A CATALOGUE OF DOSEMETERS AND DOSIMETRIC SERVICES WITHIN EUROPE—AN UPDATE

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The catalogue of dosemeters and dosimetric services within the European Union (EU) Member States and Switzerland that was issued by EURADOS in the year 2000 has been updated and extended with information on dosimetric services in the new EU Member States and Bulgaria, Croatia, Romania, Serbia and Montenegro, and Ukraine. The total number of dosimetric services in these European countries is now estimated to be about 200. The present catalogue is based on information collected from 90 European dosimetric services, among which 34 questionnaires from 32 services were obtained over the years 2001–2004 for the first time. This article assesses and updates the present use of personal dosemeters and the extent to which occupationally exposed persons in Europe are monitored with dosemeters able to measure the operational quantity— personal dose equivalent, $H_P(d)$. The perspective of joining EU by the new countries accelerated the implementation of the EU Basic Safety Standard Directive to their national regulations. As a result, all newly investigated services reported their ability to measure $H_P(d)$. The catalogue provides information on the dosemeters, dose calculation and background subtraction algorithms, calibration methods, energy and angular response, and performance.

INTRODUCTION

In the year 2000, an overview of dosemeters and dosimetric services within the European Union (EU) Member States and Switzerland, where external radiation doses were estimated in the form of personal dose equivalent, $H_P(d)$, was prepared by the EURADOS working group and published in a special issue of *Radiation Protection Dosimetry*[1]. Information for the compilation of that report was obtained from questionnaires sent to dosimetric services. In the report it was estimated that roughly 50% of the occupationally exposed persons in the EU and Switzerland were at that time monitored in terms of personal dose equivalent, $H_P(10)$ and $H_P(0.07)$. Over the years 2001–2004 a slightly modified EURADOS questionnaire was distributed among dosimetric services in the EU candidate countries (Czech Republic, Estonia, Hungary, Latvia, Lithuania, Poland, Slovakia and Slovenia), and other European countries (Bulgaria, Romania, Ukraine, Croatia, Serbia and Montenegro). In addition, some services from Italy, Greece and Germany supplied updates of their data. The aim of this article is to assess and update information on the present use of personal dosemeters and their design. The perspective of joining EU by the new countries accelerated the implementation of the EU Basic Safety Standard Directive[2] to their national regulations.

As a result, all newly investigated services reported that they were able to measure $H_P(d)$. The present catalogue is based on information collected from 90 European dosimetric services, among which 34 questionnaires from 32 services were obtained over the years 2001–2004 for the first time. The list of dosimetric services that responded to the questionnaire is given in the Appendix.

The discussion on the properties of the dosimetric systems and the dosemeters design does not imply any comparison of the quality of the systems. Therefore, in this article, the dosimetric performance of the services listed is presented in anonymous form to avoid any comparison between particular dosimetric services.

The present catalogue is essentially based on the report issued by the EURADOS working group in 2000 and is structured into the following sections:

- General information on European dosimetric services
- Dosemeter design
- Photon dose calculation and background subtraction algorithms
- Energy and angle dependence of response
- Calibration sources
- Performance

The amount of information collected from the questionnaires cannot be fully presented in this article due to the lack of space. Therefore, the full text of the report, including tables in Annexes, is available on the EURADOS web page www.eurados.org.

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GENERAL INFORMATION ON EUROPEAN DOSIMETRIC SERVICES

The EURADOS questionnaire distributed in 2002–2003, named the "EURADOS 2002 Questionnaire for a catalogue of dosemeters used for individual monitoring in European Countries" is in fact a copy of the questionnaire distributed in 1997–1998. Only the front page specifying the contact persons, return addresses and instructions were modified. The 14-page questionnaire consisted of seven sections that included information on the name and relevant addresses of the service; make, type and principles of dosemeters and the dosimetric system; dose calculation and background subtraction algorithms; type-testing methods, energy and angular response, calibration and Quality Assurance programmes. A copy of the questionnaire distributed in the years 2001–2004 is available in Annex I at www.eurados.org.

In the first round (1997–1999), each EURADOS action group member received a number of copies of the questionnaire and distributed them to services in his or her Member State. At that time, a total of 56 dosimetric services from 15 EU countries and Switzerland responded to the questionnaire. The dosimetric services that responded in the first run monitored about 615,000 occupationally exposed approximately one-half of the population of radiation workers in these countries. Within this population, 450,000 workers were monitored in terms of $H_P(d)$. The difference was due to services in Austria and Germany, which did not monitor in terms of $H_P(d)$ but reported 'Photonen-Äquivalentdosis' (H_X), and in Italy, where dosimetric services reported kerma free-in-air values. In 2004, the legal quantity in Austria is represented by $H_P(d)$ but due to the lack of the corresponding ordinance, most services were still using the old units.

In the second run, in the years 2001–2004, members of the EURADOS Working Group 2 and volunteers agreed to distribute the questionnaires to services in their countries. The list of the country coordinators is given in Table 1. The present catalogue is based on information collected from 90 European dosimetric services, among which 34 questionnaires were obtained for the first time in 2001–2004, and 12 services from Germany, Italy and Greece who updated their questionnaires. The questionnaire was available as an MS-Word file or in a printed form. Four participants returned their questionnaires in hard copy, all others in electronic form, by e-mail.

In the first run (1997–1999) over 30 services supplied detailed information on the characteristics of their dosimetric systems, including energy and angular response. In the second run, most of the services provided rather limited sets of data, often with scant

Table 1. List of country coordinators, who distributed and collected EURADOS[1] questionnaires.

Bulgaria	Metody Guelev
Croatia	Maria Ragonajec
Czech Republic	Karla Petrova
Estonia	Toomas Koop
Hungary	Marika Osvay
Latvia	Constantin Boguciarskis
Lithuania	Gendrutis Morkunas
Poland	Pawel Olko
Romania	Constantin Milu
Serbia and Montenegro	Mirjana Prokic
Slovakia	Denisa Nikodemova
Slovenia	Helena Janzejovic
Ukraine	Vadim Chumak

detail on the dosimetric characteristics. However, even this limited information was extremely useful in reviewing and cataloguing the personal dosimetric systems used in European countries.

In Table 2, the data are presented on the number of dosimetric services and monitored workers, who responded to the EURADOS questionnaire in 1997–1999 (columns 3 and 4), the number of services that reported in 1997–1999 their ability to assess $H_P(d)$ and the number of workers who were monitored previously (columns 5 and 6) and in 2001–2004 (columns 7 and 8). In 1997–1999 most of the missing data were from a large number of Italian dosimetric services that did not measure $H_P(d)$ but kerma free-in-air. In the updated questionnaires sent in the year 2002 the Italian services reported their results in terms of $H_P(d)$. The data does not include workers monitored for neutron exposures. The number of services and monitored persons given in this report are an attempt to reflect the status between 1999 and the end of 2003. The information on the number of monitored persons was assessed from the average number of dosemeters processed per month because some services issue their dosemeters not only every month but also over 2-month or 3-month periods.

It was estimated in 2000[1] that, based on the data provided by the responding dosimetric services, approximately half of the occupationally exposed persons of the EU and Switzerland were monitored by services that assessed the dose in terms of $H_P(10)$ and $H_P(0.07)$. The present set of data indicates that the services in the new Member States, which entered the EU in 2004, and in many other European countries almost exclusively monitor their workers in terms of personal dose equivalent.

General information on the dosimetric services and type of dosemeters, listed by country, is given in Table 3. The countries are given in alphabetical order of their EU country codes.

Table 2. Data on the number of dosimetric services and monitored workers, who responded to the EURADOS questionnaire in 1997–1998 and 2002–2003.

Country code	EU country in 2004	EURADOS 1997–1998				EURADOS 2002–2003, Hp only	
		Total		H_p (d) only			
		Services	Workers	Services	Workers	Services	Workers
A	Yes	4	33500	—	—	—	—
B	Yes	3	6000	3	6000	3	6000
BG	No					5	12 450
CH	No	10	62 000	7	44 900	7	44900
CZ	Yes					4	20 420
D	Yes	8	52 900	—	—	—	—
DK	Yes	4	11 000	3	11 000	3	5350
E	Yes	4	52 800	4	52 800	4	52 800
EL	Yes	3	5350	2	5350	1	8000
EST	Yes					1	1050
F	Yes	7	224900	7	224 900	6	224 900
FIN	Yes	2	3400	2	3400	2	3400
H	Yes					2	30 000
HR	No					2	3700
I	Yes	2	8000	—	—	12	44 170
IRL	Yes	1	4500	1	4500	1	4500
L	Yes	1	1100	1	1100	1	1100
LT	Yes					2	4850
LV	Yes					1	400
NL	Yes	4	32 600	4	32 600	4	32 600
PL	Yes					3	35 000
P	Yes	1	4000	1	4000	1	4000
RO	No					6	13 350
S	Yes	3	13 300	3	13 300	3	13 300
SI	Yes					2	3150
SK	Yes					1	3700
UA	No					2	2100
UK	Yes	7	46 900	7	46 900	7	46 900
YU	No					2	5100
Total	29	62	562 250	48	450 750	89	627 190

The data does not include workers monitored for neutrons.

DOSEMETER DESIGN

An ideal dosemeter should provide a reading proportional to dose (dose equivalent) to tissue at the given depth, independently of the radiation energy. A typical dosemeter used in individual monitoring consists of a detector placed in a holder. The holder protects the detector from disturbing environmental factors, corrects the energy and angular response and assures response at an appropriate depth. Therefore, the design of dosemeters has to take into account mainly the energy response, thickness and physical shape of the detector(s) and the composition, thickness and shape of the filters applied. The design of the holder has also taken into account the fact that the calibration is performed on the phantom, to consider the radiation backscatter from the body.

This article provides an overview of individual dosemeters used by dosimetric services in Europe. A catalogue is provided of the detectors applied (film, TLD) and different filters used in the dosemeters of the services, which responded to the questionnaires.

Photon and beta + photon dosemeters

Principles of dosemeter design

One of the requirements concerning detectors is their tissue equivalence, i.e. that their atomic composition should provide similar interaction of radiation to that with human tissue. The detector is considered to be tissue-equivalent if the ratio of its reading to the value of dose to tissue is independent of photon energy. The atomic composition of a material with

Table 3. List of dosimetric services, with number of services applying given type of dosemeters and number of personnel under control.

Country Code		PF	PT	PV	BF	BT	BV	NA	NH	NS	NM	Various
A	Number of services		4									
	Number of workers											
	Comments	All four dosimetric services in Austria issue TLDs that assess the dose quantity 'Photonen Äquivalentdosis' H_x. ARCS starts to measure personal dose equivalent, $H_P(10)$ in 2004										
B	Number of services	1	2	1	2							
	Number of workers	1000	5000									
BG	Number of services	1	5									1
	Number of workers	5000	7300									150
	Comments	Various—electronic dosemeters. The monitoring periods are 1 month and 3 months										
CH	Number of services	1	9	1	6				1	1		1
	Number of workers	6000	56 000	6000	54 000				4000	1000		20
	Comments	Various—direct storage device										
CZ	Number of services	2	2	2				2				
	Number of workers	16,700	1650	2070				95				
	Comment	PV- AlP glas dosemeters										
D	Number of services	1	3			2						
	Number of workers	35 000	9500									
	Comments	All dosimetric services assess the dose quantity 'Photonen Äquivalentdosis' H_x. However, one dosimetric service uses a film dosemeter designed to measure personal dose equivalent, both $H_P(10)$ and H_x. The dosimetric systems based on glass dosemeters are also capable of assessing both $H_P(10)$ and H_x.										
DK	Number of services	1	2	1	2						1	
	Number of workers	10,000	1150									
E	Number of services		4		1							
	Number of workers		40,800									
EL	Number of services		1					1				
	Number of workers		8000					50				
EST	Number of services		1									
	Number of workers		1050									
	Comments	Monitoring periods are 1, 3, 6 months. Average number of dosemeters per month: 400										
F	Number of services	6	2						2	2	2	
	Number of workers	213 000	29 800						1100	12 100	1800	
	Comments	The albedo dosemeters are used in combination with film dosemeters in multi-element type-1 or type-2 dosemeters										
FIN	Number of services		2		1			1				
	Number of workers		3400					10				
H	Number of services	1	1									
	Number of workers	30 000	1000									
HR	Number of services	1	1					1				
	Number of workers	2500	1200					10				
I	Number of services	2	10					1				
	Number of workers	24 250	21 920					200				
IRL	Number of services		1									
	Number of workers		5500									
L	Number of services		1									
	Number of workers		1100									
LT	Number of services		2					1				1
	Number of workers		4850					400				400
LV	Number of services		1									
	Number of workers		400									
NL	Number of services		4		2			1				
	Number of workers		34 000					1800				
PL	Number of services	2	3					1				
	Number of workers	31 000	4000					60				
	Comments	Monitoring periods are 1, 2, 3 and 4 months										
P	Number of services		1									
	Number of workers		4000									

Table 3. Continued

Country Code		PF	PT	PV	BF	BT	BV	NA	NH	NS	NM	Various
RO	Number of services	4	2	1								
	Number of workers	11 650	1700									
S	Number of services	1	1			1		1				
	Number of workers	10 000	3300			300		3000				
SI	Number of services		2					1				1
	Number of workers		3150					6				
SK	Number of services	1	1					1				
	Number of workers		3700					20				
	Comments	Film dosimetry is performed by National Radiation Protection Service in the Czech Republic										
UA	Number of services		2									
	Number of workers		2100									
UK	Number of services	5	2							3		
	Number of workers	47 000	21 000									
YU	Number of services		2									
	Number of workers		5100									

The following categories of dosemeters are specified: photon whole-body dosemeters (PF: photographic film, PT: thermoluminescent, PV: various (glass, electronic, OSL), beta whole-body dosemeters (BF: photographic film, BT: thermoluminescent, BV: various (electronic, OSL), neutron whole-body dosemeters (NA: albedo, NH: high energy, NS: Multi-element type 1 (one detector type and different converters), NM: Multi-element type 2 (different detector types)).

