54	12,000 s	0.035/0.043 Bq per sample
Nl-RE	LSC	N/A	0.15 (average)	3600 s	80 Bq l^{-1}
No-IE	LSC	Pico Fluor 40	Weekly	900 s	0.4 MBq m^{-3}
Ro-CN	LSC	1 ml sample and 10 ml liquid scintillator	Minimun acceptable: ^{3}H: 58%,^{14}C: 95%	180 s	^{3}H: 113 Bq l^{-1} ^{14}C: 65 Bq l^{-1}
Ro-PR	Radiochemical separation ^{90}Sr	Radiochemical separation with HNO_3 method	0.14–0.18	6000 s (repeated)	0.13 Bq
Se-RI	LSC ^{3}H	None	30%	600 s	35 Bq l^{-1}
Sk-BO		Without special preparation (by intakes up to investigation level); distillation or condensing of samples (by intakes > investigation level)	25–50%	1800 s	97 Bq l^{-1}
Sk-BO		Radiochemical preparation	~33%	100,000 s	1.2 Bq l^{-1}

N/A, not available

Table 18. *In vitro* detection of gamma emitters in European laboratories: type of samples.

Ref.	Samples	Urine samples	Urine volume	Faecal samples	Faecal aliquot
At-AR	U, F	24 h sample	Whole volume of sample	Full voiding	2 g dry ash
Cz-DU	U, F	24 h sample	0.5 litre	24 h sample	Aliquot for 1 d
Cz-RP	U, F	24 h sample	Whole volume of sample	24 h sample	1
Cz-TE	U, F	24 h sample, minimum 3 d	0.5 litre	24 h sample, minimum 3 d	0.25 litre
Dk-RI	U	Not routine	100 ml		
Gb-AW	U, F				
Hr-NM	U, F	24 h urine sample + creatinine	0.75 litre		
It-AG	U	24 h sample	130 ml		
It-BU	U	Collection of 100 ml of urine at the end of the working day. In case of positive result, collection of 24 h urine. The frequency of sampling is daily for $^{99}Tc^{m}$, weekly for other isotopes	100 ml, 1 litre		
It-EN	U	Collection of whole urine excretion in 4 d working shifts	1000 ml		
It-ON	U	One excretion once a week (Thursday) at about 10:00 am, no creatinine, standard daily volume considered	0.1 litre		
Lt-RP	U	24 h sample	Whole volume of sample		
Ro-CN	U	24 h sample	1 litre		
Ro-PG	U	24 h sample	0.1 litre		
Se-OK	Lung tissue (*in vitro*)				
Se-RI	U	24 h sample		24 h sample, ~5 d	
Si-OS	Foodstuff, fodder				
Sk-BO	U, F	24 h sample	0.5 litre	24 h sample	Whole volume of 24 h sample

U, urine and F, faeces.

It is important that the doses received by workers travelling and working in different facilities be assessed in a similar way by each internal dosimetric services. Information about reference levels (annual dose limit, lowest reporting dose and investigation level) was collected from the answers of Eurados questionnaire Q2 in each country and are listed in Table 22. The existence or not of a national record of doses is also reported. An important point to focus on is the software and dosimetric tools used in each service to evaluate internal doses and the assumption of AMAD considered together with the lung model (ICRP 30/ICRP 66), the dose factors (ICRP 26/ICRP 68) and the type of individual monitoring programmes (ICRP 54/ICRP 78).

The information provided by the 26 participating countries indicates that 60% have implemented an annual dose limit of 20 mSv for internal exposures. The remaining 40% applied a limit of 100 mSv in 5 y or 20 mSv y^{-1} during 5 y with a maximum dose of 50 mSv y^{-1} in this period. Out of the 24 countries, 14 included in Table 22, have or will have a National Record of Doses.

Software available to European services for dose assessments include IMBA, LUDEP, IMIE, Mondal/Moldes, MIRD, INDAC, Cindy, Remedy and Retex. It is important to note that not all of them include the latest ICRP recommendations implemented in the EU directive. It is clear that computer software supports the best estimate of intakes and the resultant committed effective dose, but they must be appropriate to the application. One of the more important conclusions of the Eurados study is the need for harmonisation in the evaluation process of internal exposures after the direct/indirect measurement of the retained/excreted activity of the radionuclide of interest.

Table 19. Indirect techniques and MDA associated with the determination of gamma emitters in excreta.

Ref.	Source preparation	Detector system	Counting efficiency	Tc (s)	MDA
At-AR	Urine: Marinelli beaker 1.01	HPGe, 30%	0.0055 (^{60}Co) 0.00905 (^{137}Cs)	1000–200,000	0.081, 0.060
Cz-DU	Without source preparation	HPGe (48 mm diameter, 43 mm length, distance from windows 5 mm)	3.71E−3 (^{137}Cs) 1.99E−3 (^{60}Co, 1333 keV)	3600	0.1 Bq l^{-1} ^{60}Co
Cz-RP	^{137}Cs sorption on a selective composite sorbent	8 HPGe detectors from 10 to 110% of relative efficiency	From 0.02 to 0.08	350,000	0.01 Bq (detector of relative efficiency = 110%)
Cz-TE	^{241}Am weighing of an aliquot of faecal ash into a test tube	HPGe weel-type detector	0.68	100,000	10 mBq per daily excretion
Dk-RI	No	HPGe (62 × 62 mm^2)	40%	To reach MDA	0.1 Bq l^{-1}
Gb-AW	Urine in Marinelli beaker Faecal: HF/HNO_3 digestion	HPGe HPGe	0.5% ^{60}Co 0.9% ^{137}Cs 2.6% ^{241}Am	50,000 50,000 50,000	0.04 Bq ^{60}Co 0.06 Bq ^{137}Cs 0.2 Bq ^{241}Am
Hr-NM		Ge, 30–40%			
It-AG	No source preparation	HPGe diameter 46.5 mm, length 49.5 mm	17.1% (^{60}Co, 1332 keV)	72,000, 80,000	0.01 Bq ^{60}Co
It-BU		NaI(Tl) 3 inch	7%	3600	<1 Bq
It-EN		GeLi 2 inch	2%	3600	<1 Bq
It-ON	Check on the sample volume, check on integrity of the vial	P-type intrinsic coaxial HPGe, diameter 52 mm, length 44 mm, volume 80 cm^3	^{137}Cs (661.6 keV): Marinelli 1 litre: 0.531; 100 ml vial: 0.853	60,000	Marinelli: 0.2 Bq l^{-1} ^{131}I; 100 ml vial: 1 Bq l^{-1} ^{131}I
Lt-RP	No preparation	HPGe (20% efficiency)		60,000	0.5 Bq l^{-1} of ^{137}Cs
Ro-CN	N/A	HPGe diameter 54.0 mm, 41 mm length	20%: ^{60}Co, 1.33 MeV	43,200	1 Bq ^{60}Co 0.78 Bq ^{137}Cs
Ro-PG	Fresh urine counting and counting of residue after evaporation to 50 ml volume, cylindrical counting geometry	HPGe detector, OXFORD 55.5 mm diameter, 55.3 mm h; CANBERRA HPGe detector 55 mm diameter, 41.5 mm h	0.017 (^{137}Cs)	300,000 maximum	0.1 Bq kg^{-1} ^{137}Cs
Se-OK	N/A	HPGe diameter 54.0 mm, length 41 mm	20%: ^{60}Co, 1.33 MeV	43,200	1 Bq ^{60}Co 0.78 Bq ^{137}Cs
Se-RI	Analysed as received	Ge(Li) coaxial, 43 × 37 mm^2	^{131}I: 0.0097 (364 keV) ^{137}Cs: 0.0044	60,000	0.6 Bq ^{131}I 0.9 Bq ^{137}Cs
Sk-BO	None	HPGe (17–38%, five different detectors)	7E−3 absolute	Depend on the sample activity	35 Bq; Tc = 300s

N/A, not available

Table 20. PAS/SAS monitoring in European facilities.

