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► To cite this version:

E. Carinou, L. Donadille, M. Ginjaume, J. Jankowski, A. Rimpler, et al.. Intercomparison on measurements of the quantity personal dose equivalent, $H_p(0.07)$, by extremity ring dosimeters in medical fields. *Radiation Measurements*, 2008, 43 (2-6), pp.565-570. 10.1016/j.radmeas.2008.01.002 . hal-03001443

HAL Id: hal-03001443

<https://hal.science/hal-03001443>

Submitted on 29 Jun 2022

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Intercomparison on measurements

of the quantity personal dose equivalent, $H_p(0.07)$, by extremity ring dosimeters in medical fields

E. Carinou^{a*}, L. Donadille^b, M. Ginjaume^c, J. Jankowski^d, A. Rimpler^e, M. Sans Merce^f, F. Vanhavere^g, M. Denoziere^h, J.

Daures^h, J.M. Bordy^h, C. Itie^b, P.Covensⁱ

^aGreek Atomic Energy Commission, Ag. Paraskevi, Attiki, Greece

^bInstitute for Radiological Protection and Nuclear Safety (IRSN), BP17, F-92264 Fontenay-aux-Roses, France

^cInstitut de Tècniques Energètiques, Universitat Politècnica de Catalunya, Diagonal 647, 08028 Barcelona, Spain

^dNofer Institute of Occupational Medicine, St. Teresa Street 8, 90-950 Lodz, Poland

^eBundesamt für Strahlenschutz, 10312 Berlin, Germany

^fInstitut Universitaire de Radiophysique Appliquée, Lausanne, Switzerland

^gBelgian Nuclear Research Centre SCK-CEN, Environment, Health and Safety, Mol, Belgium

^hCEA LIST Laboratoire National Henri Becquerel, CEA Saclay 91191 Gif sur Yvette CEDEX, France

ⁱUniversity of Brussels and Academic Hospital AZ-VUB, Radiation Protection Department, Brussels, Belgium

Received DATE; received in revised form DATE; accepted DATE

Abstract

In the framework of the CONRAD project, the EURADOS WG9 organized an intercomparison of extremity dosimeters that are used in a variety of medical fields. The overall objective of the intercomparison was to verify the performance of different extremity ring dosimeters to measure the quantity $H_p(0.07)$ in photon and beta reference fields as well as in realistic fields in interventional radiology and nuclear medicine. The selection of the participating services has been done in a way to have a good representation of different types of detectors, filter materials and filter thicknesses that are used in Europe. All the irradiations have been performed on the ISO rod phantom. For the reference fields, the reference values of $H_p(0.07)$ have been determined by the irradiation laboratories with traceability to primary calibrations, in agreement with the relevant standards. For the realistic fields, the reference values have been obtained with the aid of Monte Carlo simulations. The vast majority of the services fulfill the accuracy requirements according to the European Technical Recommendations for the photon and realistic interventional radiology fields. However, only a limited number of services fulfill these requirements in all tested beta irradiation configurations.

Keywords: extremity dosimeters; intercomparison; personal dose equivalent $H_p(0.07)$

1. Introduction

In the increasing use of ionising radiation in medicine radiation protection of patients and staff is of major concern. The rapidly evolving medical practices and the introduction of new techniques make the implementation of special monitoring programs more than necessary.

In the framework of the CONRAD project EURADOS Working Group 9 (WG9) is presently funded by the European Commission. WG9 is coordinating research activities on the assessment of occupational exposures at workplaces in therapeutic and diagnostic radiology as well as in nuclear medicine. For some of these applications the skin of the fingers is the limiting organ for the individual monitoring of external radiation. A recent literature review showed that doses especially in nuclear medicine can be quite high (Vanhavere et al., 2007). One of the objectives of the WG9 is to assess the capabilities of the extremity ring dosimeters used in Europe by organizing an intercomparison exercise for ring dosimeters. The wide variety of radiation fields in medical applications together with the difficulties of designing an appropriate ring dosimeter, makes difficult to perform extremity dosimetry with accuracy similar to that of a whole-body one (Bordy et al., 2000). Moreover, there is a

* Corresponding author. Tel.: +30 2106506718; fax: +302106506748.

E-mail address: ecarinm@ceae.gr (E.Carinou)

growing need for harmonization of dosimetric practices in extremity monitoring across Europe with the aim of mutual recognition of extremity dose results (Kamenopoulou et al., 2006)

The objective of this intercomparison is to verify the performance of extremity dosimetry systems in order to measure the quantity $H_p(0.07)$ in photon and beta reference fields. Also, the performance of extremity dosimeters to measure $H_p(0.07)$ in realistic fields in interventional radiology (IR) and nuclear medicine (NM) is examined. Three types of irradiation fields have been used: photon fields, beta fields and realistic fields that refer to IR and NM procedures.