Table 4. Effective atomic number, with regard to X rays, for different TLDs.

Detector	Z_{eff}
LiF	8.3
CaF_2	16.3
$Li_2B_4O_7$	7.35
Al_2O_3	11.3
$CaSO_4$	15.7

respect to interaction with photons is frequently expressed in terms of effective atomic number Z_{eff}. A substance is considered tissue-equivalent with regard to interactions with photons if its Z_{eff} is close to that of soft tissue, which in turn is equal to 7.4. In Table 4, the values of Z_{eff} calculated are given for the most common thermoluminescent detectors. Since the ratio of tissue kerma to air kerma for photons in the energy range between 10 keV and 10 MeV is approximately constant, a dosemeter calibrated in terms of air kerma will give a good estimate of tissue dose, to within 10%[3]. It should be noted that radiation fields used in radiation protection for calibration of personal dosemeters are typically characterised in terms of air kerma but the properties of dosemeters (detectors and filters) should determine the ability of personal dosemeters to follow the legal dosimetric quantity, $H_P(d)$.

The photon energy response of a detector is calculated as the ratio of the detector signal measured for the given type of radiation and energy, to the signal obtained after irradiation of the detector with the same dose in tissue (or kerma in air) of reference radiation, e.g. ^{137}Cs- gamma rays. To the first approximation the photon energy response of the detector depends on the material composition, which determines the cross sections for photon interaction within the detector, as compared to tissue (air). Therefore, the energy response of the given detector is frequently estimated as the ratio of dose in the detector material to that in tissue (air). In Figure 1 the ratio of mass energy absorption coefficients of LiF and air, and $Li_2B_4O_7$ and air (solid lines) are plotted against the measured response of LiF:Mg,Ti (MTS-N), LiF:Mg,Cu,P (MCP-N) and $Li_2B_4O_7$:Cu detectors. The measured energy response of MTS-N is approximately 10% higher due to the variation of thermoluminescence efficiency for conversion of deposited energy into TL light (LET effect). This phenomenon is quite pronounced for LiF:Mg,Cu,P detectors and for aluminium oxide detectors, Al_2O_3:C, where the ratio between the calculated and measured response reaches 1.25 for 100 keV photons. Therefore, for the design of dosemeters one should apply only the experimentally determined detector energy response.

The over-response of dosemeters can be compensated for by the use of appropriate filters. The role of the filter is mainly to reduce the fluence of photons by taking advantage of absorption edges of materials with Z higher than that of tissue elements.
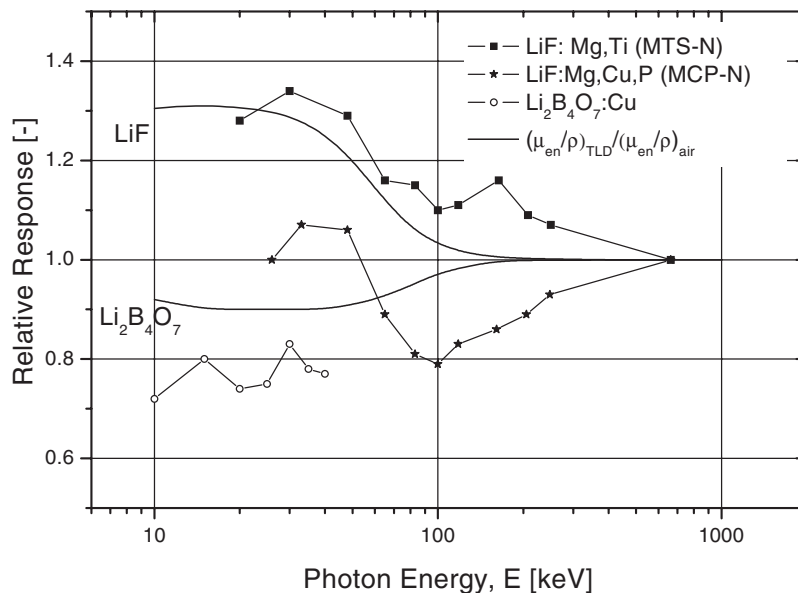
Figure 1. The ratio of measured response of LiF:Mg,Ti (MTS-N) (squares), LiF:Mg,Cu,P (MCP-N) (stars) and $Li_2B_4O_7$:Cu (circles) thermoluminescence detectors, normalised to kerma free-in-air, K_{air}, as a function of photon energy. The solid lines represent the ratio of mass energy response coefficients of LiF to air and $Li_2B_4O_7$ to air.

A combination of filters can be optimised so that the dosemeter (with the given detector) will follow the required $H_P(d)$ energy response. In film dosimetry, high over-response for X rays can be compensated for by using filters with a higher atomic number than that of the detector or by filtration analysis, i.e. by using more than one detector covered with different filters (or by screening one film with different filters). In this case the effective energy of incident radiation can be estimated from the ratio of responses under the different filters and a correction factor for the unscreened part of the film. In another approach, each part of the film is covered with a different filter and is regarded as an individual dosemeter. An example of the response of a dosemeter with four filters and an algorithm is presented in Figure 2.

Dosemeters for photon or beta and photon dosimetry

Whole-body dosemeters for photon or beta and photon dosimetry are divided below into three categories: film, thermoluminescence and 'various' (glass, electronic). The catalogue of different filters used in the film and the thermoluminescence dosemeters (TLDs) of the services that responded to the questionnaire, is presented in Annex II, in the full version of the report under www.eurados.org. This variety of dosemeter design reflects the broad range of dosemeters currently used in Europe. It should be pointed out that only about 30% services reported

for those dosemeters the response characteristics, which were obtained mainly during type testing.

In Table 5 the list of dosimetric films, applied in European services, is presented. In the previous version of the EURADOS report, Agfa and Kodak films were reported to be exclusively applied by services in the 15 old EU countries. In five dosimetric services in the Czech Republic, Slovakia and Poland, FOMA dosimetric films (made in the Czech Republic) are applied for whole body photon and beta monitoring.

Table 6 lists the various TLD type thermoluminescent detectors applied. In the present catalogue lithium borate, calcium sulphate and calcium fluoride detectors are being applied in radiation monitoring, as compared to the previous specification of TLDs. No service reported routine application of the OSL technique and of the aluminium oxide detectors.

Beta dosemeters

The state of the design of beta dosemeters currently applied in European countries was presented in the previous EURADOS catalogue[1], basing on dosemeters included in the beta dose performance tests. Beta dosemeters are typically available as whole-body dosemeters or extremity dosemeters (wrists, finger rings). The whole-body personal dosemeters have usually a dedicated detector (or a fragment of the dosimetric film) designed to measure $H_P(0.07)$. The text below summarises the main
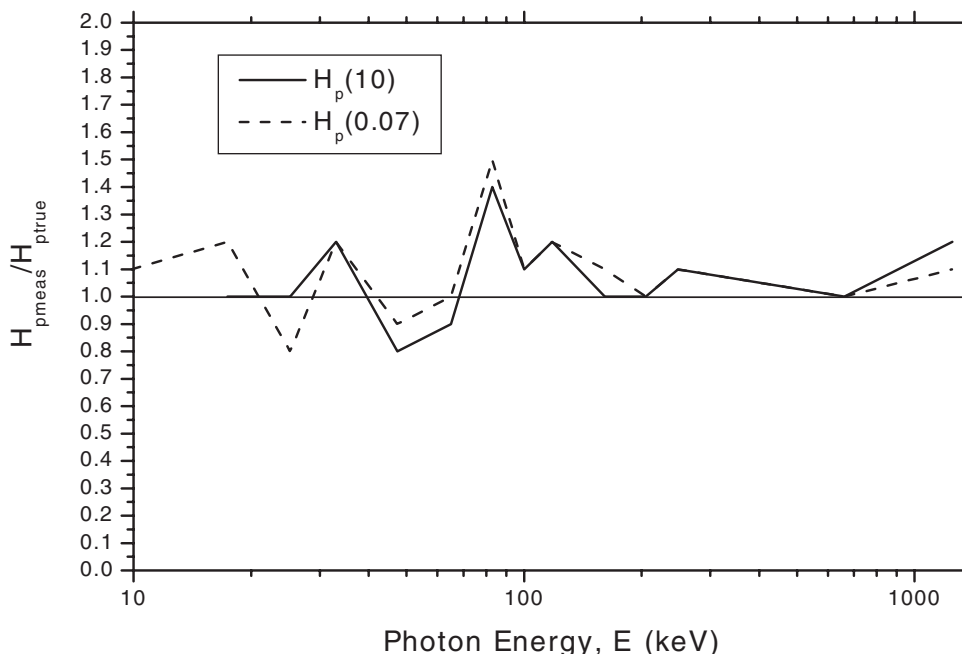
50

Figure 2. Response of a photographic film dosemeter with four filters and an algorithm for calculating dose from film densities.

Table 5. List of dosimetric films, applied in European dosimetric services for personal monitoring of photon and beta doses.

Producer	Type
Foma Bohemia Ltd (Cz)	Monitoring Film R10 + R2
Kodak (USA)	Kodak Type II Monitoring Film
Agfa (D)	Agfa PM

properties of a beta dosemeter, which have to be taken into account in its design and type testing. These properties remain valid for whole body dosemeters, described in the previous section. For 61 TLD badges, presented in Annex II, only six had no thin filter/window for $H_P(0.07)$ dosimetry.

Skin, extremities and the lens of the eye are the main organs at risk due to exposure to beta rays with energies below 2 MeV. For most beta-radiation fields, skin is the part of the extremity receiving the highest dose. Therefore, the dose limit for skin extremities is more likely to become the limiting organ than the extremity itself. The personal dose equivalent, $H_P(d)$ for beta radiation fields is then determined at the depth $d = 0.07$ mm for skin dose assessment, $d = 3$ mm for dose to the eye lens and $d = 10$ mm for high energy (above 2 MeV) beta rays, e.g. for dose to the testes.

Table 6. The list of abbreviations and trade names for TLD materials used in European dosimetric services.