Ref.	Technique	Radionuclides	Type of sample
Cz-DU	SAS, monitoring with natural radioactivity compensation	Alpha and beta emitters	Aerosol filters 50 and 100 mm
Cz-RP	Gamma spectrometry of the filters	Gamma emitters	Aerosol filter, charcoal cartridge
De-SH	SAS	^{241}Am and alpha-emitting nuclides of U and Pu	Alpha-activity deposited on filters
Ee-AS	Sampling on filter and measurement of total alpha activity	Sum long-lived alpha emitters	Filter
Es-EN	SAS	^{238}U, ^{235}U	AMAD = 5 μm
Es-TR	Air sampling (static and moving)	^{131}I, ^{58}Co, ^{60}Co, ^{54}Mn, ^{124}Sb, ^{51}Cr, ^{59}Fe	Charcoal and paper filters
Gb-AW	PAS	Alpha emitters	Glass fibre filter
	SAS	Alpha and beta emitters	Glass fibre filter and cellulose filters
Gb-RR	SAS, PAS	Uranium (^{238}U, ^{235}U and ^{234}U)	Roteroe Mitchell Bird and Tole (SAS)
Gb-RW	PAS (gross alpha)	Uranium	
	PAS (thorium) (gross alpha)	Thorium (^{232}Th, ^{228}Th)	
	PAS (plutonium) (gross alpha)	^{238}Pu, $^{239+240}$Pu	
It-BU	Air pump in working rooms, time of sampling: 1 h	^{131}I	Active charcoal cartridge for gas, paper filter on cartridge for particulate
Lt-RP	SAS	^{131}I	Aerosols
Se-HU	EDGAR		
Si-KR	SAS	Gamma emitters	Glass fibre filter, charcoal filter

Application of ICPR publications varies greatly among facilities, for instance, in relation to the lung model (ICRP 30/ICRP 66), the dose factors (ICRP 26/ICRP 68) and the type of individual monitoring programmes (ICRP 54/ICRP 78). In some cases a combination (mixing new and old recommendations) is used in the software for internal dose calculations. Other parameters affecting dose calculations, such as the AMAD of particles, were also studied in the Eurados action. The results show that an AMAD of 5 μm is selected in 50% of the countries participating in the study, with values ranging from 1 to 10 μm.

Using the guidance of the IAEA safety guide No. RS-G-1.2[13], the application of reference levels associated with monitoring workers with risk of internal exposures was analysed in different European countries. Investigation levels and recording levels, expressed as an appropriate fraction of the committed effective dose E_{50} limit, are of relevance to monitoring for internal contamination in the case of occupational intakes of radionuclides. Eurados harmonisation action collected information about the lowest reported dose and the investigation level established in each country. The results are presented in Table 22. In some instances different answers were reported by facilities of the same country.

The lowest reporting level applied in internal dosimetric services in Europe are presented in Figure 7. This value is the level above which the calculated dose is entered in the individual exposure record of the worker. Approximately 50% of the services use recording levels in the interval 0.1–0.3 mSv. A total of five laboratories report any estimation of dose (from measured Activity >AMD), five countries use 1 mSv as a recording level and the remaining five prefer a lower reference level of 0.01 mSv.

Figure 8 shows the investigation level employed by different European countries, when dealing with individual monitoring of workers for internal occupational exposures. Three distinct groups emerge from the data: eight countries apply investigation levels in the interval 0.1–0.3 mSv, seven countries reported values of 1–2 mSv and five selected 5–6 mSv as investigation level.

The extensive information obtained from this section of the Eurados study (Table 22) yields an overview of the status of evaluation processes for internal doses in European services. A further harmonisation action in this matter is recommended which would investigate in detail dosimetric tools, training activities and availability of qualified experts in each laboratory for the optimisation of procedures involving intake and dose estimations.

Table 21. Indirect techniques and MDA associated with PAS/SAS Monitoring in European facilities.

Ref.	Technique	Air flow	Respirable fraction	MDA
Cz-DU	SAS, monitoring with natural radioactivity compensation	Gas-flow meter	Total	Alpha: 30–300 Bq; beta: 100–1000 Bq on filter
Cz-RP	Gamma spectrometry of the filters	30–120 $m^3\ h^{-1}$ (SAS including six stages cascade impactor)	Total (respirable fraction by using cascade impactor)	
De-SH	SAS sampling on filter and measurement total alpha activity	10–12 $m^3\ h^{-1}$	Total	2.50 mBq m^{-3}
Ee-AS	SAS	High-volume–air-sampler, vacuum system, other	Total	5.00 mBq m^{-3}
Es-EN	Air sampling (static and moving)	1.2 $m^3\ h^{-1}$	Total	0.10 Bq
Es-TR	Air pump in working rooms, time of sampling: 1 h	50 l min^{-1}	~0.01%	~0.10 Bq m^{-3}
Gb-AW	PAS	2 l min^{-1}	Total fraction	5.00 mBq
	SAS	50 l min^{-1}	Total fraction	1.80 mBq
Gb-RR	PAS (uranium) (gross alpha)	Flow rate = 2 l min^{-1}	Total fraction; breathing rate = 1.2 $m^3\ h^{-1}$	0.02 Bq total uranium
	PAS (thorium) (gross alpha)	Flow rate = 2 l min^{-1}	Total fraction; breathing rate = 1.2 $m^3\ h^{-1}$	0.02 Bq ^{232}Th; 0.02 Bq ^{228}Th
	PAS (plutonium) (gross alpha)	Flow rate = 2 l min^{-1}	Total fraction; breathing rate = 1.2 $m^3\ h^{-1}$	0.02 Bq (Pu-alpha)
It-BU	SAS	25 l min^{-1}	Fraction	1.05 Bq m^{-3}
Lt-RP	EDGAR	50 l min^{-1}	Total	0.10 Bq per filter
Se-HU	SAS			
Si-KR	PAS			

Legal aspects and quality assurance

Information relating to the status of implementation of Council Directive 96/29, regulatory bodies and the legal requirements to be met by internal dosimetric services were collected for each European country. As an objective is harmonisation of requirements and procedures in this area, focus should be placed on the following points:

(1) Status of implementation of Council Directive 96/29 in European countries.
(2) Current status within European states of requirements for approved internal dosimetric services:
   (a) National regulatory body: procedures to be undertaken to achieve the status of an approved internal dosimetric service.
   (b) National legislation, technical guidelines, official protocols and so on.
   (c) Procedures to demonstrate compliance with regulatory requirements.
(3) International recommendations and guidelines to take into account: ICRP publications, ISO and ANSI standards, IAEA safety series and so on.
(4) Quality assurance and quality control procedures: the participation of internal dosimetric services in exercises of intercomparison of measurements and dose assessments are highly recommended.

The previous report on 'Implementation of standards' (E. Fantuzzi *et al.*) in this publication, shows a reference of documents, standards and recommendations established at an international level, to be applied in internal dosimetry facilities; the objective is to provide each service of appropriate equipments and procedures, with a quality assurance programme that guarantees the reliability in the results of measurements.

The extensive information related to legal aspects of internal dosimetric services in Europe was summarised and is presented in Table 23, providing an overview of how European countries are responding

Table 22. Reference levels, dosimetric tools and ICRP application for internal dose assessments.

Country	Annual dose limit	Lowest reporting dose	Investigation level	National record	Software	AMAD	ICRP application
AT	Occupation: 20 mSv Public: 1 mSv	0 mSv	0.17 mSv	No	Retex	10 μm	ICRP 66/68/54
BE	20 mSv			No	Ludep, IMIE, IMBA	5 μm	ICRP 66/68/78
BG	20 mSv	0.10 mSv	2 mSv	No	Dose Art, Ludep	5 μm	ICRP 66/68
CH	Occupation: 20 mSv Public: 1 mSv	0.1 mSv	2 mSv	Yes		5 μm	ICRP 30/54 ICRP 68/78
CS	20 mSv	10% of ADL		Yes			ICRP 66/68/78
CZ*	50 mSv in 1 y 100 mSv over 5 y	0.1 mSv >MDA 100 Bq–dose according to the nuclides	6 mSv 0.1 ALI 0.2 mSv 200–300 Bq Dose according to nuclides	Yes	Ludep, CINDY ISOD (VF Cerna hora) Nuclear Interprisec, NRX	1, 5 μm, others Conservative: the worst case	ICRP 68/78 ICRP 30/54
DE*	20 mSv 300 mSv Thyroid	0 mSv 0.01 mSv 1 mSv	1 mSv 6 mSv 30% critorg 30% ALD	Yes	Ludep, IMIE, MIRD, Retex, INKOR	1 μm 5 μm	ICRP 30/26/54 ICRP 66/68/78
EE		0.3 mSv: for working place					ICRP 68
ES	100 mSv per 5 y Maximum 50 mSv y^{-1}	1 mSv y^{-1}	1 mSv y^{-1}	Yes	INDAC IMIE, IMBA	5 μm	ICRP 66/68/78
GB*	20 mSv	0.01 mSv 0.1 mSv 1 mSv	0.1 mSv	Yes	IMBA	ICRP defaults or user-derived	ICRP 66/68/78
GR	20 mSv y^{-1} for 5 y Maximum 50 mSv y^{-1}	1 mSv y^{-1}		In progress	Ludep	5 μm, others	ICRP 30/54 ICRP 66
HR	20 mSv y^{-1} for 5 y maximum 50 mSv y^{-1}				AbacosII, MIRD Mondal/Mondes, Remedy, Cindy		ICRP 30/54 ICRP 66/68
HU	20 mSv y^{-1} 100 mSv per 5 y	0.1 mSv	6 mSv	In progress	Mondal/Mondes	5 μm	ICRP 78
IE	20 mSv: category A 6 mSv: category B	>MDA	1 mSv	Yes	Abacos II		ICRP 30/26
IT*	20 mSv 1 mSv	0.05 mSv 0.15 mSv	0.1 mSv 2 mSv	No		1, 5 μm	ICRP 66/68/78 ICRP 66/26/54
Lithuania	20 mSv y^{-1} 100 mSv per 5 y^{-1}	1 mSv y^{-1}	5 mSv y^{-1}	Yes	Ludep, IMBA	1, 5 μm	ICRP 66/68/78