The participants have been selected in order to guarantee a good representation of different EU countries and of various types of dosimetric systems used in medical fields. Some data relevant to the characteristics of the dosimeters and the participating dosimetric services were also collected.

A similar intercomparison was organized 7 years ago by the PTB for extremity dosimeters in beta and/or photon radiation fields (Helmstädter et al., 2001). The study was more oriented in the requirements of the extremity dosimeters for the above fields. However, the present study is focused on radiation fields used in medical fields.

The results of the present intercomparison are presented in detail and are correlated with the dosimetric characteristics of the detectors and dosimeters.

2. Program of the irradiation exercises

To accomplish the objectives of the intercomparison, an irradiation program has been designed in order to investigate dosimeters' performance in standard reference photon and beta fields and under realistic conditions. The following irradiation fields were selected:

- Photon fields at Cs^{137} sources at 0° , 60° and 180° ,
- Realistic IR fields; two positions were used: in beam above the phantom and out of the beam in the scattered field near the edge of the patient phantom. A typical spectrum was chosen: 70 kVp, with the filtration of 4.5 mm Al and 0.2 mm Cu,
- Beta fields using Sr^{90}/Y^{90} , Kr^{85} and Pm^{147} sources at 0° and 60° and
- Realistic mixed NM fields using a syringe, without shield, with Tc^{99m} and F^{18} with the dosimeters placed at 14 cm distance.

The beta sources were selected in a way to test dosimeters at average energies ranging from 60 keV (Pm^{147}) to 800 keV (Sr^{90}/Y^{90}). The irradiations were performed using the ISO rod phantom, which is a PMMA cylinder of 19 mm diameter and 300 mm length (ISO, 1999 and ISO, 2006a). The relevant ISO standards have been used for the reference irradiations, ISO 4037 and 6980 series (ISO, 1996 and ISO 2006b).

The irradiation program was performed in four laboratories: IRSN, CEA/LNHB (France), BFS (Germany) and AZ-VUB (Belgium) in collaboration with the SCK-CEN (Belgium).

3. Determination of the reference $H_p(0.07)$ values

The reference values of $H_p(0.07)$ were determined according to the irradiation configuration. In particular:

- For Cs^{137} irradiation fields the $H_p(0.07)$ was determined according to the equation $H_p(0.07) = h_p(0.07, \alpha) \times K_{air}$, where $h_p(0.07, \alpha)$ is the conversion coefficient from kerma free in air to $H_p(0.07)$ for an irradiation angle α provided by Grosswendt (Grosswendt, 1995). The K_{air} value was measured at IRSN using a secondary standard ionization chamber,
- For IR fields the $H_p(0.07)$ was determined using the same equation; the h_p coefficients for the IR setup have been determined using a spectrum that was calculated with the MCNPX code for the specific setup (MCNPX2.5.0, 2005),
- For beta fields the reference values of $H_p(0.07)$ were provided directly by a BSS-2 secondary standard chamber, traceable to the primary laboratory at the PTB,

- For NM fields, the reference values of $H_p(0.07)$ were calculated using the MCNPX code (MCNPX2.4.0,2002, MCNPX2.5.0, 2005) normalized by the measured activity of the radioactive solution.

The reference values of the $H_p(0.07)$ are shown in table 1.

Table 1:

4. Dosimetric services

24 services from 16 countries participated in the intercomparison. The dosimeters represented in this study are used to monitor over 60 000 workers. Table 2 shows the main characteristics of the dosimeters. The intercomparison includes extremity dosimeters manufactured by Rados, TLD Poland, Panasonic and Harshaw (Thermo Electron Corporation) type. Home made dosimeters are also included. The detectors are of many different types: TLD-100, TLD-100H, TLD-700H, MCP-N, MCP-Ns, MTS-N, MCP-7, $Li_2B_4O_7$, $CaF_2:Mn$ and $Li_2B_4O_7:Cu$. The filter material, in most of the cases, is plastic of thickness 3-30 mg/cm². Most of the dosimeters are calibrated to Cs^{137} sources, when five services also use X-rays from the ISO 4037 series to calibrate their dosimeters. Nine out of 24 services have been accredited according to ISO 17025 standard and four have been approved by the relevant governmental authorities.