TLD-100	LiF:Mg,Ti natural Li isotopes from Thermo Electron (former Harshaw/Bicron NE) Both ^{6}Li and ^{7}Li are available as TLD-600 and TLD-700
GR-200	LiF:Mg,Cu,P natural Li isotopes from Beijing Shiying Radiation Detector Works, China. Both ^{6}Li and ^{7}Li are available as GR-206 and GR-2007
MCP-N	LiF:Mg,Cu,P TLD Poland (former TLD Niewiadomski). Both ^{6}Li and ^{7}Li available as MCP-6 and MCP-7
MTS-N	LiF:Mg,Ti TLD Poland (former TLD Niewiadomski). Both ^{6}Li and ^{7}Li available as MTS-6 and MTS-7
LiF	LiF:Mg,Ti unspecified
DTG-4	LiF:Mg,Ti, Russian production
LiF:Mg,Cu,P	LiF:Mg,Cu,P unspecified
$Li_2B_4O_7$:Mn	$Li_2B_4O_7$:Mn, RADOS, Finland
$Li_2B_4^{11}O_7 : Cu$	Panasonic, Japan. Both $^{\prime\prime}$Li and ^{7}Li available
$Li_2B_4O_7$:Cu,Ag,P	Vinca, Serbia and Montenegro
MgB_4O_7: Dy,Na	Vinca, Serbia and Montenegro
$CaSO_4$:Dy	$CaSO_4$:Dy unspecific
$CaSO_4$:Tm	Panasonic, Japan
CaF_2	CaF_2 unspecific

In designing a beta dosemeter with satisfactory energy and angle dependence of response for measurement of $H_P(0.07)$ the following design parameters should be considered:

Thickness of the detector. If the thickness of the detector is higher than the range of beta rays, a skin dose correction factor may be applied to obtain the true $H_P(0.07)$ value from the measured value[4]. This is possible if the monitored radiation field is known. For low-energy beta particles (e.g. for [147]Pm with average energy 60 keV) detectors with a thickness of about 5 mg cm^2 are preferable and, in principle, do not require correction after calibration with standard ^{137}Cs, ^{60}Co or ^{90}Y/^{90}Sr sources[5]. A decreased effective thickness of the detector can be obtained for TL detectors after mixing the grains of sensitive material with graphite, to reduce the layer from which TL light escapes from the TL detector[5].

Detector efficiency as a function of electron energy. The change of detection efficiency with electron energy must be taken into account in the new generation of high-sensitive phosphors (LiF:Mg,Cu,P, LiF:Mg,Na, Al_2O_3:C). A decrease of detection efficiency in these phosphors with decreasing electron energy is an ionisation density (LET) effect. Due to this effect the detection efficiency for thin layer LiF:Mg,Cu,P (MCP-Ns) detectors per unit absorbed dose for [147]Pm beta rays (relative to ^{137}Cs) is only 0.90 [6].

Sensitivity of the detector. Over the last decade, high-sensitive detectors were introduced into practice, mainly LiF:Mg,Cu,P and Al_2O_3:C, which allow one to obtain the required measurement precision from a 5 mg cm^2 detector layer after doses of 10 μGy.

Thickness of the filter. A filter is applied to protect the detector against the harmful effects of the environment and to simulate the outermost layer of the skin, which is not sensitive to radiation. The optimum filter thickness is 7 mg cm^{-2} for a very thin detector. The filter thickness also strongly influences the angle dependence of the dosemeter.

Filter/detector geometry. The detector should be held as close as possible to the filter to minimise the shadow effect for beta rays entering the detector from large incident angles.

Neutron dosemeters

Neutron personal dosemeters are usually worn on the body trunk and are intended to determine personal dose equivalent, $H_P(10)$. In Figure 3 the Monte Carlo-calculated conversion coefficients[8] from neutron fluence to $H_P(10)$ are shown for normal neutron incidence. Energy and angle response of an ideal neutron dosemeter should match as closely as possible this conversion coefficient, i.e. the ratio of measured response per unit fluence, Φ of neutrons with the given energy and the $H_P(10)/\Phi$ conversion coefficient should be approximately constant over the considered range of neutron energy. In such a case a single calibration coefficient, universal for all beams, can be applied. This is typically not the case for personal neutron dosemeters, which are frequently calibrated for particular radiation fields.

The physics of neutron dosimetry is based on interactions of neutrons with nuclei producing charged secondaries that can be registered by appropriate detector systems[1]. For some isotopes
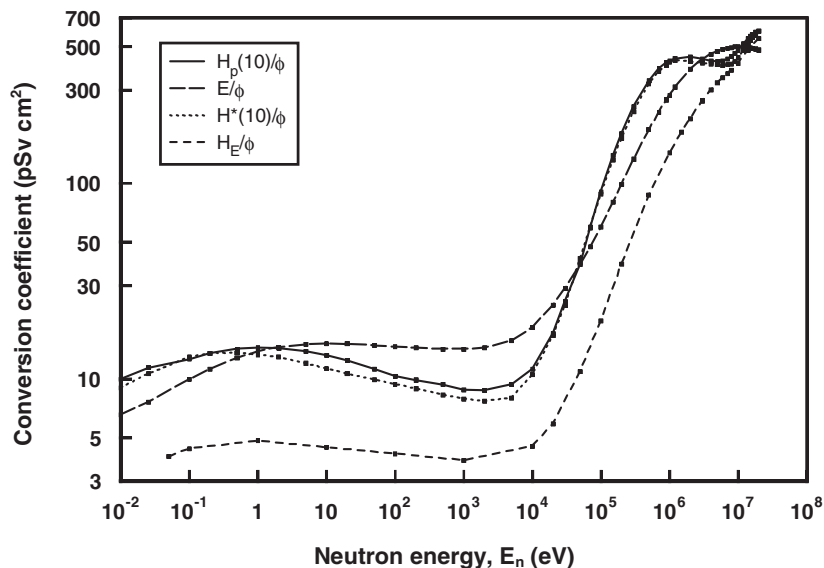

Figure 3. Conversion coefficients from neutron fluence to $H_P(10)$, $H^*(10)$, H_E and E from ICRU 57[7].

(e.g. ^{10}B, ^{6}Li, ^{113}Cd) very high cross sections for such nuclear reactions with thermal neutrons occur. Therefore, dosemeters based on the detection of neutrons thermalised in the body (albedo dosemeters) are relatively easy to build and are used most frequently. Commercially available albedo dosemeters typically use pairs of thermoluminescent detectors, one with ^{6}Li, with a high cross section for the reaction $n(^6$Li, $\alpha)^3$H, and another with ^{7}Li, sensitive predominantly to the γ-ray dose. The difference in the measured signals of those two detectors may be attributed to the neutron dose. However, albedo dosemeters show a pronounced dependence of the measured signal on the neutron spectrum, which decrease rapidly with increasing neutron energy and therefore require field calibration. No generalised energy dependence can be given since variations between systems are considerable, but albedo dosemeters are typically used for assessing doses from neutrons of energies not exceeding a few mega electron volt.

Technically more demanding, but still feasible, are systems to measure dose from fast neutrons in the energy range of 0.1–100 MeV. These systems are capable of detecting charged secondaries produced by high energy neutrons, mainly recoil protons and alpha particles. For neutrons of lower (except thermal) and higher energy, personal neutron dosimetry is extremely difficult. To overcome the problems of energy dependence, multi-element dosemeters sensitive to thermal and fast neutrons have been designed. Dose evaluations for unknown neutron spectra are then carried out using specific algorithms.

The available neutron dosemeters can be listed as albedo dosemeters, high energy dosemeters, and multi-element dosemeters. The last, third, category may be subdivided into dosemeters with one type of detector and different converters, and dosemeters with different types of detectors.

In this article the following abbreviations are used:

NA:	(Neutron) Albedo dosemeter
NH:	(Neutron) High energy dosemeter
NS:	(Neutron) Multi-element dosemeter, type 1 (one detector type and different converters)
NM:	(Neutron) Multi-element dosemeter, type 2 (different detector types)

In Table 7, a list is given of the detectors and converter materials used in the neutron dosemeters in European dosimetric services, responded to the questionnaires.

Table 7. Types of neutron dosemeters in use at the dosimetric services in the European countries.

Country code	Service code	Dosemeter type	Detector	Converter	Dosemeter per period
B	SCK-CEN	NM	Bubble: BD-PND/BDT		15
CH	CERN	NS	PACD (CR-39) from 2005		4000
CH	PSI	NS	PADC (CR39)	PE(Li), PE	1000
CZ	Temelin NPP	NA	TLD (6LiF/7LiF)		35
CZ	Dukovany NPP	NA	TLD (6LiF/7LiF)		60
CZ	IRP	NS	Mylor foil	U,Th	400
D	FZK HS-M	NA	TLD (6LiF/7LiF)		1200
DK	RISO	NM	PADC (CR39)/TLD	Plastic	75
EL	GAEC	NA	TLD (6LiF/7LiF)		60
EL	NPL	NS	PADC (CR39)	6LiF, PE	
F	COGEMA	NS	TLD (6LiF/7LiF)		12,100
F	IRSN	NS	PADC (CR39)		2000
F	LCiE	NS	PADC (CR39)		1300
FIN	STUK	NA	TLD (6LiF/7LiF)		30
H	EPS	NA	TLD (6LiF/7LiF)		50
HR	RBI	NA	TLD (6LiF/7LiF)		10
I	ENEA	NM	PADC (CR39)/TLD (7LiF/LiF)		800
LT	Ignalina NPP	NA	TLD (6LiF/7LiF)		400
NL	ECN	NA	TLD (6LiF/7LiF)		2200
PL	IFJ	NA	TLD (6LiF/7LiF)		60
S	Ringhals	NA	TLD		3000
SI	Krsko NPP	NA	TLD (6LiF/7LiF)		6
SK	Bohunice NPP	NA	TLD (6LiF/7LiF)		20
UK	NRPB	NS	PADC (CR39)		600
UK	NRPB	NS	PADC (CR39)	Nylon	1800

PHOTON DOSE CALCULATION AND BACKGROUND SUBTRACTION ALGORITHMS

To find the dose from the signal of the evaluating equipment, such as the output of a densitometer for measuring optical densities of a photographic film or the signal from the photomultiplier tube of a TLD-reader, some calculations must be performed. For a single detector per measured quantity these calculations can be as simple as subtracting the zero signal, R_0, from the gross signal, R, and dividing by a factor F:

$$H_P(d) = \frac{(R - R_0)}{F}. \tag{1}$$

An algorithm which consists of a linear combination of the signal of multiple detectors can be used for multi-detector designs:

$$H_P(d) = \sum_{i=1}^{n} \frac{(R_i - R_{0,i})}{F_i}. \tag{2}$$

The algorithm can contain non-linear terms, such as raising the signal to a power:

$$H_P(d) = \sum_{i=1}^{n} \frac{(R_i - R_{0,i})^{q_i}}{F_i}. \tag{3}$$

In various algorithms the ratios of the signals are used in 'if then else' algorithms:

$$\text{if } \frac{R_k}{R_l} > r_1 \quad \text{then } H_P(d) = \sum_{i=1}^{n} \frac{(R_i - R_{0,i})}{F_i},$$
$$\text{else } H_P(d) = \sum_{i=1}^{n} \frac{(R_i - R_{0,i})}{F_i'}. \tag{4}$$

In most cases the factors F are (for each i) a combination of a factor determined during the type testing of the dosemeter, f_t, a calibration factor f_c for the individual detectors and a factor, f_r, accounting for the sensitivity of the reading equipment:

$$F = f_t f_c f_r. \tag{5}$$

Film dosemeters

All dosimetric services that issue film dosemeters use an algorithm to calculate the operational quantity from the optical densities of multiple detectors. With the exception of one service, the algorithm used is a linear combination of the readings from the different detectors in the dosemeter or from the part of the film covered with different filters. As almost every dosemeter composition differs, the algorithms also differ from service to service. One service (PF5) reported the use of an algorithm where the photon

energy is taken into account by the formula dose = $K(\text{reading})^N$, where the values of parameters K and N depend on calibration and photon energy.

An example of the if–then algorithm, for the determination of $H_P(0.07)$ and $H_P(10)$ from the reading of film covered with different filters is given below:

For energy range, 20–1250 keV,
$H_P(0.07) = (K_{\text{air Sn/Pb}} + 0.11 K_{\text{air P300}} - 0.1 K_{\text{air Cu300}})$ Sv.
For energy range < 20 keV (where $K_{\text{air P300}}/K_{\text{air Cu300}} > 4$), $H_P(0.07) = (0.4 K_{\text{air Cu300}} + 0.61 K_{\text{air P50}} - 0.6 K_{\text{air P300}})$ Sv.

Algorithm for calculation of $H_P(10)$ from the detector signals
For the energy range 20–1250 keV, $H_P(10) = (K_{\text{air Sn/Pb}} + 0.11 K_{\text{air P300}} - 0.1 K_{\text{air Cu300}})$ Sv.
For energy range <20 keV (where $K_{\text{air P300}}/K_{\text{air Cu300}} > 4$), $H_P(10) = (0.04 K_{\text{air P300}})$ Sv,

where:

$K_{\text{air Sn/Pb}}$ is apparent gamma ray air kerma under 440 mg cm^{-2} Sn and 340 mg cm^{-2} Pb filters.
$K_{\text{air P300}}$ is apparent gamma ray air kerma under 300 mg cm^{-2} plastic filter.
$K_{\text{air Cu300}}$ is apparent gamma ray air kerma under 300 mg cm^{-2} Cu filter.
$K_{\text{air P50}}$ is apparent gamma ray air kerma under 50 mg cm^{-2} plastic filter.