Table 22. Continued

Country	Annual dose limit	Lowest reporting dose	Investigation level	National record	Software	AMAD	ICRP application
NL	20 mSv	0.0002 mSv	N/A	No	Only activity is reported	N/A	N/A
NO	20 mSv	0.1 mSv	0.1 mSv	No	Ludep	5 μm	ICRP 66/26/54
PT	50 mSv under revision				Ludep Mondal/Mondes,	5 μm	ICRP 66/68/54
RO*	20 mSv	0.2 mSv	1 mSv	No	Self-developed	5 μm	ICRP 30/54
		^{40}Knat radiation		Yes	Ludep		ICRP 66/54
SE*	20 mSv y^{-1} 100 mSv per 5 y Maximum 50 mSv y^{-1}	0.25 mSv	>0.25 mSv action	Yes	Abacos (Directive 96/29) Nuclear data (ICRP 30)	5 μm (default value)	ICRP 30/68/54 ICRP 66/68/78
SI*	Occupation: 20 mSv Public: 1 mSv	0 mSv	1.6 mSv	Yes, at the moment only doses due to radon	Cindy Ludep, NRPB-SR245 ECRS (Rn software)	1 μm	ICRP 30/26/54 ICRP 66/68/78
	0.2 mSv	0.01 mSv	0.2 mSv	No	Ludep	1 μm: routine 5 μm: investing	ICRP 66
SK	20 mSv	0.1 mSv	6 mSv	2 mSv	Ludep	5 μm	ICRP 66/68/78
UA		0.01 mSv	0.01–150 mSv	Yes	Self-developed	1–10 μm	ICRP 30/68/54

Abbreviations: ADL, annual dose limit; ALI, annual limit of intake; Critorg, dose limit of the critical organ; MDA, minimum detectable activity; and N/A, not available.
*Different data from different services.

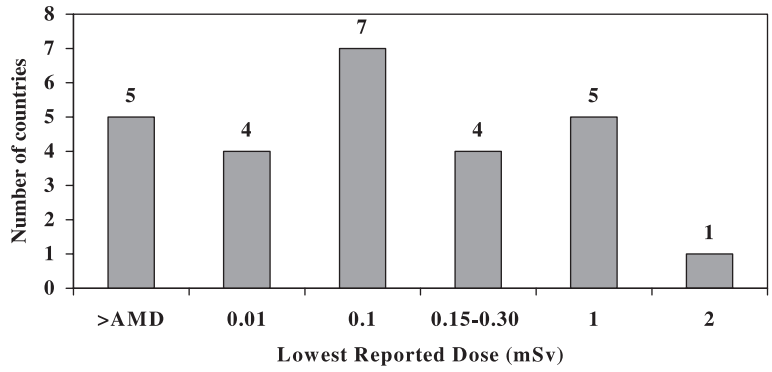

Figure 7. Lowest reported dose associated with the monitoring of internal exposures in Europe.

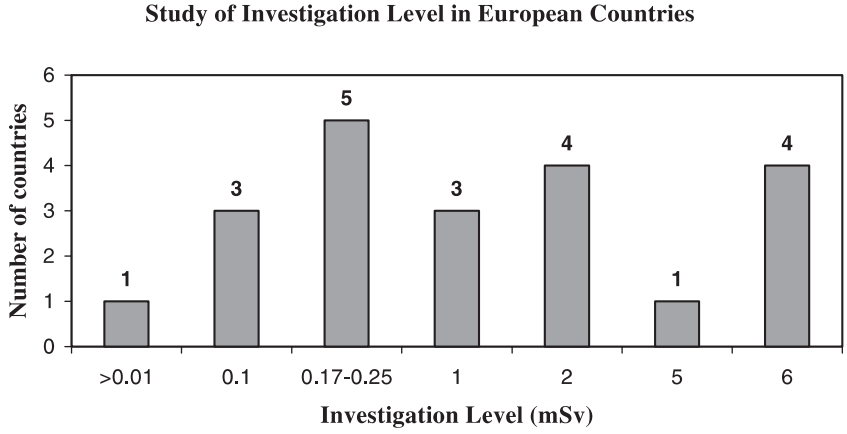

Figure 8. Investigation level associated with the monitoring of internal exposures in Europe.

to this issue. As first conclusion, the almost general implementation of the Council Directive 96/29 in the group of 26 countries collaborating with Eurados for harmonisation.

INVENTORY FOR EACH MEMBER STATE

A network of experts involved in dosimetry from 26 countries collaborated with Eurados. The information collected gives a good overview of the status of internal dosimetry in Europe in 2001. The contact persons, in each country, took responsibility for distributing the questionnaire Q2 among laboratories undertaking internal dosimetry. The answers yielded an overview of services, methods, type of exposures and national regulation. The coordinators in each country supplied other relevant information such as the number of approved services, total number of facilities and a list of other services (in case not all collaborated with Eurados). A summary of the facilities in each European country performing internal dosimetry is presented as follows.

Austria (AT)

Austria is a European member state with five approved internal dosimetric services. ARC Seibersdorf Research Centre and Graz University Medical Centre collaborated with Eurados (Table 24). They outlined the methods used to evaluate the different types of internal exposures: research, decommissioning, medical field, non-nuclear industry and waste conditioning management. Both services use direct techniques to measure gamma-emitters in the whole-body and radioiodine in the thyroid. ARC also performs *in vivo* measurements for actinides in the lungs and can perform

Table 23. Implementation of Council Directive 96/29, and legal aspects by country.

Country	Implementation 96/29 Directive	Regulatory body	Legal requirements
AT	Yes, 2002	Ministry of Agriculture, Forestry, Environmental and water	100% European Directive
BG	Yes, 2000	BNSA Ministry of Health Nuclear Regulatory Agency (NRA)	
CH	Yes	Federal Office of Public Health (BAG) Federal Nuclear Safety Inspectorate (HSK)	Radiological protection law (1991) and ordinance (1994), personal dosimetry ordinance (1999)
CS	Yes, BSS is implemented	Federal Ministry of Health	Occupationally exposed to open sources shall be subjected to internal dose monitoring programme
CZ	Yes	State Office for Nuclear Safety SÚJE Praha	Licence issued by the Regulatory Body according to the relevant legal act
DE	Yes, 2001	Federal and state authorities Strahlenschutzverordnung StrlSchV	Radiation Protection Ordinance Guideline on health physics for the determination of body doses General calculation basis for the determination of body doses caused by internal radiation exposure Accreditation by state government
DK	Yes	NIRH (SIS)	
EE	Radiation Act (1997) and regulations of Government and Ministers	Radiation Protection Centre	Radiation Act (1997) as amended Government Regulation 37 'Statute of the National Dose Register of Radiation Workeers; Procedure for Certifying Radiation Workers and Issuing Certificates' Regulation of the Minister of the Environment No. 49 'Inhalation and Ingestion Dose Coefficients for Radiation Workers' (1999)
ES	Yes, 2001	CSN (Nuclear Safety Council)	Guidelines established in the CSN Guide 7.1 (GSG- 07.01, 1985) published by the Spanish Regulatory Body: 'Guía de Seguridad 7.1. del Consejo de Seguridad Nuclear: Requisitos técnico administrativos para los Servicios de Dosimetría Personal Individual'. Ref: ISBN 84-87275-46-X
GB	Yes, 2000	Health and Safety Executive	Ionising Radiations Regulations, 1999
GR	Yes	Greek Atomic Energy Commision	
HU	Yes	Ministry of Health	In case incorporation could occur, procedures are published in methodological letters by NRIRR in co-operation with the competent professional board Appropriate dosimetric surveillance shall be provided by the licensee, in accordance with the approved Workplace RPR. The laboratory performing the monitoring of internal exposure shall be accredited

Table 23. Continued.