Each participating service was asked to prepare two dosimeters per irradiation field, meaning 26 dosimeters for the irradiations and four sets of at least 2 detectors for background correction. The dosimeters were labeled differently for photon (Cs^{137} and IR) and mixed fields (beta and NM). This is because, some services provide different dosimeters for different applications. Four services chose not to participate in the mixed field tests.

Table 2:

The participants were informed only about the results of their own dosimeters. However, in this study the names of the services are not mentioned, but they are presented using the numbers 1 to 24 to preserve their anonymity.

The analysis of the results has been based on the European Technical Recommendations (Christensen et al., 1994).

5. Results of the intercomparison

The first evaluation of the results is shown in figures 1 to 4. The vertical axis refers to the ratio H_s/H_r , where H_s is the value of $H_p(0.07)$ reported by the service and H_r is the reference value. As mentioned above, on the horizontal axis numbers 1 to 24 refer to the participating services. Although most services reported the uncertainties on their results, these are not included in the figures for reasons of clarity.

The angle dependence for the Cs^{137} irradiation was examined for 0°, 60° and 180°. The relative response is satisfactory, even for the 180° and varies from 0.35 to 2.37, with only one service being out of limits; the average response of the remaining 23 services is 0.86. Most of the participants' responses are close to unity since most of them calibrate their dosimeters to Cs^{137} sources.

Fig 1.

For the IR configurations (in and out of beam) the responses vary from 0.20 to 2.85 (out of beam) and 0.27 to 3.59 (in beam), with two services in each case being out of limits, one of which overestimated also the reference Cs^{137} values and the other uses $CaF_2:Mn$ detectors. The high effective atomic number of this material (16.5) causes the over response of the detector to the X-

rays. Generally, in most cases the relative responses for the IR irradiation configurations are higher than those of Cs¹³⁷ ones, with average value of 1.29 in both setups (in and out of the beam). Most of the services use LiF detectors with effective atomic number of 7.7, which could explain the over response to the X-rays. It should be noted that the services that use Li₂B₄O₇ detectors report an underestimation of 10 to 20% for the IR fields. This could be due to the lower effective atomic number of Li₂B₄O₇ (7.2).

Fig. 2.

For the NM irradiations the relative response to Tc^{99m} is also satisfactory. The average response of the 20 services is 1.08. However, for the F¹⁸ irradiations the majority of the services underestimates the H_p(0.07); the average response of the 20 dosimeters is 0.55. The services response to the F¹⁸ irradiation is very similar to the Kr⁸⁵ one, which shows the importance of the positrons emitted by the F¹⁸. It should be noted that according to the Monte Carlo simulations and for the tested geometrical configuration, the positrons have similar energies to the betas emitted from the Kr⁸⁵ and contribute up to 57% of the total estimated dose.

As to the Sr⁹⁰/Y⁹⁰ irradiations, all of the reported doses are within the limits for both angles (0° and 60°) examined. The average relative response for all services for the normal incident irradiation is 1.00. For the Kr⁸⁵ irradiations, only 9 services are within the limits; the rest underestimated the H_p(0.07) up to a factor of 20. Finally, for the Pm¹⁴⁷ irradiations the situation is worse; only 5 services are within the limits. As it is expected, dosimeters with thin filters and detectors have a better response to the lower energy betas.

Fig. 3.

Fig.4.

6. Conclusions

The following conclusions can be drawn after the first evaluation of the present intercomparison:

- Some services need to check their calibration at Cs¹³⁷,
- The general overestimation in the IR fields could be explained by the energy response of LiF that is the material mostly used by the participating services. The two services that use Li₂B₄O₇ detectors present an underestimation due to the lower effective atomic number of the detector material,
- CaF₂:Mn should not be considered as a proper detector in medical fields, without any energy corrections,
- The under-response of detectors to the F¹⁸ is due to the positron contribution that can give a significant amount of the dose for unshielded syringes,
- There is a clear correlation between filter and detector thickness and response to beta particles,
- A few dosimeters show good results for all radiation qualities, especially the ones with thin detectors and filters.

Finally, it should be noted that some dosimeters have been tested for fields for which they are not intended to be used. Among them there are dosimeters with very good response to photons without being appropriate for beta particles; however, if they are not supposed to be used in mixed fields they can still be considered adequate for use in photon fields.

Acknowledgments

The authors are grateful to the staff of the irradiation facilities for their valuable help in the irradiation of the dosimeters. The authors also wish to thank EC for funding the project.