To subtract the density due to fogging, all services use a set of control dosemeters. In some cases the dosemeters used to determine the characteristic curve of the film also serve for this purpose. In that case all films are of the same batch, stored in normal laboratory environment and developed at the same time as the films of the dosemeters of the customers.

Thermoluminescence dosemeters

Algorithms

The different algorithms that are used to calculate the dose from the TLD-reader signal as reported by the services can be divided into three categories:

No algorithm used: The quantity is directly calculated from the signal from one of the detectors in the dosemeter by applying a sensitivity correction factor (Equation 1),
Algorithms using multiple detectors: A combination of the readings of different detectors is used to obtain the desired quantity (Equations 2 and 3),
If-then algorithm: Depending on the ratio of different detectors, a different formula is used to calculate the quantity (Equation 4).

Table 8. Algorithms (no algorithm, multiply algorithm and if-then algorithm) used to calculate $H_P(10)$ and $H_P(0.07)$ from the TLD-reader signal, as reported by the services.

		$H_P(10)$			$H_P(0.07)$		
		No	Multiply	If-then	No	Multiply	If-then
A	PT1						
A	PT2		x				
A	PT3		x				
B	PT4			x			
B	PT5						
BG	PT39		x			x	
BG	PT40		x				
BG	PT41		x				
BG	PT42		x				
BG	PT43	x				x	
CH	PT6	x					
CH	PT7	x					
CH	PT8			x			
CH	PT9		x				
CH	PT10						
CZ	PT44	x			x		
CZ	PT45	x			x		
D	PT11						
DK	PT12	x					
DK	PT13	x					
E	PT14			x			
E	PT15						
E	PT16						
E	PT17			x			
EST	PT46	x					
FIN	PT19	x					
FIN	PT18		x				
HR	PT47						
I	PT21	x			x		
I	PT22	x					
I	PT32	x			x		
I	PT33						
I	PT34						
I	PT35						
I	PT36	x			x		
I	PT37	x			x		
I	PT38						
IRL	PT20		x				
LT	PT49		x		x		
LT	PT50	x			x		
LV	PT48						
NL	PT23	x					
NL	PT24			x			
NL	PT25						
NL	PT26	x					
PL	PT51	x				x	
PT	PT27	x					
RO	PT52	x			x		
RO	PT53		x				
S	PT28	x					
S	PT29	x					
SI	PT54		x				
SI	PT55	x			x		
SK	PT56	x			x		
UA	PT57	x					

Table 8. Continued

		$H_P(10)$			$H_P(0.07)$		
		No	Multiply	If-then	No	Multiply	If-then
UA	PT58	x					
UK	PT31						
UK	PT30	x					
YU	PT59						
YU	PT60	x				x	

Most services determine the zero signal R_0 during the calibration of the reader, but glow curve analysis is also used.

In Table 8 the categories of algorithms used to calculate dose by services, are specified. Most services calculate $H_P(d)$ without any special algorithm, by using an appropriate calibration factor, subtracting the background signal, sometimes applying correction for individual detector sensitivity and averaging the signal from 2–3 detectors.

Background subtraction

Dose due to natural background during the issuing period is usually below the detection limit of film dosemeters, therefore any background correction is seldom needed in these systems. If correction is needed, background control dosemeters are used.

The dosimetric services issue the correct TLDs for the dose due to the natural background radiation in three different ways: (i) no correction, (ii) control dosemeters and (iii) fixed national or regional averages. In Table 9 is summarised the information on the methods of subtraction of the natural background and the values applied, which are collected from the questionnaires. For 60 services, 35 use control dosemeters to assess the value of the background correction and 16 use the value of the national background. The subtracted values of natural background radiation vary between 0.4 and 2.4 mSv y^{-1}.

ENERGY AND ANGLE DEPENDENCY OF RESPONSE

In the questionnaire, information on the response characteristics of the dosemeters was requested. The response is the quotient of the measured dose of radiation of specified energy and angle of incidence, and the true dose, $H_P(d)_{measured}/H_P(d)_{true}$. The true dose, $H_P(d)_{true}$, is calculated from a measured dose rate, generally as air kerma free-in-air, using equipment traceable to a national (primary) standard, in conjunction with appropriate conversion co-efficients[7,9].

Of the responding services, 32 gave sufficient information to show the energy dependence of the

Table 9. Method of background subtraction and values in mSv y^{-1}

Country	Service	Method	Value (mSv y^{-1})
A	PT1	No correction	
A	PT2	No correction	
A	PT3	No correction	
B	PT4	National average	0.88
B	PT5	National average	0.66
BG	PT39	Control dosemeters	2.4
BG	PT40	Control dosemeters	0.8–1.0
BG	PT41	Control dosemeters	0.8–1.5
BG	PT42	No correction	
BG	PT43	Control dosemeters	1
CH	PT10	National average	0.72
CH	PT6	National average	0.5
CH	PT7	Control dosemeters	
CH	PT8	Control dosemeters	0.7–0.9
CH	PT9	National average	1.8
CZ	PT44	Control dosemeters	
CZ	PT45	Control dosemeters	
D	PT11	National average	0.6
DK	PT12	Control dosemeters	0.72
DK	PT13	Control dosemeters	1.4
E	PT14	Control dosemeters	1.2–2.5
E	PT15	Control dosemeters	1.0–1.2
E	PT16	National average	0.72
E	PT17	Control dosemeters	0.7
EST	PT46	National average	0.48
FIN	PT18	Control dosemeters	0.07–1.7
FIN	PT19	Control dosemeters	1.8–3.1
HR	PT47	Control dosemeters	1.2
I	PT21	Control dosemeters	2–2.5
I	PT22	National average	0.8
I	PT32	Control dosemeters	1.5–2.0
I	PT33	Control dosemeters	
I	PT34	Control dosemeters	0.6
I	PT35	Control dosemeters	
I	PT36	Control dosemeters	0.4–2.0
I	PT37	Control dosemeters	
I	PT38		
IRL	PT20	National average	1.46
LT	PT49	National average	0.6
LT	PT50		
LV	PT48	Control dosemeters	1.6
NL	PT23	Control dosemeters	0.66
NL	PT24	National average	0.8
NL	PT25	National average	0.77
NL	PT26	Control dosemeters	0.66
P	PT27	No correction	
PL	PT51	Control dosemeters	
RO	PT52	National average	1.7
RO	PT53	Control dosemeters	1
S	PT28	Control dosemeters	
S	PT29	Control dosemeters	0.6–1.8
SI	PT54		
SI	PT55	Control dosemeters	1.0–1.2
SK	PT56	Control dosemeters	
UA	PT57	Control dosemeters	1.0–1.2
UA	PT58	Control dosemeters	0.7–0.98
UK	PT30	National average	0.6

Table 9. Continued

Country	Service	Method	Value (mSv y^{-1})
UK	PT31	Control dosemeters	
YU	PT59		
YU	PT60	National average	0.96

response in graphical form. Only a few services gave information on the response at angles other than normal incidence.

The presented response curves are typically the results of type-test experiments in which the dosemeters are exposed to monochromatic or narrow spectrum radiation qualities, all at the same angle of incidence. In practical situations, this is seldom the case. In a number of dosemeters in which the detectors are far from tissue-equivalent there is strong reliance on algorithms that essentially attempt to estimate the quality of the radiation to which they were exposed. These systems may operate very successfully in monochromatic or narrow spectrum fields, but fail in mixed radiation situations. This can result in multi-detector dosemeters with very good response characteristics as judged from type tests, being, for specific practical situations, inferior to dosemeters with only one but approximately tissue-equivalent detector, which may show less favourable type-test response characteristics.

Whole-body photon dosemeters

Information on the energy dependency of the response of their film dosemeters was given by 10 services in terms of $H_P(10)$, while 7 services provided data on response in terms of $H_P(0.07)$. The information is shown in an anonymous form in Figures 4 and 5.

Information on the energy response of TLDs was supplied by 26 dosimetric services. Information concerning $H_P(10)$ is shown in anonymous form in Figure 6 and that concerning $H_P(0.07)$ in Figure 7. Due to the flat energy response of TLDs for photon energy above 100 keV, the response of most TLDs fall within the plus and minus 20% limits. Only quite a few systems show larger deviations at energies below 100 keV.

Whole-body beta dosemeters

Information on the response characteristics of beta whole-body dosemeters was given by 15 dosimetric services. Five of these used film dosemeters and one service gave information on a direct ion storage dosemeter. Four services, using film dosemeters, reported response equal to 1.0 for all beta energies. In Figure 8 the data for nine beta TLDs are presented.
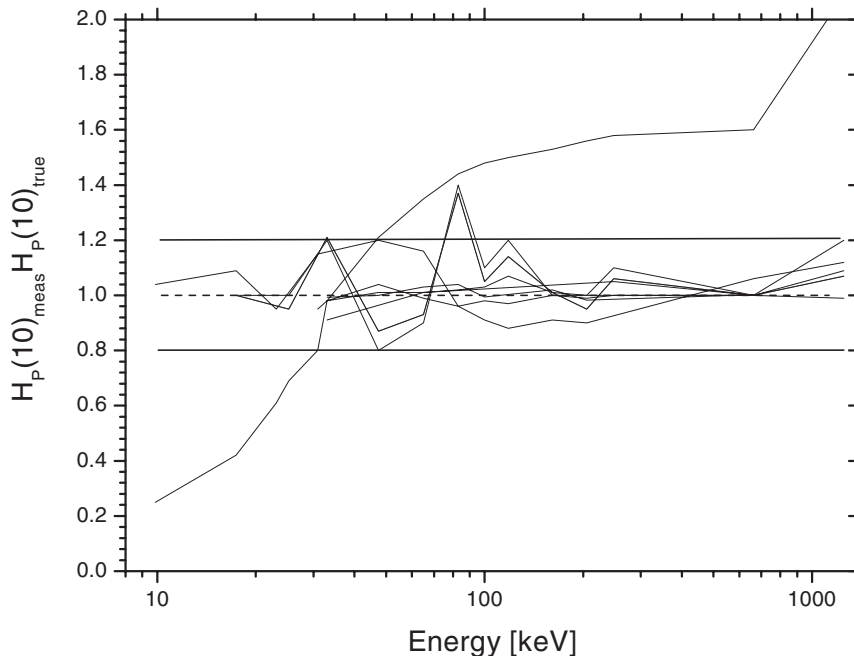
Figure 4. Response, $H_P(10)_{measured}/H_P(10)_{true}$ as a function of energy for whole-body photographic film photon dosemeters for normal incidence.
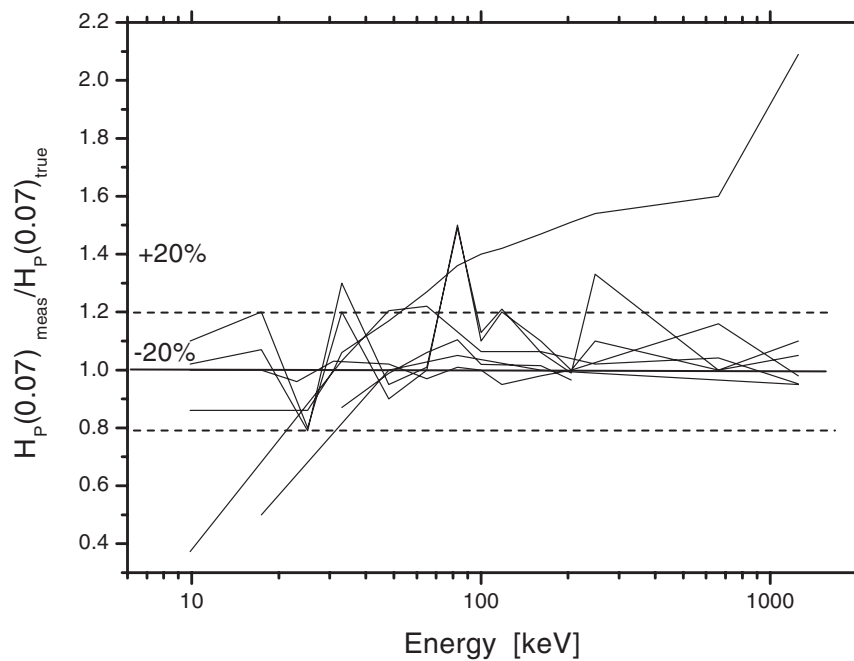