Country	Implementation 96/29 Directive	Regulatory Body	Legal requirements
			For the purposes of the central registry the results beta, neutron, and internal dosimetric investigations shall be communicated to the NRIRR with a frequency prescribed for the given workplace
IE	SI 125 of 2000	Radiological Protection Institute of Ireland	Demonstrate compliance with dose limits
IT*	Yes, but in dosimetric services not yet	Decreto Legislativo n. 230/95, modified by D.L. n. 241/00 and by D.L. n. 187/00. All of them are implementation of EU Directive ANPA	The requirements are still not well specified by the current laws Legal requirements in progress
LT	Yes, BSS is implemented	Ministry of Health, Radiation Protection Centre	100% European Directive
NL	Yes, 2002	Ministry of Social Affairs and Employment	No specific requirements
NO	No	NRPA	FOR 2003-11-21 no. 1362: 'Forskrift om stralevern og bruk straling'
PT	Under Implementation	Not available	
RO	Yes, 2000	CNCAN	ICRP 60 and IAEA- BSS-115 application Fundamental norms for radiological security published in Romanian Official Monitor no. 404 bis/2000
SE	Yes, 1998	Swedish Radiation Protection Authority (SSI)	Fullfil stipulated (SSI FS 1998: 5/2000:10) control program defined by three categories, group of reference—group with work giving higher risk for intake—incidents with known intake Dose assessment, effective dose (E_{50}) using dose coefficients from 96/29/EURATOM Appendix III, according to intake type (inhalation/ingestion) Report to National Dose Register if $E_{50} \geq 1$ mSv. If $E_{50} \geq 5$ mSv full incident report immediately to SSI WBC shall be performed according to a documented procedure that is approved by the SSI (SSI 2000:10)
SI	Yes	Ministry of Health, Slovenian Radiation Protection Administration (SRPA)	Radiation Protection and Nuclear Safety Act (O.J. RS No. 50/2003, 46/2004) and underlying legislation. Prior the issuing a license the assessment of internal exposure as well as a monitoring programme are prepared. The assessment and the programme are subjects of a consultation with an approved expert and should finally be approved by the SRPA. The internal exposure monitoring programme become a part of a licensing conditions

*Different data from different services

Table 24. Internal dosimetric services in Austria (AT) collaborating with Eurados.

Facility	Exposure	Direct techniques	Indirect techniques
ARC Seibersdorf Research GmbH	Research, decommissioning, medical field, non-nuclear industry, waste conditioning management	WBC, lung counting, thyroid counting	Spectrometry for urine and faeces (alpha spectrometry and LSC)
Prüfstelle für Strahlenschutz, Landeskrankenhaus-Universitätsklinikum Graz	Research, medical field, non-nuclear industry	WBC, thyroid counting	—

Table 25. Other internal dosimetric services in Austria (AT).

Country	Facility
Austria	SMZ Ost Allgemeines Krankenhaus der Stadt Wien Universitätsklinikum Innsbruck

Table 26. Internal dosimetric services in Belgium (BE).

Facility	Exposure	Direct techniques	Indirect techniques
SCK–CEN Mol	NFC, Research	WBC, lung counting, wound counting	Alpha spectrometry, LSC

bioassay evaluations using spectrometry on urine and faeces samples. Alpha spectrometry is used for actinides, while LSC is used for beta emitters.

Three other internal dosimetric laboratories operate in Austria. They are small services, situated in hospitals, and only monitor personnel in their nuclear medicine departments (Table 25).

Belgium (BE)

SCK–CEN Mol is an important research centre in Belgium with a great reputation in the field of Internal Dosimetry (Table 26). This institute evaluates internal doses using *in vivo* and *in vitro* measurements. In Belgium the risk of internal exposure comes from the nuclear fuel cycle workplace and research activities. Gamma emitters are detected using whole-body counting. The assessment of actinides is carried out using results from lung counting and alpha spectrometry (bioassay). LSC is used to assess beta exposures. As there is no national requirement for approval, the SCK–CEN Mol laboratory is not a legally approved internal dosimetric service. Of particular interest here is the methodology that has been developed for the evaluation of accidental contamination of a wound by radionuclides.

Table 27. Internal dosimetric services in Bulgaria (BG) collaborating with Eurados.

Facility	Exposure	Direct techniques	Indirect techniques
Kozloduy NPP	NPP	WBC, lung counting	—

Table 28. Other internal dosimetric services in Bulgaria (BG).

Country	Facility
Bulgaria	National Centre of Radiobiology and Radiation Protection Laboratory (Ministry of Health) Military Medical Academy (Military Hospital) in Sofia

Bulgaria (BG)

Bulgaria is an eastern European country collaborating with Eurados (Tables 27 and 28). There are three legally approved internal dosimetric services in Bulgaria. The department of individual dosimetry at the Kozlodui Nuclear Power Plant in Bulgaria is well equipped with three WBCs. This plant answered questionnaire Q2 (internal dosimetry) and indicated that exposed workers at risk of internal exposures are monitored using whole-body counting and lung counting for actinides. Indirect techniques are not used for the assessment of internal doses.

The national regulatory body in Bulgaria is the Nuclear Regulatory Agency (NRA). As metrology is regulated and well organised, metrology certification plays the role of accreditation.

Switzerland (CH)

Seven internal dosimetric services are legally approved in Switzerland. All of them supplied data on techniques and procedures, explaining that laboratories deal with internal exposures in research workplaces, medical field and non-nuclear industry. Direct (whole-body and thyroid counting) and indirect techniques are available for the measurements of radionuclides and the assessment of effective doses (Table 29).

Serbia and Montenegro (CS)

Two Internal dosimetric services are legally approved in the former Yugoslavia (Table 30). They are involved in the evaluation of doses in the medical and research fields and non-nuclear industries. Direct and indirect techniques are available to determine internal exposures. Special attention is given to the doses associated with military applications using depleted uranium.

Czech Republic (CZ)

There are four Internal dosimetric services in the Czech Republic. All facilities are legally approved and collaborated with Eurados (Table 31). Direct and indirect techniques are available for the assessment of effective doses coming from all types of internal exposures from NPPs, nuclear fuel cycle,

Table 29. Internal dosimetric services in Switzerland (CH).

Facility	Exposure	Direct techniques	Indirect techniques
PSI–Paul Scherrer Institute	Research	WBC, thyroid counting	LSC, spectrometry for urine and faeces
Institut Universitaire de Radiophysique Appliquée	Research, medical field, non-nuclear industry	Thyroid counting	LSC, alpha spectrometry, proportional counting
BKW FMB Energie AG	NPP	WBC	—
RC Tritec Ltd	Research	—	LSC of urine samples
Suva (Swiss National Accident Insurance Fund)	Non-nuclear industry	—	Urine measurements
mb-microtec ag	Industry (tritium)	—	LSC
Whole body counter University Hospital Basel	Medical field	WBC	—

Table 30. Internal dosimetric services in Serbia and Montenegro (CS).

Facility	Exposure	Direct techniques	Indirect techniques
Institute of Occupational Health, Belgrade	Medical field	—	Spectrometry for urine
Institute of Nuclear Sciences Vinca	Research, medical field, non-nuclear industry, military application of DU	WBC, lung counting, thyroid counting	Alpha and gamma spectrometry, ^{3}H measurements

Table 31. Internal dosimetric services in Czech Republic (CZ).

Facility	Exposure	Direct techniques	Indirect techniques
National Radiation Protection Institute	NPP, research, medical field, decommissioning, non-nuclear industry, others	WBC, skull counting	Alpha and gamma spectrometry, LSC, low-level beta, fluorimetry
Personal Dosimetry Service–Temelin	NPP	WBC, thyroid counting	Gamma spectrometry (urine, faeces), LSC (urine), proportional counter (^{90}Sr)
Nuclear Research Institute Rez	Research, medical field	WBC, thyroid counting	—
Dukovany Nuclear Power Plant	NPP, NFC	WBC, thyroid counting	Gamma spectrometry (urine, faeces)

Table 32. Internal dosimetric services in Germany (DE) collaborating with Eurados.

Facility	Exposure	Direct techniques	Indirect techniques
Universitätsklinikum Essen-Klinik fuer Nuklearmedizin	Medical field	WBC, thyroid detector	Spectrometry ICP-MS
A.K. St Georg Abteilung für Nuklearmedizin, Hambourg	Medical field	^{131}I in thyroid	Spectrometry for urine and faeces
Landesanstalt für Umweltschutz Baden-Württemberg, Karlsruhe		WBC	—
Bundesamt für Strahlenschutz (BfS)	Fission and activation products, ^{125}I	WBC, thyroid detector	—
Framatome ANP GmbH, Erlangen	Decommissioning	—	—
Siemens AG, Power Generation, DP Hanau	NPP, decommissioning	WBC, lung counting (+other organs, wound counting)	—
Forschungszentrum, Jülich, Inkorporationsmessstelle, Jülich	NPP, NFC, research, medical field, decommissioning, non-nuclear industry	WBC, thyroid detector	Alpha spectrometry, ICP-MS
Forschungszentrum Karlsruhe, Inkorporationsmessstelle, Karlsruhe	NPP, NFC, research, medical field, decommissioning, non-nuclear industry	WBC, lung counting, thyroid counting	Alpha spectrometry, ICP-MS

research, medical field, decommissioning and non-nuclear industries. Special attention was given to the evaluation of actinides in the skull with a methodology being developed at the National Radiation Protection Institute in Prague.

Germany (DE)

Twenty-five services are involved in the assessment of internal exposures employing both direct and indirect techniques. Eight laboratories answered questionnaire 2, and the information related to monitoring programmes and techniques is shown in Table 32.

Laboratories receive their authorisation to carry out measurements from local government. Other internal dosimetric services in Germany (not participating) are presented in Table 33.