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Fig 1. Relative responses of the 24 dosimeters to the Cs¹³⁷ for three angles

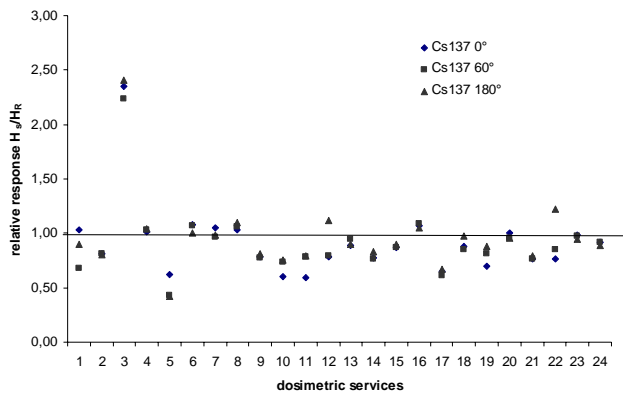


Fig. 2. Relative responses of the 24 dosimeters to the IR fields

Note: Dosimetric Service no 15 reported a relative response 12.15 and 10.98 for the IR setup, in and out of the beam respectively

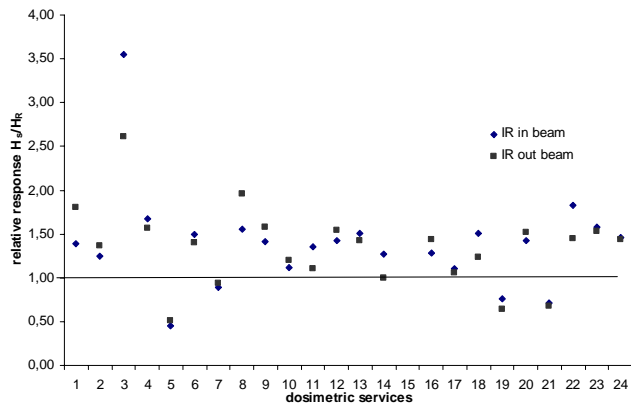


Fig. 3. Relative responses of the 20 dosimeters to the NM fields

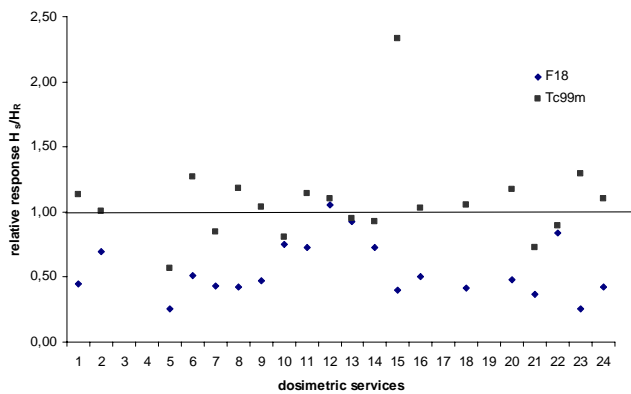


Fig.4. Relative responses of the 20 dosimeters to the beta fields

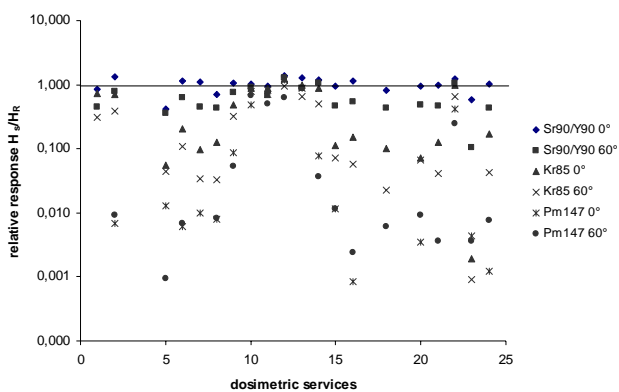


Table 1: Reference $H_p(0.07)$ values for the various irradiation fields

Field	Description	$H_p(0.07)$ [mSv]	Uncertainty [%], 2σ
Cs^{137}	0°	4-6	4.8
Cs^{137}	60°	4-6	4.8
Cs^{137}	180°	4-6	4.8
IR	70 kVp, 4.5 mm Al, 0.2 mm Cu, in beam	2.60	6.5
IR	70 kVp, 4.5 mm Al, 0.2 mm Cu, out beam	0.61	6.5
Sr^{90}/Y^{90}	0°	8.22	2.3
Sr^{90}/Y^{90}	60°	9.01	2.3
Kr^{85}	0°	10.29	2.3
Kr^{85}	60°	10.99	2.3
Pm^{147}	0°	5.84	3.0
Pm^{147}	60°	8.25	3.7
Tc^{99m}	Unshielded syringe	4-6	7.8
F^{18}	Unshielded syringe	10-15	7.8

Table 2: Main characteristics of the dosimeters used at the intercomparison