Figure 5. Response, $H_P(0.07)_{measured}/H_P(0.07)_{true}$ as a function of energy for whole-body photographic film photon dosemeters for normal incidence.
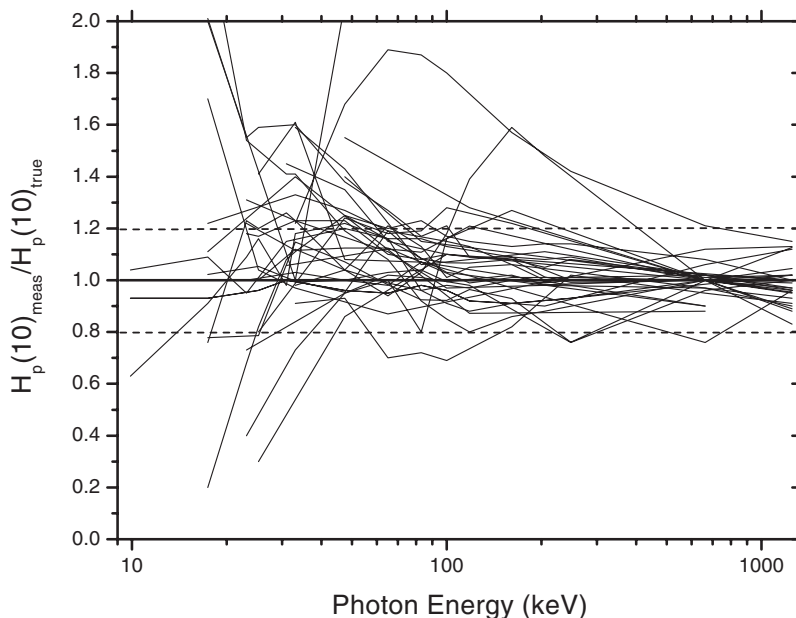
Figure 6. Response, $H_P(10)_{measured}/H_P(10)_{true}$ as a function of energy for whole-body photon TLDs for normal incidence.
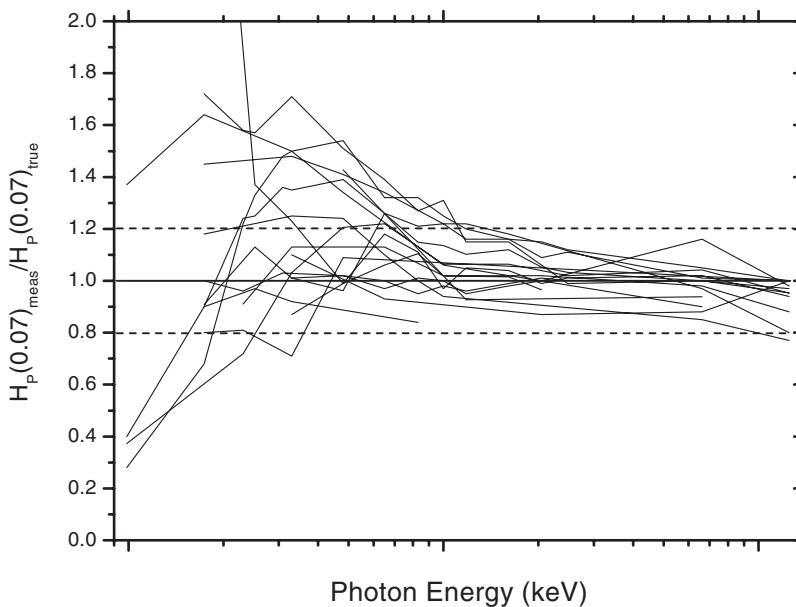

Figure 7. Response, $H_P(0.07)_{measured}/H_P(0.07)_{true}$ as a function of energy for whole-body photon TLDs for normal incidence.

Whole-body neutron dosemeters

Ten services gave information on the energy response of their neutron dosemeters. Figure 9 shows the response curves for these multi-element dosemeters (NS and NM). As it is not feasible to generate neutrons in the energy range of roughly 10^{-7} to 10^{-2} MeV, no experimental data are available for that range. Therefore in this energy range, the calculated response for one system is shown.
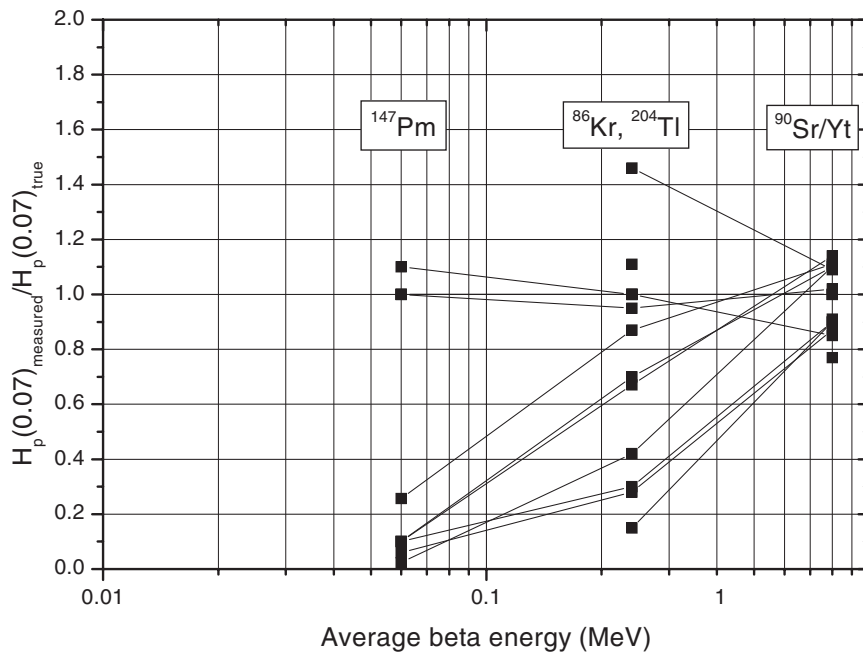
Figure 8. Response, $H_P(0.07)_{measured}/H_P(0.07)_{true}$ as a function of average beta energy (MeV) for whole-body beta TLDs at normal incidence.
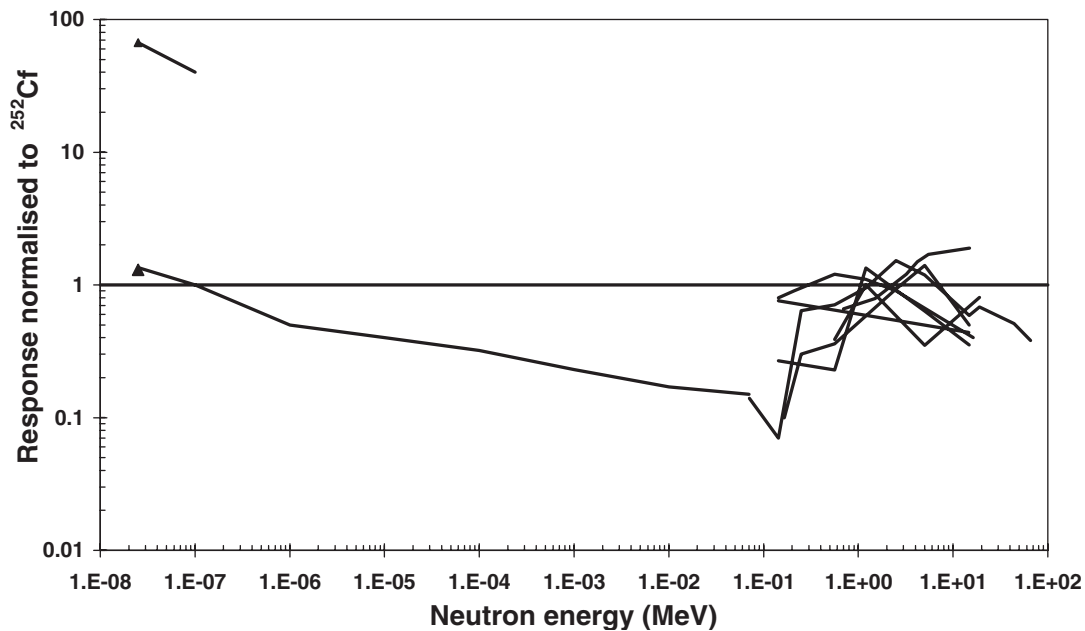
Figure 9. Response, $H_P(10)_{measured}/H_P(10)_{true}$ as a function of energy for multi-element (NS and NM) whole-body neutron dosemeters for normal incidence, normalised to ^{252}Cf.

CALIBRATION

The calibration procedure of the personal dosemeter relates the evaluated detector signal to the legal dosimetric quantity, e.g. $H_P(d)$. The calibration process consists typically of two steps, i.e. (i) irradiation of the dosemeter in the reference field, with dose rate traceable to primary standards and performed typically on the relevant phantom and (ii) readout of the detector in the standardised conditions. The radiation field is frequently characterised in term of kerma in air rate, K_{air}, and $H_P(d)$ is calculated using the conversion coefficients $H_P(d)/K_{air}$[7] relevant for the given beam and phantom

In most cases the calibration factor F is calculated as a combination of a factor determined during the type testing of the dosemeter, f_t, a calibration factor f_c for the individual detectors and a factor, f_r, accounting for the sensitivity of the reading equipment (see 3.4).

The calibration procedures for different dosimetric systems, including film dosemeters and TLDs, are similar but some differences should be noted. One of them is that TLDs are typically re-used and therefore for most systems each detector can be characterised individually, by introducing individual calibration coefficients. A common practice is that these coefficients for the given batch of detectors are determined once a year, typically after 10–15 readouts. For films, nuclear emulsions and track etch dosemeters no individual correction coefficients can be applied and typically only a batch homogeneity is checked.

The signal generated from the irradiated reference dosemeters at the output of the evaluating equipment have to be related to the value of dose. This signal is used to calibrate the entire evaluating system (e.g. TL reader), f_r. However, the parameters of the system can show a short-term (within a single working day) and long-term instability. A full calibration in reference conditions is time consuming for every day operation of the dosimetric service. Therefore, for the daily check of stability of TLD-readers, simple ^{90}Sr–^{90}Y irradiators can be applied. The signal from detectors exposed by the irradiator should be related to the signal from detectors that underwent the full calibration performed in reference conditions (beam traceable to national standards, relevant phantom). After type testing of dosemeters on appropriate phantoms, the routine recalibration, which essentially is the determination of a sensitivity correction factor, can be done free-in-air. Of the services that use a phantom, about 50% use the ISO water filled slab, the others use the ICRU PMMA slab phantom. Most services use PMMA sheets for build-up.

Irradiation sources. For the actual calibration radioactive sources are used. Isotopes in general use are ^{137}Cs and ^{60}Co. A few services report the use of ^{90}Sr–^{90}Y and ^{226}Ra. Most services that responded to the section of the questionnaire on calibration report that their sources are traceable to a national (primary) standard.

Evaluating equipment. In many cases, the evaluating equipment, in particular TLD-readers, is tested and calibrated daily with reference dosemeters irradiated to a known dose. Some frequencies are reported for as low as once a year. Most services use ^{137}Cs sources for this routine calibration, but several others use ^{60}Co and ^{90}Sr–^{90}Y irradiators.

Dosemeters. Batches of photographic films are calibrated periodically, usually once per month or on arrival of a new consignment from the manufacturer, by taking representative samples.

Thermoluminescence dosemeters are in general recalibrated once a year or after a number of issuing periods that may also often be annually. For the radiation sources used the same applies as for the equipment calibration.

PERFORMANCE

Requirements for approval of a dosimetric service by the authorities always address the performance of the dosemeter and its evaluation system. These approval requirements can be very detailed, setting criteria for a great number of performance parameters, or set only limits to the overall uncertainty in a dose assessment. In general the international and national requirements for the performance of dosimetric systems are derived from ICRP and ICRU recommendations. In ICRP Publication 75 'General Principles for the Radiation Protection of Workers'[8] the following is stated:

> In practice, it is usually possible to achieve an accuracy of about 10 % at the 95 % confidence level for measurements of radiation fields in good laboratory conditions. In the workplace, where the energy spectrum and orientation of the radiation field are generally not well known, the uncertainties in a measurement made with an individual dosemeter will be significantly greater. Non-uniformity and uncertain orientation of the radiation field will introduce errors in the use of standard models. The overall uncertainty at the 95 % confidence level in the estimation of effective dose around the relevant dose limit may well be a factor of 1.5 in either direction for photons and may be substantially greater for neutrons of uncertain energy, and for electrons. Greater uncertainties are also inevitable at low levels of effective dose for all qualities of radiation.