Denmark (DK)

This Scandinavian country has no legally approved internal dosimetric services, but the Riso national laboratory performs *in vivo* and *in vitro* measurements of exposed workers involved in research activities, decommissioning and non-nuclear industries (Table 34).

Estonia (EE)

There is no legal requirement to be an approved service. One laboratory evaluates internal doses using SASs in workplaces that are processing raw materials containing natural uranium and natural thorium (Table 35). Measurements of total activity of long-lived alpha emitters in the air are made at AS Ecosil. This facility provides a measurement service for the factory of Silmet. The internal doses of the factory workers are estimated on the basis of the SAS results.

Spain (ES)

There are nine internal dosimetric services legally approved by the Nuclear Safety Council (national regulatory body) to perform the official evaluation of internal doses in Spain (Table 36). Eight services are dealing with exposures in NPPs (operatives or in phase of decommissioning) carrying out *in vivo* measurements of gamma-emitters deposited in the body.

CIEMAT is a research centre with two of its laboratories being responsible for using direct and indirect techniques to assess internal doses. The CIEMAT internal dosimetric service is the only place in Spain which performs measurements of actinides in lungs and in bone and where bioassay determinations can be carried out. Workers involved in the fabrication of nuclear fuel elements for NPPs are routinely monitored at CIEMAT with LEGe detectors for the measurement of 3.6% enriched uranium in lungs. The fabrication facility is authorised to perform indirect determinations of uranium in urine (Phosphorescence laser induced technique) and uranium in SASs.

Table 33. Other internal dosimetric services in Germany (DE).

Country	Facility
Germany	Freie Universität Berlin, Inkorporationsmessstelle, Berlin Universität Tübingen, Strahlenschutzbereich UKT, Tübingen Bayerisches Landesamt für Umweltschutz, Kulmbach Justus-Liebig-Universität Gießen, Landesmessstelle, Gießen Universität Hamburg, Abteilung für Nuklearmedizin, Hamburg Medizinische Hochschule Hannover, Landesmessstelle, Hannover Landesanstalt für Arbeitsschutz, Düsseldorf Klinikum der Universität zu Köln, Inkorporationsmessstelle, Köln Universität Münster, Klinik und Poliklinik für Nuklearmedizin, Münster Bayer AG, Metabolismus und Isotopenchemie, Wuppertal RWTH Aachen, Abteilung Strahlenschutz, Aachen Klinikum der Johannes-Gutenberg-Universität Mainz, Inkorporationsmessstelle, Mainz Johannes-Gutenberg-Universität Mainz, Institut für Kernchemie, Mainz Landesamt für Umweltschutz und Gewerbeaufsicht, Oppenheim E.ON Kernkraft GmbH, Messstelle Inkorporation, Brokdorf Kernkraftwerk Krümmel GmbH, Inkorporationsmessstelle, Geesthacht VKTA Rossendorf e.V., Inkorporationsmessstelle, Dresden

Table 34. Internal dosimetric services in Denmark (DK).

Facility	Exposure	Direct techniques	Indirect techniques
Applied Health Physics, Riso National Laboratory	Research, decommissioning, non-nuclear industry	WBC	LSC, total beta, gamma spectrometry

Table 35. Internal dosimetric services in Estonia (EE).

Facility	Exposure	Direct techniques	Indirect techniques
AS Ecosil	Processing of raw material containing Unat and Thnat. Remediation of the Simillamäe Radioactive Tailings Pond		SAS

United Kingdom (GB)

A total of 10 internal dosimetric services operated in the United Kingdom; 9 of which are legally approved (Tables 37 and 38). Three collaborated with Eurados, supplying information about methods and procedures. Information of UK was supplied by NRPB, as co-ordinator of the OMINEX project. This project is supported by EC under the fifth framework programme and studies the optimisation of individual monitoring of occupational exposures.

Greece (GR)

The facility in Greece, dealing with the evaluation of internal exposures, is made up of two research laboratories (the Department of Environmental Radioactivity of the Greek Atomic Energy Commission and the Ioannina University Medical Physics Laboratory). Typical exposures that are assessed are related to research activities, medical field and non-nuclear industry (Table 39). Special attention was also given to Greek soldiers and personnel returning from Kosovo who were involved in the Balkans war.

The Medical Physics Department at the University of Athens Medical School will probably, in the future, be capable of performing *in vivo* measurements (WBC) for the assessment of internal exposures.

Croatia (HR)

There is one legally approved internal dosimetric service in Croatia (Table 40), the Department of Nuclear Medicine and Radiation Protection. Here *in vivo* (WBC, thyroid counting) measurements and also indirect techniques (spectrometry for urine and faeces) are carried out to assess internal exposures.

Table 36. Internal dosimetric services in Spain (ES).

Facility	Exposure	Direct techniques	Indirect Techniques
CIEMAT (Centro de Investigaciones Energéticas Medioambientales y Tecnológicas)	NFC, research, medical field, decommissioning, waste management	WBC, lung counting, thyroid counting, Bone counting	Alpha spectrometry, LSC
ENUSA	NFC	(lung counting at WBC-CIEMAT)	Uranium in urine (phosphorescence laser induced), SAS
TECNATOM-Servicio de Dosimetría	NPP, decommissioning	WBC, Quicky, thyroid counting	—
Central Nuclear Ascó	NPP	WBC	—
Central Nuclear Vandellos II	NPP	Quicky, thyroid counting	—
Central Nuclear Trillo	NPP	WBC	—
Central Nuclear Almaraz	NPP	WBC	—
Central Nuclear Jose Cabrera (Zorita)	NPP	WBC	—
Central Nuclear Cofrentes	NPP	WBC	—
Central Nuclear Sta María de Garoña	NPP	WBC	—

Table 37. Internal dosimetric services in the United Kingdom (GB) collaborating with Eurados*.

Facility	Exposure	Direct techniques	Indirect techniques
Rolls Royce Marine Operations Limited	NFC	—	Routine: uranium in SAS (also PAS measurements and determination of uranium in urine)
AWE plc	Research, decommissioning	Lung counting for actinides, wound monitoring (incidents)	^{3}H in urine; uranium and plutonium in PAS/SAS+urine/faeces
RWE NUKEM Ltd	NPP, NFC, research, decommissioning, non-nuclear industry	WBC, thyroid counting, lung counting	^{3}H in urine; gross beta in urine; PAS (and SAS); U, Th, Pu, in urine; Pu in faeces; ^{90}Sr/^{90}Y in urine (incidents), thorium in faeces (incidents)

*Data obtained from OMINEX questionnaire

Table 38. Other internal dosimetric services in the United Kingdom (GB).

Country	Facility
United Kingdom	BNFL Sellafield BNFL Springfields RWE Nukem (Dounreay) DSTL Radiological Protection Services NRPB (internal dosimetry, tritium, in-urine only) Nycomed Amersham

Hungary (HU)

At present there are a total of three accredited IDSs out of four in Hungary; only one is legally commissioned for country-wide record keeping. The National Research Institute for Radiobiology and Radiohygiene performs *in vivo* (WBC) and *in vitro* measurements (LSC and gamma spectrometry) on exposed workers employed in NPPs, nuclear fuel cycle, research activities and medical field (Table 41). The KFKI Atomic Energy Research Institute provides services on *in vivo* monitoring by WBC and thyroid counting for the whole centre (research reactor, activation analysis, etc.) and, upon request, for other institutions (isotope production, NPPs, research activities, etc.) as well as for the public. The other two laboratories performing internal dosimetry in Hungary are listed in Table 42.

Ireland (IE)

There is only one internal dosimetric service in Ireland and it is approved by the national authority. It performs evaluations of internal exposures in

Table 39. Internal dosimetric services in Greece (GR).

Facility	Exposure	Direct techniques	Indirect techniques
Greek Atomic Energy Commission–Department of Environment Radioactivity	Research, medical field, non-nuclear industry, Greek soldiers and personnel from Kossovo	WBC, thyroid uptake	Alpha spectrometry for urine
Ioannina University Medical Physics Laboratory	Research, medical field	WBC, partial whole-body counter (hand)	Alpha spectrometry for urine

Table 40. Internal dosimetric services in Croatia (HR).

Facility	Exposure	Direct techniques	Indirect techniques
Department of Nuclear Medicine and Radiation Protection	Medical field	WBC, thyroid counting	Spectrometry for urine and faeces

research activities, the medical field and non-nuclear industry. Whole-body counting and bioassay measurements in urine samples are carried out in St Vincent's University Hospital (Table 43).

Italy (IT)

A total of 18 facilities in Italy are involved in the assessment of internal exposures. There is no legal requirement for the approval of internal dosimetric services. Eight laboratories collaborated with Eurados (Table 44).

The Casaccia radiobioassay laboratory is the only facility measuring the uranium in urine using alpha spectrometry. In the near future it will also be in a position to measure the thorium in urine. Furthermore, in time the Casaccia centre will also be able to measure U in urine with ICP-MS.