And further on: ... the recording level for individual monitoring should be derived from the duration of the monitoring period and an annual effective

dose of no lower than 1 mSv ... and ... 'the recording level is useful in defining the low dose requirements of dosemeters; it can be used as the basis for defining performance requirements'.

For the evaluation of the uncertainty in a dose assessment, e.g. using the procedures recommended in the ISO Guide for the Expression of Uncertainty in Measurements (GUM)[10], the asymmetrical confidence band given in ICRP 75[9] is inconvenient. In the EU recommendations[11], therefore, the uncertainty is given as a relative standard uncertainty of 0.21 (21%). The interpretation in ICRU report 47[12] states, 'in most cases, an overall uncertainty of one standard deviation of 30 % should be acceptable' thus translating the range of 1/1.5 to 1.5 as mentioned in ICRP 75 into a relative standard uncertainty of 0.30.

All these confidence limits and uncertainties are in general interpreted as referring to the instrumental errors only. Thus inappropriate use of the dosemeter and very inhomogeneous fields where a single dosemeter can never provide a good estimate of total body exposure are conditions that are not considered in these discussions.

The performance can roughly be analysed in two ways: (1) A performance test where irradiation takes place in simulated workplace conditions and (2) a type test in which the characteristics of the dosemeters are assessed and the uncertainties evaluated from the test results.

Performance test

One method is irradiating an appropriate number of dosemeters to a variety of radiation fields and conditions of which the dose rates are known and traceable to national standards. These fields should preferably be representative of realistic workplace fields. If the number of dosemeters and the number of irradiation conditions is large and varied enough, then if 95% of the results lie within 0.667 times and 1.5 times the true value, it can be claimed that the dosemeter complies with the above-mentioned ICRP recommendations.

Such performance tests are, for example, organised by international organisations such as the IAEA[13] and EURADOS[14]. In the results of the most recent EURADOS, intercomparisons are plotted and the irradiation conditions are summarised.

Figure 10 shows that for all but four irradiation conditions, all points (all but one in the case of PO11) fall within the range 0.667–1.5. The fields that some dosemeters seem to have a problem with are the 6 MeV photons of PO2, PO3 and PO4. In field PO2, the R-F radiation is mixed with 80% 300 keV wide spectrum photons rotated at angles ranging from +80 to −80° (See Table 10). In field PO4, there was no electronic equilibrium, a condition for which the dosimetric quantities are not defined. The field PO12 also presents a problem, however, this is a low-dose field for which the
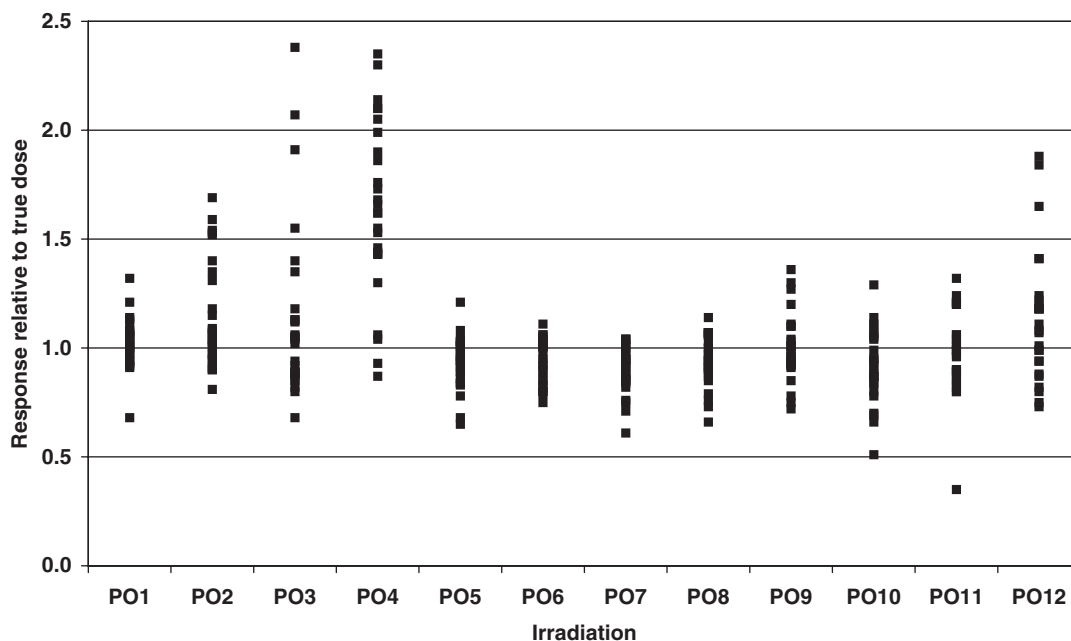

Figure 10. Results of the EURADOS intercomparison showing the response of 26 different dosemeter types for 12 irradiation conditions.

Table 10. Radiation qualities, angles of incidence and nominal dose values selected together with some additional information.

Radiation field code	Radiation quality	Irradiation laboratory	Nominal $H_P(10)_{slab}$ dose value (m Sv)
P1	R-F (0°) + W-300 (WA ± 80°) [50 + 50%]	PTB	1.0
P2	R-F (0°) + W-300 (WA ± 80°) [20 + 80%]	PTB	7.2
P3	R-F (0°)	PTB	1.0
P4	R-F (0°) without electronic equilibrium	PTB	1.0
P5	S-Ir (0°) + S-Ir (WA ± 80°) [50 + 50%]	ARCS	10
P6	S-Ir (0°)	ARCS	1.0
P7	S-Ir (0°)	ARCS	40
P8	S-Ir (WA ± 80°)	ARCS	10
P9	S-Co (0°) + W-80 (WA ± 80°) [50 + 50%]	NRPB	3.0
P10	S-Co (0°) + W-80 (WA ± 80°) [80 + 20%]	NRPB	80
P11	S-Co (0°) + W-80 (WA ± 80°) [80 + 20%]	NRPB	1.0
P12	W-80 (WA ± 80°)	NRPB	0.4

Field codes as in ISO 4037 WA denote wide angle irradiations giving the angles of rotation and the percentages show the dose proportions for mixed fields.

ICRP recommends a wider range from 0.5 to 2 for the 95% confidence interval. Over all, excluding PO4, 94% of the measurements were within the 0.667–1.5 range. Film dosemeters tend to have more problems with mixed fields than have TLDs, mainly because the detectors are much closer to being tissue-equivalent. Of the results from TLDs, 98% were within the recommended limits. The response curves of the participating dosemeters are among the curves shown in Figures 6 and 7.

Type test

Guidance for type testing of dosemeters can be found in the recommendations of the EU[11], Safety Guides of the IAEA[15] and International standards, such as ISO 1757[16] for film dosemeters, IEC 61066[17] for TLD and IEC 61283[18] for electronic personal dosemeters (See Table 11). As an example, the results of type testing of three different TLD systems has been reported by Julius et al.[19].

Major issues in the type test are determination of the energy and angular dependence of the response, the repeatability of a measurement and the detection and determination limits. Using the methods given in the GUM[10] the combined results of such experiments can be used to estimate the combined standard uncertainty in a dose assessment. This combined standard uncertainty can than be compared with the recommendations mentioned earlier. If the recording level of 1 mSv on an annual basis is interpreted as a detection limit, then it can be converted to a required detection limit on a monthly basis of about $\frac{1}{12}$ or 0.3 mSv and thus a standard uncertainty of less than 0.1 mSv. It must be emphasised, however, that the notion of recording level, as coined in ICRP 75[9] does not go together with the current concepts of quality assurance as recommended in international standards, such as ISO

17025[20]. The recording level must only be used for deriving a requirement for the detection limit and certainly not as a recommendation to delete dose measurements from the databases.

The results of repeated measurements can be evaluated by standard deviations. The standard deviation of doses at the level of the natural background radiation can be used to determine the detection limit, as a rule-of-thumb, 3 times the standard deviation, and the limit of quantitative determination, roughly 10 times the standard deviation[21]. These limits can then be compared with the recording level, as discussed above. The variation in measurement results, as expressed by the standard deviation, is of course also a measure for the uncertainty in individual dose assessment. The ISO GUM[10] assigns to the standard uncertainty the same numerical value of the standard deviation in what is called type-A evaluation of standard uncertainty.

The results of measurements of the response, the ratio of the measured dose and the true dose, as a function of radiation energy and as a function of angle of radiation incidence can be used to estimate the contribution of these factors to the overall uncertainty in a dose assessment. Using methods given in the ISO GUM[10] and called type-B evaluation of standard uncertainty can then be used to convert these results to standard uncertainty. This evaluation requires presuppositions on the probability distribution of the influence parameters. If such a distribution is not known a rectangular distribution is considered in most cases, meaning that all responses found in the type test have equal probability. The corresponding standard uncertainties are then calculated as being the difference between the highest and lowest response divided by 2/3.

Having thus the results of type-A and type-B evaluations for the various parameters, the combined

Table 11. Statistics on the quality assurance programme of dosimetric services in Europe.

Country Code	'Blind' test	ISO 9000	EN 45000	GLP	ISO 17025	Comments
A			4			All approved dosimetric services are subjected to a quality test programme by the Federal Office of Metrology (BEV).
B						None of the services indicated that a QA-programme was implemented.
BG	5					One QA programme of the department was reported.
CH	4	1	1		2	
CZ		1		1		Every year verification by Czech Metrological Institute. Own programme of the Institute.
D						None of the services reported to have a QA-programme implemented. However, approved dosimetric services in Germany are subjected to a quality test programme by the Physikalisch Technische Bundesanstaltt PTB
DK	3					
E	1		1			
EL	1				1	The service has applied for laboratory accreditation through the National Accreditation Board (NAB)
EST						
F		1	1	1		Dosimetric services are subject to 'announced' performance tests organised by the Office de Protection contre les Rayonnements Ionisants (OPRI).
FIN	2		1			
H		1			1	
HR						
I						Two dosimetric services that responded, both participate in the voluntary QA-test programme 'Experts in Personal Dosimetry' (EPD) by ENEA.
IRL						
L						
LT				1		Local Quality Assurance programme.
LV						
NL	2	1				
PL			3			All services are accredited by the Polish Centre of Accreditation, PCA. All services will adopt their procedures to IS_17-25
P						
RO	1		1	1		NPP Cernavoda reported that its QA programme is based on Canadian Standard for NPP
S	1					
SI	2					The procedures of one Laboratory follow IEC 1066
SK						One service reported its own QA programme
UK	4	1				
YU		1	1	1		One service reported ISO-900, EN-4500 and GLP

uncertainty is calculated by taking the square root of the sum of squares of the individual uncertainty components. Using this evaluation method on the data supplied by the 20 respondents to the questionnaire, which supplied sufficient information on their systems, it is found that for only one (film) system is the combined standard uncertainty significantly larger than that recommended.

Comparing with requirements

The above evaluation based on type-tests results in larger standard uncertainties than those estimated on the basis of performance studies, such as the EURADOS and IAEA intercomparisons. This indicates that the supposed uniform distribution is not realistic for circumstances encountered in practical workplace fields. Quite likely, a triangular or normal distribution of errors is more appropriate, in particular for the angular dependence of the response. If these evaluations are used for metrological purposes this does not pose a serious problem when used with the knowledge of background dose. However, if type-test results are to be used as input for an approval procedure, percentages can become very important. The various ways of

setting criteria based on type-test results in national and international standards and recommendations reflects the complexity of the discussion in this field[16–22].

SUMMARY AND CONCLUSIONS

The catalogue of dosemeters and dosimetric services within the EU Member States and Switzerland, which was issued by EURADOS in the year 2000[1], has been updated and extended by information on dosimetric services in the new EU Member States and Bulgaria, Croatia, Romania, Serbia and Montenegro, and Ukraine. The total number of dosimetric services in these European countries is now estimated to be about 200. The present catalogue is based on information collected from 91 European dosimetric services, among which 34 questionnaires from 32 services were obtained over the years 2001–2004 for the first time. The new report reviews and updates the presently used designs of personal dosemeters and the extent to which occupationally exposed persons in Europe are monitored with dosemeters, which are able to measure the operational quantity—personal dose equivalent, $H_P(d)$. The perspective of joining EU by the new countries has accelerated the implementation of the EU Basic Safety Standard Directive[2] to their national regulations. As a result, all newly investigated services reported their ability to measure $H_P(d)$. The catalogue provides updated information on the dosemeters, dose calculation and background subtraction algorithms, type-testing methods, energy and angular response and performance.

The main objective of the harmonisation of radiation protection systems within European states is to allow for the reliable comparison and transfer of dosimetric data for occupationally exposed people within Europe and in consequence, to facilitate mobility of radiation workers. A large number of dosimetric services in Europe, using a great variety of dosemeters with different types of detectors, makes this task difficult. A further harmonisation work is needed, oriented at periodical organisation of European intercomparisons of personal dosemeters that can be used for dosimetric services, which we wish to participate.

REFERENCES

1. van Dijk, J. W. E., Bordy, J. M., Vanhavere, T. F., Wernli, C. and Zamani-Valasiadou, M., *A catalogue of dosemeters and dosimetric services within EU Member States and Switzerland able to estimate external radiation doses as personal dose equivalent*. Radiat. Prot. Dosim. **89**, (1–2), 53–105 (2000).
2. European Commission. *Council Directive 96/29/ EURATOM of 13 May 1996 laying down basic safety standards for the protection of the health of workers and the general public against the dangers arising from ionizing radiation*. Off. J. Eur. Commun. L159 **39**, (1996).
3. Bartlett, D. T. and Steele, J.D. *Characteristics of personal dosemeters to measure $H_P(10)$ for photons*. In Intercomparison for Individual Monitoring of External Exposure from Photon Radiation, IAEA TECDOC 1126 (1999).
4. Christensen P., Herbaut Y. and Marshall T. O. *Personal monitoring for external sources of beta and low energy radiations*. Radiat. Prot. Dosim. **18**, 241–260 (1987).
5. Bilski, P., Olko, P., Burgkhardt, B. and Piesch, E. *Ultra-thin LiF:Mg,Cu,P detectors for Beta Dosimetry*, Radiat. Measur. **24**, 439–443, (1995).
6. Bilski, P., Olko, P., Burgkhardt, B., Piesch, E. and Waligórski, M. P. R. *Thermoluminescent efficiency of LiF:Mg,Cu,P (MCP-N) detectors to photons, beta-electrons, alpha particles and thermal neutrons*. Radiat. Prot. Dosim. **55**, 31–38, (1994).
7. International Commission on Radiation Units and Measurements. *Conversion coefficients for use in radiological protection against external radiation*. ICRU Report 57, (Bethesda, MD: ICRU) (1998).
8. International Commission on Radiological Protection. *General Principles for the Radiation Protection of Workers*. ICRP Publication 75. Ann. ICRP 27 (1) (Oxford: Pergamon Press) (1997).
9. International Commission on Radiation Units and Measurements. *Quantities and units in radiation protection dosimetry*. ICRU Report 51 (Bethesda, MD: ICRU) (1997).
10. International Organization for Standardization. *Guide to the expression of uncertainty in measurement*. Supported by BIPM, IEC, IFCC, ISO, IUPAC, IUPAP and OIML, (Geneva: ISO) (1995).
11. Christensen, P., Julius, H. W. and Marshall, T. O. *Radiation protection 73, technical recommendations for monitoring individuals occupationally exposed to external radiation*. EUR 14852 European Commission DGXI (Luxembourg: EC) (1994).
12. International Commission on Radiation Units and Measurements. *Measurement of dose equivalents from external photon and electron radiations*. ICRU Report 47, (Bethesda, MD: ICRU) (1992).
13. International Atomic Energy Agency. *Intercomparison for individual monitoring of external exposure from photon radiation*. IAEA-TECDOC-1126 (Vienna: IAEA) (1999).
14. Bordy, J. M., Stadtmann, H., Ambrosi, P., Bartlett, D. T., Christensen, P., Colgan, T. and Hyvonen, H., *Performance test of dosimetric services in the EU Member States and Switzerland for the routine assessment of individual doses (photon, beta and neutron)*. Radiat. Prot. Dosim. **89**, 107–154 (2000).
15. International Atomic Energy Agency. *Assessment of occupational exposure due to external sources of radiation*. IAEA Safety Standards Series No. RS-G-1.3 (Vienna: IAEA) (1999).
16. International Organization for Standardization. *Personal photographic dosemeters*. ISO 1757 (Geneva: ISO) (1996).
17. International Electrotechnical Commission. *Thermoluminescent dosimetry systems for personal and*

environmental monitoring. IEC 61066 (Geneva: IEC) (1991).

18. International Electrotechnical Commission. *Radiation protection instrumentation—direct reading personal dose equivalent (rate) monitors—X, gamma and high energy beta radiation.* IEC 61283 (Geneva: IEC) (1995).

19. Julius, H. W., Marshall, T. O., Christensen, P. and VanDijk, J. W. E., *Type testing personal dosemeters for photon energy and angular response.* Radiat. Prot. Dosim. **54** (3–4), 273–277 (1994).

20. International Organization for Standardization. *General requirements for the competence of testing and calibration laboratories.* ISO/IEC 17025:2000, (Geneva: ISO) (2000).

21. Currie, L. A., *Limits of qualitative detection and quantitative determination.* Anal. Chem. **40** (3), 586–593 (1968).

22. American National Standards Institute. *American national standard for dosimetry—personal dosimetry performance criteria for testing.* ANSI/HPS 13.11:2001 Health Physics Society (2001).

APPENDIX

List of Dosimetric Services in Europe, which Responded to the Questionnaire

1. A Dosemeterservice Seibersdorf Austrian Research Centre Seibersdorf, Hannes Stadtmann, 2444 Seibersdorf, Austria, Tel: +43 2254 780 2514, Fax: +43 2254 780 2502, E-mail: hannes.stadtmann@arcs.ac.at

2. A Pruefstelle fuer Strahlenschutz PSS, Harald Spreizer, Auenbruggerplatz 32, A-8036 Graz, Austria, Tel: +43 316 385 2440, Fax: +43 316 385 4147

3. A Gemeinsame Einrichtung fur Personendosimetrie, Dietmar Muller, Innrain 66, 6020 Insbruck, Austria, Tel: +43 512 504 5780, Fax: +43 512 504 5729, E-mail: dietmar.mueller@uklibk.ac.at

4. A Physikalisch Technische Prüfanstalt für Radiologie, Dr. Spreitzer, Wärwger Gurtel 18-20, A-1090 Vienna, Austria, Tel: +43 1 40400 6000, Fax +43 1 40400 6030

5. B Radiation Protection Dept. University Ghent, H.M.A. Thierens, Proeftuinstraat 86, 9000 Ghent, Belgium, Tel: +32 9 264 66 43 or 54

6. B Dosimetry SCK-CEN, Filip Vanhavere, Boeretang 200, 2400 Mol, Belgium, Tel: +32 14 33 28 80, Fax: 32 14 32 1056, E-mail: fvanhave@sckcen.be

7. B Radiotherapy UZ Gasthuisberg, J. van Dam, Herestraat 49, 3000 Louven, Belgium, Tel: +32 16347642

8. BG Kozloduy NPP, Kozloduy Nuclear Power Plant-Personnel Dosimetry, Maria Neshkova, Kozloduy NPP - PLC, 3321 Kozloduy, Bulgaria, Tel: ++359973 72538, E-mail: mneshkova@npp.cit.bg

9. BG Operational Radiation Dosimetry Control Service Radioactive Wastes Treatment Plant (RAWTP)(Kozloduy NPP), G. Dimov, Radioactive Wastes Treatment Plant (RAWTP), 3321 Kozloduy, Bulgaria, Tel: +359 973 7 3027, E-mail: dimov@npp.cit.bg

10. BG Laboratories Protecta Laboratories Protecta Ltd., M.G. Gelev, 22 Ivan Vazov St., 1000 Sofia, Bulgaria, Tel: +359 98 384254, E-mail: MGelev@yahoo.com

11. BG Laboratory for Radiation Protection (LRP-INRNE) Institute for Nuclear Research and Nuclear Energy, M.G. Gelev, 72 Tzarigradsko chaussee blvd, 1784 Sofia, Bulgaria, Tel: +3592 7144 358, Fax: +3592 975 3619, E-mail: mguelev@inrne.bas.bg

12. BG NCRRP Nat Centre of Radiobiology and Radiation Protection Lab-Dosimetry of External Radiation, A.G. Karadjov, 132 Kliment Ohridski Blvd, 1756 Sofia, Bulgaria, Tel: +359 2 623214, Fax: +359 2 621059, E-mail: ncrrp@ncrrp.org

13. CH BKW FMB Energie AG, Markus Zuercher, ZUM, 3203 Muehleberg, Switzerland, Tel: +41 31 754 71 11, Fax: 41 31 754 71 23, E-mail: markuszuercher@swissonline.ch

14. CH Service de Dosimetrie Individuelle CERN, Otto Thomas, NS Division, 1211 Geneva, Switzerland, Tel: +41 22 767 21 55, E-mail: thomas.otto@cern.ch

15. CH Comet Technik AG, David Maurer, Stationsstrasse 12, 3097 Liebefeld, Switzerland, Tel: +41 31 970 4463, Fax: +41 31 970 4564, E-mail: ct.zurbrugg@bluewin.ch

16. CH Institut de radiophysique appliquee, A. Besancon, 1015 Lausanne, Switzerland, Tel: +41 21 693 3165

17. CH Division for Radiation Protection and Waste Management Paul Scherrer Institute PSI, Markus Boschung, 5232 Villigen, Switzerland, Tel: +41 56 310 2111, E-mail: markus.boschung@psi.ch

18. CH Messtelle fuer Personendosimetrie PEDOS AG, B.S. Beat Steck, Unterer Wehrliweg 7B, 3074 Muri bei Bern, Switzerland, Tel: +41 31 954 13 13

19. CZ Temelin NPP Personal Dosimetry Service-Temelin NPP, Martin Schacherl, CEZ, a.s., Divize Výstavba-jete, 37305 Temelín, Czech Republic, Tel: +420334783540, Fax: +4203342794, E-mail: schacm1.ete@mail.cez.cz

20. CZ Personal Dosimetry Department CEZ a.s – NPP Dukovany, Zdenek Zelenka, 67550 Dukovany, Czech Republic, Tel: +420 618 813779, Fax: +420 618 866360, E-mail: zelenz1.edu@mail.cez.cz

21. CZ NRI Rez Thermolluminescent Dosimetry NRI Rez, Milos Vidra, Husinec- Rez 130, 25063 Rez/ Praha, Czech Republic, Tel: +420 266173671, Fax: +4202 20940500, E-mail: vid@nri.cz

22. CZ IRP National Personal Dsoimetry Service, Jaroslav Trousil, Na Truhlarce 39/64, 18084 Praha, Czech Republic, Tel: +4202 84840400-1, Fax: +4202 8484040 0, E-mail: csod@iol.cz

23. D Auswertungsstelle fuer Strahlendosemeter AWS, J. Davis, Ingoldstaetter Landstrasse 1, 85761 Unterschleißheim, Germany, Tel: +49 89 318 722 20

24. D HS/Messstelle Forschungszentrum Karlsruhe, Bertram Burgkhardt, Herman-von-Helmholtz-platz 1, D-76344 Eggenstein-Leopoldshaven, Germany, Tel: +49 7247 82 2082, Fax: +49 7247 82 2054, E-mail: burgkhardt@hs.fzk.de

25. D Materialprufungsambt NRW, Frank Busch, Marsbruchstr. 186, D 44285 Dortmund, Germany, Tel: +49 231 4502 514, E-mail: frank. busch@physik.uni-dortmund.de

26. D Messstelle fuer Strahlenschutz, Kar-Heinz Anger, Max-Brauer-Allee 134, 22765, Germany, Tel: +49 40 38073128, Fax +494042811-3273 E-mail: karl-heinz.anger@bug.hamburg.de

27. DK Laboratory for Personal Dosimetry and Medical Physics AKH, K.A. Jessen, Norrebro-gade 44, 8000 Arhus, Denmark, Tel: +45 89 49 2486, E-mail: kaj@medfysik.aau.dk