There are 10 other whole-body counting facilities in Italy but they have not provided information related to their activities. These facilities are listed in Table 45.

Lithuania (LT)

There are two internal dosimetric services in Lithuania, the whole-body counting facility at the Ignalina Nuclear Power Plant and the *in vitro* laboratory at the Radiation Protection Centre. The second facility examines exposures at different workplaces: NPPs, research, decommissioning, medical field and non-nuclear industries. The evaluations of internal doses were carried out using indirect techniques only, but since 2004 direct techniques (whole-body and thyroid counting) are available at the Radiation Protection Centre (Table 46).

Netherlands (NL)

One internal dosimetric service, at the NRG Institute, operates in the Netherlands. Here whole-body counting, a direct technique, is used for *in vivo* detection of gamma-emitters in the body. LSC is used for *in vitro* monitoring of beta emitters (Table 47).

Norway (NO)

There are three internal dosimetric services operating in Norway and there is no legal requirement for approval. Institut for energiteknikk, IFE, has laboratories which can perform direct (whole-body and thyroid counting) and indirect techniques (spectrometry for urine samples) to monitor exposed workers in research institutes (Tables 48 and 49).

Poland (PL)

One internal dosimetric service exists in Poland (no legal approval). It undertakes *in vivo* measurements, detecting radioiodine in the thyroid of exposed medical workers (Table 50).

Portugal (PT)

There is no legally approved internal dosimetric service in Portugal. One whole-body counting facility is available at the Nuclear Technology Institute (ITN) in Lisbon. This is involved in monitoring exposure of workers medical and research fields (Table 51).

Romania (RO)

There are five legally approved internal dosimetric services in Romania (Table 52). All services supplied data relating to their monitoring programmes. Romanian laboratories are capable of undertaking direct (WBC, thyroid counting) and indirect

Table 41. Internal dosimetric services in Hungary (HU) collaborating with Eurados.

Facility	Exposure	Direct techniques	Indirect techniques
'National Research Institute for Radiobiology and Radiohygiene	NPP, NFC, research, medical field, public	WBC	
KFKI Atomic Energy Research Institute	Research reactor, radio chemistry, isotope production, NPP, public	WBC, thyroid monitoring	Gamma Spectrometry, LSC

Table 42. Other internal dosimetric services in Hungary (HU).

Country	Facility
Hungary	Institute of Isotopes Co. Ltd Nuclear Power Station Paks

Table 43. Internal dosimetric services in Ireland (IE).

Facility	Exposure	Direct techniques	Indirect techniques
St Vincent's University Hospital	Research, medical field, non-nuclear industry	WBC	Urine samples

(spectrometry for alpha, beta and gamma-emitters in urine) methods. Internal exposures come from a variety of sources: one NPP, research activities, the medical field and members of the public who have been affected by Chernobyl accident.

Sweden (Se)

There are 12 institutes performing internal dosimetry in Sweden. To date there is no legal approval system in place. Three services provided data about methods and procedures for this study (Table 53).

With reference to dose assessment in Sweden, as in Norway and Denmark, the radiation protection authorities are capable of evaluating internal doses, but the responsibility for that is, under normal conditions, given to workplaces.

Westinghouse Atom AB has a lung counter with low-level planar detectors especially designed for measurements in lungs. The *in vivo* assessment of thorium is carried out at the Lund University, in collaboration with SSI, which uses recently calibrated instrument developed for collecting thoron-progeny in exhaled air. Other internal dosimetry services in Sweden are listed in Table 54.

Slovenia (Si)

There are three internal dosimetric services in Slovenia (Table 55), one of them is legally approved. In addition to the above-mentioned services one service, which is approved, does not perform internal dosimetry. Monitored workers work mainly in two facilities: the Krško Nuclear Power Plant and the Nuclear Medicine Department at the University Medical Centre. Internal occupational doses in the Krško Nuclear Power Plant are evaluated applying direct techniques (WBC, lung or thyroid counting). Intakes due to work in research or medical facilities are calculated using measurements at the WB counter at the Nuclear Medicine Department at the University Medical Centre. *In vitro* methods, except for the assessment of internal dose performed by the Institute of Occupational Safety, are not available in Slovenia.

The legal framework in Slovenia has been already updated. Slovenia adopted the Radiation Protection and Nuclear Safety Act in 2002, which defines two regulatory authorities. Besides the Slovenian Nuclear Safety Administration a new regulatory authority was established: the Slovenian Radiation Protection Administration (SRPA). The SRPA is a constituent part of the Ministry of Health, competent for the surveillance of radiation sources used in medicine and veterinary, radiation protection of exposed workers and population, medical surveillance of exposed workers, education and training of exposed workers in the field of radiation protection. The updating process of the legislation is still going on but the EU Directive 96/29 EURATOM has been already fully transposed. Data on occupational personal doses are collected in the Central State Dose Record at the SRPA. Regarding the internal exposure only internal doses related to radon are included at present.

Slovakia (Sk)

There are two institutes performing internal dosimetry in Slovakia. From them one is legally approved internal dosimetry service in Slovakia, associated to the Radiation Protection Department

Table 44. Internal dosimetric services in Italy (IT) collaborating with Eurados.

Facility	Exposure	Direct techniques	Indirect techniques
Ospedale Niguarda Ca'Granda-Servizio di Fisica Sanitaria	Medical field	Thyroid counting	Gamma spectroscopy, LSC
ISPRA–Radiological Protection Unit	NPP, research	WBC, lung counting	—
SOGIN–Societa Gestione Impianti Nucleari–NPP Enrico Fermi	NPP, decommissioning	WBC	—
SOGIN–Caorso NPP Health Physics Department	Decommissioning, non-nuculear industry	WBC, lung counting, thyroid counting, GI counting	—
ARPA Piemonte–Dipartimento di Ivrea*	—	—	
Bufalini Hospital–Health and Medical Physic Department	Medical field	—	Gamma spectrometry (urine); air filters
Lab. Servizio Fisica Sanitaria Policlinico University Agostino Gemelli	Medical field	Thyroid counting	Spectrometry (urine)
ENEA	Research, decommissioning, medical field, non-nuclear industry, others (waste management, medicine)	WBC, lung counting, thyroid counting, bone (head) counting	Urine: gamma and alpha spectrometry, LSC, beta counting, fluorimetry Faeces: alpha spectrometry

*Dose assessment

Table 45. Other internal dosimetric services in Italy (IT).

Country	Facility
Italy	'S.Maria della Misericordia' Hospital, Health Physic Department, Udine Varese Hospital, Health Physic Department, Varese 'Casa Sollievo della Sofferenza' Hospital, Health Physic Department, S. Giovanni Rotondo (FG) Galliera hospital, Health Physic Department, Genova 'Istituti Ospitalieri' Hospital, Health Physic Department, Cremona Maggiore Hospital, Health Physic Department, Bologna Latina NPP, SOGIN, Borgo Sabotino (LT) Garigliano NPP, SOGIN, Scauri (LT) Saluggia Research Center, ENEA, Saluggia (VC) Trisaia Research Center, ENEA, Rotondella (MT)

of Bohunice Nuclear Power Plant (Table 56). Workers are *in vivo* monitored in WBC and thyroid counting (^{131}I) geometries. *In vitro* techniques applied in the service are LSC for beta emitters in urine and gamma spectrometry for urine and faeces; Pu isotopes assessment in faeces after radiochemical separation is also considered.

The second institute (no need of legal approval yet) is associated with the Department of Radiation Hygiene of Research base of Slovak Medical University, Institute of Preventive and Clinical Medicine, Bratislava. Monitored workers develop tasks in two different facilities: the Cyclotron Centre of Slovak Republic and Nuclear Medicine Department at the Oncological Institute of St Elizabeth, Bratislava. Occupational exposures are evaluated applying direct techniques (WBC, lung counting and thyroid counting). Intakes produced in research and medical facilities are calculated using WBC results as *in vivo* technique.

Ukraine (Ua)

The WBC laboratory at the Research Centre for Radiation Medicine AMS collaborated with

Table 46. Internal dosimetric services in Lithuania (LT).

Facility	Exposure	Direct techniques	Indirect techniques
Ignalina Nuclear Power Plant	NPP	WBC	—
Radiation Protection Centre	NPP, research, decommissioning, medical field, non-nuclear industry, others	—	Alpha, beta and gamma spectrometry, gross beta counting, SAS

Table 47. Internal dosimetric services in Netherlands (NL).

Facility	Exposure	Direct techniques	Indirect techniques
NRG Radiation and Environment	NPP, non-nuclear industry, visits	WBC	LSC

Table 48. Internal dosimetric services in Norway (NO) collaborating with Eurados.

Facility	Exposure	Direct techniques	Indirect techniques
Institutt for energiteknikk, IFE, Halden	Research	WBC, thyroid detector	Urine samples

Table 49. Other internal dosimetric services in Norway (NO).