28. DK National Institute of Radiation Hygiene, Jens Munk, 378 Frederikssundsvey, 2700, Denmark, Tel: +45 44 89 9119, Fax: +45 44 53 2773, E-mail: jm@sis.dk

29. DK Personal Dosimetry Service RISO, P Christensen, Frederiksborgvej 399, 4140 Riso, Denmark, Tel: +45 46774914

30. EL Physics Department Aristotle University of Tessaloniki, M Zamani-Valasiadou, Tessaloniki, Greece, Tel: +30 31 998176, E-mail: zamani@paros.physics.auth.gr

31. EL Greek Atomic Energy Commission, V. Kamenopoulou, 153 10, Greece, Tel: +30 1 65 11 360

32. ES Approved Dosimetry Service BNFL Chapel-cross, R.H. Millard, DG12 6RF Annan, Dumfriesshire, Scotland, Tel: +44 1461 20 28 35

33. ES Centro de Dosimetria S.L., J Gultresa, Muntaner 447 bajos, 8021 Barcelona, Spain, Tel: +34 3 201 34 95

34. ES Centro Nacional de Dosimetria, E. Casal, Avda. Campanar 21, PO Box 46009 Valenzia, Spain, Tel: +34 96 349 79 22, E-mail: emilio. casal@uv.es

35. ES CIEMAT, J.C. Saez Vergara, Av. Complu-tense 22 (Ed. 7), 28040 Madrid, Spain, Tel: +34 1 346 62 53

36. ES Servicio de Radioproteccion Centro Nacional de Sanidad Ambiental, C. Ruiz, 28220 Madrid, Spain, Tel: +34 1 509 79 84, E-mail: cruiz@isciii.es

37. EST ERPC Estonian Radiation Protection Centre, Kiira Kornysheva, Kopli str. 76, 10416 Tallinn, Estonia, Tel: +372 660 3336, Fax: +372 660 3352, E-mail: ekk@ekk.envir.ee

38. F IPSN-DPEA-SEC Institut de Protection e de Sureté Nucléaire, Yvon Magry, F-92265 CE Fontenay-aux-Roses BP 63, France, Tel: +33 1 46547508

39. F Laboratoire Central des Industries Electriques LCiE, Guy Le Roy, 33 Avenue de General Leclerc, 92260 Fontenay-Aux-Roses, France, Tel: +33 1 40 95 62 90, Fax: +33 1 40956289

40. F Laboratoire de Dosimetrie et de Metrologie des Rayonnements—Cogema Marcoule—SPR/CR/DMR CEDEX, M Espagnan, BP 170, 30206 Bagnol-sur-Ceze, France, Tel: +33 4 66795321

41. F OPRI, A. Biau, 31 Rue de l'Ecluse, 78116 Le Vessinet CEDEX, France, Tel: +33 1 30 15 52 00

42. F Division dosimetrie Philips Systemes Medicaux SAS, P. Pellissier / D. Jaegle, Route d'Ergnies, 80690 Ailly le Haut Clocher, France, Tel: +33 322 280 016, Fax: +33 32228084, E-mail: dominique. jaegle@brill.philips.com

43. F Service de prevention et de radioprotection, Jaques Kalimbadjian, Cogema/La Hague, 50444 Beaumont-Hague, France, Tel:+33 2 33026000, Fax: +33 2 33026205

44. FIN Loviisa powerplan (IVO) Imatran Voima Oy, Esko Hytonen, 07901 Lovisa, Finland, Tel: +35 8 19 5501, Fax: 35 8 195504435, E-mail: Esko.hytonen@ivo.fi

45. FIN Personal Dosimetry STUK, Radiation and Nuclear Safety Authority, Hannu Hyvoenen, Laippatie 4, 00881 Helsinki, Finland, Tel: +358 9 759881, Fax: 358 9 75988248, E-mail: hannu. hyvonen@stuk.fi

46. HR RBI Ruðer Boŝkovi Institute, Branko Veki, Bijenicka cesta 54 PO Box 180, 10000 Zagreb, Croatia, Tel: +385 1 4561111, Fax: +385 1 4680084, E-mail: bvekic@rudjer.irb.hr

47. HR Ekoteh Dosimetry Co. Rad Protection Service, Mladen Novakobi, Vladimira Ruzdjaka 21, 10000 Zagreb, Croatia, Tel: +385 1 604 3882, Fax: +385 1 604 3883, E-mail: ekoteh@zg.tel.hr

48. I C.I.R. s.a.s. Centro Italiano de Radioprote-zione, Anna Ialenti, Via Filippo Chiappini n. 15, 00153 Roma, Italy, Tel: +39 6 588 04 95

49. I Institute for Radiation Protection ENEA, Elena Fantuzzi, Via dei Colli 16, 40136 Bologna, Italy, Tel: +39 51 609 83 49

50. I Servizio di Fisica Sanitaria—Ospedale Mag-giore, Gabriella Raimondi, via Pace 9, 20122

Milano, Italy, Tel: +39 02 55035223, Fax: +39 02 55035100, E-mail: rai@policlinico.mi.it

51. I Servizio di Fisica Sanitaria Spedali Civili di Brescia, Piero Feroldi, Piazzale Spedali Civili, 1, 25100 BRESCIA, Italy, Tel: +39 030 3995284, Fax: +39 030 3995075, E-mail: fisicasan. bs@numerica.it

52. I Laboratorio di dosimetria personale ed ambientale Istituto Nazionale per lo studio e la cura dei Tumori, Marta Borroni, Via Venezian 1, 20133 Milano, Italy, Tel: +39 223902309, Fax: +39 223902124, E-mail: filmdos@istitutotumori.mi.it

53. I X - Gammaguard, Vincenzo De Iorio, Via Gorizia, 40, 21047 SARONNO, Italy, Tel: +39 296702029, Fax: +39 29625945, E-mail: xg.guard@xgammaguard.it

54. I Fisica Sanitaria—ASL n.9 della RegioneVeneto, Lino Mantovani, Piazza Ospedale, 1, 31100 Treviso, Italy, Tel: +39 422 322278, Fax: +39 0422 322249, E-mail: Lmantovani@ulss.tv.it

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56. I Umberto I Hospital Medical Physics Department, Lidia Angelini, Via Conca, 1, 60020 ANCONA, Italy, Tel: +39 071 5964799, Fax:+39 071 5964897

57. IRL Radiological Protection Institute of Ireland, Tony Colgan, 3 Clonskeagh Square, 14 Dublin, Ireland, Tel: +353 1 269 77 66, E-mail: Tony@rpii.ie

58. L Division de la Radioprotection, Nico Harpes, Villa Louvigny- Allée Marconi, L 2120 Louxembourg, Luxembourg, Tel: +352 4785673, Fax: +352 467521, E-mail: nico.harpes@ms.etat.lu

59. LT Ignalina NPP Ignalina Nuclear Power Plant, Victor Pletniov, LT-4761 Visaginas, Lithuania, Tel: +3706628828, Fax: +3706629350, E-mail: pletnev@mail.iae.lt

60. LT RPC Radiation Protection Centre, Gendrutis Morkunas, Kalvariju 153, LT- 2055 Vilnius, Lithuania, Tel: +370 2 763633, Fax: +370 2 754692, E-mail: rsc@rsc.lt

61. LV RDC Radiation Safety Centre, Konstantins Bogucarskis, 165 Maskavas str., LV-1019 Riga, Latvia, Tel: +371 2 7032691, Fax: +371 2 7032659, E-mail: k.bogucarskis@rdc.gov.lv

62. NL Dosimetry Services Nuclear Research and Consultancy Group (NRG), F.S. Draaisma, Westerduinweg 3, 1755 ZG, The Netherlands, Tel:+31 224 56 4228, E-mail: draaisma@ecn.nl

63. NL Persoonsdosimetriedienst Vrije Universiteit en VU ziekenhuis, P.H. Dignum, van der Boechorststraat 1, 1081 BT, The Netherlands, Tel: +31 20 444 90 40, E-mail: ph.dignum@dienst.vu.nl

64. NL Philips Stralingsbeschermingsdienst (P-SBD), L.T.M. Ebben, Willemstraat 22a, 5600 MD, The Netherlands, Tel: +31 40 275 63 00

65. NL NRG Radiation & Environment, Janwillem E. van Dijk, Utrechtseweg 310, 6800 ES, The Netherlands, Tel: +31 26 356 30 84

66. PL CLOR Central Laboratory for Radiological Protection, H. Dzikiewicz-Sapiecha, Konwaliowa 7, PL-03-194 Warszawa, Poland, Tel: (48-22) 811 0011, Fax: (48-22) 811 1616, E-mail: hannads@clor.waw.pl

67. PL IMP Nofer Institute of Occupational Medicine-Rad. Prot.Department, Jerzy Jankowski, Sw. Teresy 8, PO Box 199, 90-950 Lodz, Poland, Tel: +48 (42) 6314 549, Fax: +48 (42) 6314 548, E-mail: jjan@imp.lodz.pl

68. PL LADIS Institute of Nuclear Physics, Maciej Budzanowski, Radzikowskiego 152, PL 31-349 Krakow, Poland, Tel: +4812 6628457, Fax: +4812 6628066, E-mail: Maciej.Budzanowski@ifj.edu.pl

69. PT ITN-DPRSN, Antonio Ferro de Carvalho, Estrada Naciomal 10, 2686-953 Sacavém, Portugal, Tel: +351 1955 0021, Fax: +351 1994 1995, E-mail: afferoc@intl.itn.pt

70. RO CEPIEM, R. Vasilache, 25, Pop de Basesti 59, sector2, Bucharest, Romania, Tel: +40 21 252 42 23, Tele and Fax: +40 21 252 42 23, E-mail: lmilea@ cepiem.ro

71. RO DOZIMED, R. Vasilache, 25, Grigore Tocilescu St., PO Box 69 - 160, 7000 Bucharest, Romania, Tel: +40 21 423 3259, Fax: +40 21 423 3259, E-mail: dozimed@pcnet.ro

72. RO Film Detectors Survey Unit, Constantin Milu, Magurele PO Box MG 6, 76900 Bucharest, Romania, Tel: +40 14042300/4706, Fax: 40 14574432, E-mail: fmihai@ifin.nipne.ro

73. RO ELSD Environmental and Life Sciences Department, Constantin Milu, Magurele PO Box MG 7, R-76900 Bucharest, Romania, Tel: +401 4042300, Fax: +401 4574440, E-mail: stoc@ifin.nipne.ro

74. RO IRML Individual Radiation Monitoring Lab Ministry of Health and Family, Constantin Milu, Dr. Leonte No. 1-3, RO-76256 Bucharest, Romania, Tel: +40 21 224 9245, Fax: +40 21 224 9245, E-mail: cmilu@ispb.ro

75. RO Health Physics Laboratory CNE-PROD CERNAVODA, Mitica Baraitaru, Medgidiei No 1, 8625 Cernavoda, Romania, Tel: 40-41-239-340 (ext. 1865), Fax: 40-41-239-679, E-mail: mbaraitaru@cne.ro

76. S Ringhals Dosimetrie, Per Drake, Vattenfall AB, 43022 Varovbacka, Sweden, Tel: +46 340 66 7151

77. S Swedish Radiation Protection Institute, Lennart Lindborg, Sweden, Tel: +46 8 729 71 08, E-mail: lennart.lindborg@ssi.se. As from

April 1999 the dosimetric service is operated by Studsvik Instrument AB

78. SI Krsko NPP Krsko NPP, Radiation Protection-Dosimetry Laboratory, Borut Breznik, Vrbina 12, SI-8270 Krško, Slovenia, Tel: +386 7 4802 00, Fax: +386 7 49 21 006, E-mail: borut.breznik@nek.si

79. SI IOS Institute of Occupational Safety, Urban Zdesar.

80. SK Radiation Protection Department Bohunice NPP, Dobis Lubomir, 919 31 Jaslovské Bohunice, Slovakia, Tel: ++421 33 579 2128, Fax: ++421 33 597 4786

81. UA CLRHMS Central Lab for rad hygiene of medical staff of Ukraine- S.Grigoriev Institute, L. Stadnyk, 82 Pushkin, 61024 Kharkiv, Ukraine, Tel: +380 572 43 71 20, Fax: +380 572 43 71 20, E-mail: imr@online.kharkiv.com

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83. UK BNFL Sellafield Dosimetry Service, NJ Parkes, B423, CA20 1PG Seascale, Cumbria, United Kingdom, Tel: +44 19467 74 210, Fax: 441946771752

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