Country	Facility
Norway	Norwegan Radiation Protection Authority Institutt for energiteknikk–IFE, Kjeller

Eurados, supplying information about *in vivo* evaluation of internal exposures in the Ukraine (Table 57).

Other European countries

Eurados contacted the Latvian Radiation Safety Centre. Although no replies were received, the contact-person indicated that there are two internal dosimetric services operating in Latvia (Table 58). There is no legal requirement for the approval of internal dosimetric services. Both services are operating in medical field, performing *in vivo* measurement of $^{99}Tc^{m}$ and ^{131}I. In Finland, STUK is the only centre performing Internal Dosimetry.

Table 50. Internal dosimetric services in Poland (PL).

Facility	Exposure	Direct techniques	Indirect techniques
Central Laboratory for Radiological Protection	Medical field	Thyroid counting	—

Table 51. Internal dosimetric services in Portugal (PT).

Facility	Exposure	Direct techniques	Indirect techniques
ITN-DPRSN	Medical field, research	WBC	—

INTEGRATION OF DOSIMETRIC DATA

In radiation protection dosimetry, the quantity of interest for application of the dose limitation legal requirements is the effective dose (E), defined by the expression:

$$E = \sum_{T} w_T H_T = \sum_{T} w_T \sum_{R} w_R D_{T,R}$$

where $D_{T,R}$ is the absorbed dose averaged over tissue or organ T, due to radiation R, w_R is the radiation weighting factor and w_T is the tissue weighting factor for tissue or organ T.

The radiation and tissue weighting factor are specified in the ICRP Publication 60.

The limit on effective dose to an adult worker applies to the sum of the relevant effective doses from external exposures during the appropriate time period and the relevant committed effective dose from intakes of radionuclides during that period.

As $D_{T,R}$ is a quantity not directly measurable, in external dosimetry the operational quantities personal dose equivalent, $H_P(d)$, and ambient dose equivalent, $H^*(10)$, are defined (ICRU Report 39, 1985)[14,15] to provide, under appropriate conditions, an adequate and conservative estimate of

Table 52. Internal dosimetric services in Romania (RO).

Facility	Exposure	Direct techniques	Indirect techniques
Institute of Public Health, Bucharest Group I, Radiochemistry	Research, public after Chernobyl	—	Radiochemical separation of Sr in urine
Institute of Public Health, Bucharest Group II, Gamma Spectroscopy	Research, medical field, ^{137}Cs in public (after Chernobyl)	—	Spectrometry for urine
Radiobiology Centre, Fundeni Clinical Hospital Radiobiology Department	Others	—	Spectrometry for urine
Internal Contamination Monitoring Laboratory	Research, medical field	WBC, thyroid counting	—
CNE-PROD CERNAVODA-Health Physics Laboratory	NPP	WBC routine	^{3}H and ^{14}C routine; gamma spectrometry (investigation)

Table 53. Internal dosimetric services in Sweden (SE) collaborating with Eurados.

Facility	Exposure	Direct techniques	Indirect techniques
OKG Aktiebolag	NPP	WBC	Gamma spectrometry
Studsvik Nuclear	NPP, NFC, research, decommissioning, medical field	WBC, thyroid counting	Spectrometry for urine and faeces, ICP-MS, environmental dosimetry
Radiation Physics, Ringals NPP	NPP	WBC, Quick Scan	Spectrometry

Table 54. Other internal dosimetric services in Sweden (SE).

Country	Facility
Sweden	Westinghouse Atom AB
	Barsebäck Kraft AB, NPP
	Forsmarks Kraftgrupp AB, NPP
	The Swedish Defence Research Agency, FOI
	Radiophysics, Gothenburg, Medical field
	Radiophysics, Malmö, Medical field
	Radiophysics, Umeå, Medical field
	Swedish Radiation Protection Authority, SSI

effective dose for the most commonly encountered external ionising radiation fields.

Internal doses cannot be measured directly, they can only be inferred from measured quantities such as body content, excretion rates or airborne concentrations of radioactive material. The choice of measurement technique will be determined by several factors: radiation emitted by the radionuclide, the biokinetic behaviour of the contaminant, its retention in the body taking into account both biological clearance and radioactive decay; the frequency of measurements and the sensitivity, availability and convenience of the appropriate measurement techniques.

ICRP has developed a set of models to represent the behaviour of radionuclides that have entered the body either by inhalation or by ingestion; these biokinetic models are applied for the evaluation of the doses from measurements performed according to routine monitoring programmes. The estimation of doses in case of an accident needs more specific information about the time and pattern of intake, about the physicochemical form of the radionuclides and the characteristics of the individual.

Individual monitoring for estimation of internal exposures may include either direct measurements of radionuclide in the body and/or measurement of activity in excreta. Any measurement should enable each radionuclide to be identified, its activity quantified, and the measurement result interpreted in terms of intake or committed effective dose. Alternatively, measurements of activity in the body can be used to estimate dose rates directly; the calculation of committed doses from direct measurements still involves the assumption of a biokinetic model if sufficient measurements are not available to determine retention functions.

Integration of dosimetric methods for external and internal radiations will be possible where complete characterisation of the type of occupational exposure present in the workplace has been undertaken; updated information about the

Table 55. Internal dosimetric services in Slovenia (SI).

Facility	Exposure	Direct techniques	Indirect techniques
Krsko NPP, Radiation Protection Dosimetry Laboratory	NPP	WBC, lung counting thyroid counting	—
University Medical Centre, Department of Nuclear Medicine	Research, medical field, non-nuclear industry	WBC	—
Institute of Occupational Safety	—	—	*

*See Table 18.

Table 56. Internal dosimetric services in Slovakia (SK).

Facility	Exposure	Direct techniques	Indirect techniques
Radiation Protection Department, Bohunice NPP	NPP, research, decommissioning	Fastscan, WBC, ^{131}I in thyroid	LSC (urine), gamma spectrometry (urine and faeces), Pu isotopes assessment after radiochemical separation (faeces)
Department of Radiation Hygiene of Research base of Slovak Medical University, Institute of Preventive and Clinical Medicine	Radiopharmaceutical production, research	WBC	—

Table 57. Internal dosimetric services in Ukraine (UA).

Facility	Exposure	Direct techniques	Indirect techniques
WBC-laboratory of Research Centre for Radiation Medicine AMS Ukraine	NPP	WBC, lung counting, beta *in vivo* counting	—

Table 58. Internal dosimetric services in Latvia (LV).

Country	Facility
Latvia	P. Stradin Clinical Hospital Latvian Oncology Centre

actual risk of contamination of workers is required, with a knowledge of radiation fields and of physicochemical characteristics of the radioactive materials present in the workplace. In this case, the committed effective dose associated with the intake obtained from the results of direct and/or indirect measurements, applying adequate individual monitoring programmes of the exposed workers, will be integrated to external doses in a consistent dosimetric system, where both types of exposures are considered.

Table 59. Countries and contact persons collaborating with Eurados.

Code	Country	Contact-Person
AT	Austria	Alexander Brandl
BE	Belgium	Christian Hurtgen
BG	Bulgaria	Metody Guelev
CH	Switzerland	Christian Wernli
CS	Serbia and Montenegro	Mirjana Prokic
CZ	Czech Republic	Karla Petrova
DE	Germany	Andreas Dalheimer
DK	Denmark	Rolf Falk
EE	Estonia	Toomas Koop
ES	Spain	Maria Antonia Lopez
GB	United Kingdom	George Etherington
GR	Greece	Vassiliki Kamenopoulu
HR	Croatia	Maria Ragonajec
HU	Hungary	Andor Andrasi/ Marika Osvay
IE	Ireland	Lorraine Currivan
IT	Italy	Carlo M Castellani
LT	Lithuania	Gendrutis Morkunas
NL	The Netherlands	Janwillem van Dijk
NO	Norway	Rolf Falk
PL	Poland	Pawel Olko
PT	Portugal	Joao Alves
RO	Romania	Constantin Milu
SE	Sweden	Rolf Falk
SI	Slovenia	Helena Janzejovic
SK	Slovakia	Nikodemova Denisa
UA	Ukraine	Vadim Chumak

CONCLUSIONS

The final objective of EURADOS working group 2 is to achieve the harmonisation in individual monitoring for occupational exposures. Subgroup 2 looked at the integration of monitoring for external and internal exposures in the assessment of Effective Doses. An important network of information has been established among 26 European countries with the assistance of contact persons who have actively collaborated with EURADOS in the distribution of Questionnaires among their internal dosimetry facilities. An extensive amount of information was collected from some 73 services, covering a wide range of parameters, for example equipment, techniques, tools and regulations. This results in an overview of the actual status of individual monitoring for internal exposures in Europe. Harmonisation is a reality in many aspects of internal dose assessments, especially when considering the measurements of the activity retained/excreted from the body. However, a future study, detailing MDA estimation is highly recommended. Points which should be focused on in future harmonisation projects are as follows: the process of calculation of doses from measured activity, establishment of guidelines, similar dosimetric tools and application of the same ICRP recommendations. This would lead to a better and more harmonised approach to the estimation of internal exposures in all European facilities.

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We are grateful to the internal dosimetric services that responded to our questionnaires, and we especially thank the contact persons in each country collaborating with Eurados for harmonisation (Table 59). We also thank J. Francisco Navarro (CIEMAT) involved in the development of the Eurados Dosimetric Database, collaborating in the management of data supplied by services and in the generation of tables and reports.

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ANNEX

Table AN1. List of internal dosimetric services collaborating with Eurados.

AT	ARCS Seibersdorf Research GmbH (Alexander Brandl) Seibersdorf, Austria. E-mail: alexander.brandl@arcs.ac.at
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BE	SCK-CEN (Christian Hurtgen), Mol, Belgium. E-mail: churtgen@sckcen.be
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Table AN1. Continued.

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APPENDIX

Table AP1. Facilities included in the EURADOS Dosimetric Database (v 1.0).

Country	Ref-Facility	Facility
AT	At-GR	Prüfstelle für Strahlenschutz, Landeskrankenhaus-Universitätsklinikum Graz
	At-AR	ARCS Seibersdorf Research GmbH
BE	Be-SC	SCK–CEN
BG	Bg-KL	Laboratory of Dosimetry and Radiation Protection, St Kliment Ohridski University of Sofia
	Bg-KO	Kozloduy Nuclear Power Plant-PLC
	Bg-NR	Institute for Nuclear Research and Nuclear Energy
	Bg-PR	Laboratories Protecta Ltd
	Bg-RB	Nat Centre of Radiobiology and Radiation Protection Laboratory
	Bg-RW	Radioactive Wastes Treatment Plant (RAWTP)-Kozloduy NPP
CH	Ch-BA	Whole Body Counter University Hospital Basel
	Ch-BK	BKW FMB Energie AG
	Ch-MB	mb-microtec ag
	Ch-PS	PSI–Paul Scherrer Institute
	Ch-RA	Institut Universitaire de Radiophysique Appliquée
	Ch-RC	RC Tritec Ltd
	Ch-SU	Suva (Swiss National Accident Insurance Fund)
CS	Cs-NS	Institute of Nuclear Sciences, Vinca
	Cs-OS	Institute of Occupational Health, Belgrade
CZ	Cz-DU	Dukovany Nuclear Power Plant
	Cz-NP	National Personnel Dosimetry Service
	Cz-NR	Nuclear Research Institute, Rez
	Cz-RP	National Radiation Protection Institute
	Cz-TE	Personal Dosimetry Service–Temelin NPP
DE	De-BS	Bundesamt für Strahlenschutz (BfS)
	De-DO	Materialprüfungsamt NRW (MPA NRW), Personendosismesstelle
	De-FJ	Amtlich anerkannte Inkorporationsmessstelle im, Forschungszentrum, Jülich
	De-FR	Framatome ANP GmbH
	De-GA	A.K. St Georg Abteilung für Nuklearmedizin
	De-KT	Forschungszentrum Karlsruhe Technik und Umwelt
	De-LU	Landesanstalt füer Umweltschutz Baden-Wuerttemberg
	De-MS	Messtelle für Strahlenschutz, Hamburg
	De-SH	Siemens AG, Power Generation, DP Hanau
	De-UE	Universitätsklinikum Essen
DK	Dk-RH	National Institute of Radiation Hygiene
	Dk-RI	Applied Health Physics, Riso National Laboratory
EE	Ee-AS	AS Ecosil
	Ee-RP	Estonian Radiation Protection Centre (ERPC)
	Ee-TL	TLD Group–ERPC
ES	Es-AL	Central Nuclear Almaraz
	Es-AS	Central Nuclear Asco
	Es-CI	CIEMAT
	Es-CO	Central Nuclear Cofrentes
	Es-EN	ENUSA
	Es-TE	TECNATOM
	Es-TR	Central Nuclear Trillo
	Es-VA	Central Nuclear Vandellos II
	Es-ZO	Central Nuclear Jose Cabrera (Zorita)
	Es-GA	Central Nuclear de Santa María de Garoña
FI	Fi-ST	STUK- Radiation and Nuclear Safety Authority
GB	Gb-AW	AWE plc
	Gb-RR	Rolls Royce Marine Operations Limited
	Gb-RW	RWE NUKEM/Harwell Scientifics
GR	Gr-AU	Aristotle University of Thessaloniki, Polytechnic School, Laboratory of Nuclear Tech.
	Gr-GA	Greek Atomic Energy Commission–Department of Environment Radioactivity
	Gr-IU	Ioannina University Medical Physics Laboratory
HR	Hr-BO	Ru Er Boskovi Institute
	Hr-EK	EKOTEH Dosimetry Co. Radiation Protection Service
	Hr-NM	Department of Nuclear Medicine and Radiation Protection

Table AP1. Continued.

Country	Ref-Facility	Facility
HU	Hu-AE	KFKI Atomic Energy Research Institute
	Hu-RR	National Research Institute for Radiobiology and Radiohygiene
IE	Ie-RP	Radiological Protection Institute of Ireland, Natural Radiation Department
	Ie-SV	St Vincent's University Hospital
IT	It-AG	Lab Servizio Fisica Sanitaria del Policlinico Universitario Agostino Gemelli
	It-AR	ARPA Piemonte–Dipartimento di Ivrea
	It-AS	Fisica Sanitaria–ASL n.9 della Regione Veneto
	It-BR	Spedali Civili di Brescia–Servizio di Fisica Sanitaria
	It-BU	Bufalini Hospital–Health and Medical Physic Department
	It-CA	SOGIN–Caorso NPP Health Physics Department
	It-CT	Istituto Nazionale per lo studio e la cura dei Tumori
	It-EF	SOGIN–Societa Gestione Impianti Nucleari–NPP Enrico Fermi
	It-EN	ENEA
	It-IS	ISPRA–Radiological Protection Unit
	It-MA	Ospedale Maggiore–Servizio di Fisica Sanitaria
	It-ON	Ospedale Niguarda Ca'Granda–Servizio di Fisica Sanitaria
	It-PE	Azienda Ospedaliera di Perugia–Servizio di Fisica Sanitaria
	It-RI	ISPESL–Laboratorio Radiazioni Ionizzanti e Non Ionizzanti
	It-RO	C.I.R. (Centro Italiano di Radioprotezione Roma)
	It-UM	Umberto I Hospital–Medical Physics Department
	It-XG	X-GAMMAGUARD
LT	Lt-IP	Ignalina Nuclear Power Plant
	Lt-RP	Radiation Protection Centre
NL	Nl-RE	NRG Radiation and Environment
NO	No-IE	Institutt for energiteknikk, IFE
	No-RP	Norwegian radiation protection authority (NRPA)
PL	Pl-GI	Central Mining Institute (GIG)
	Pl-IF	Institute of Nuclear Physics–Laboratory of Individual and Environmental Dosmetry
	Pl-NO	Nofer Institute of Occupational Medicine-Radiation Protection Department
	Pl-RP	Central Laboratory for Radiological Protection
PT	Pt-TN	ITN-DPRSN
RO	Ro-CL	CIPIEM-Bucharest
	Ro-CN	CNE-PROD CERNAVODA–Health Physics Laboratory
	Ro-DO	DOZIMED–Bucharest
	Ro-EL	Environmental and Life Sciences Department
	Ro-FD	Film Detectors Survey Unit
	Ro-HF	Individual Radiation Monitoring Laboratory–Ministry of Health
	Ro-IC	Internal Contamination Monitoring Laboratory
	Ro-PG	Institute of Public Health Bucharest–Group II–Gamma spectroscopy
	Ro-PR	Institute of Public Health Bucharest–Group I–Radiochemistry
	Ro-RB	Radiobiology Centre–Bucharest
SE	Se-HU	Studsvik Nuclear
	Se-OK	OKG Aktiebolag
	Se-RI	Radiation Physics, Ringals NPP
	Se-RP	Swedish Radiation Protection Authority
SI	Si-JS	Jožef Stefan Institute
	Si-KR	Krsko NPP, Radiation Protection–Dosimetry Laboratory
	Si-MC	University Medical Centre, Department of Nuclear Medicine
	Si-OS	Institute of Occupational Safety
	Si-UM	Uranium Mine Zirovski vrh
SK	Sk-BA	Department of radiation hygiene of Research base of Slovak Medical University, Institute of Preventive and Clinical Medicine
	Sk-BO	Radiation Protection Department, Bohunice NPP
	Sk-RQ	State Metrological Center for Radon Quantities
UA	Ua-NR	Laboratory for Hygiene of Natural Radiation sources, Research Centre Radiation Medicine
	Ua-RM	WBC–Laboratory Research Centre for Radiation Medicine AMS Ukraine
	Ua-RP	Radiation Protection Institute ATS Ukraine
	Ua-SG	Central Lab for rad hygiene of medical staff of Ukraine–S.Grigoriev Institute