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# Results of the EURADOS 2017 Intercomparison for Whole Body Neutron Dosimeters (IC2017n)

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## Highlights

IC2017n was the second EURADOS organized intercomparison exercise for neutron personal dosimeters after IC2012n. It is an important action because international neutron dosimetry intercomparisons have been performed before only every 8-10 years.

## Key words

neutron dosimetry, neutron personal dosimeter, EURADOS, intercomparison, track detector, albedo dosimeter

## Abstract

The European Radiation Dosimetry Group (EURADOS) has set up intercomparison exercises for personal dosimeters on a regular basis. In 2017, the second EURADOS intercomparison for neutron dosimeters (IC2017n) took place. The intercomparison concerned the performance of neutron dosimeters provided by individual monitoring services to measure neutron personal dose equivalent,  $H_p(10)$ . The irradiations, which included exposures to neutrons and mixed fields of neutrons and photons as commonly encountered in workplaces, were performed in accredited irradiation facilities in terms of  $H_p(10)$ . The range of energies used in the intercomparison extended from thermal to several MeV, with different dose values and angles used. The paper reports on the results of this intercomparison for whole body neutron dosimeters.

## Introduction

The European Radiation Dosimetry Group (EURADOS) has carried out a number of different intercomparison exercises for personal dosimeters in the past that qualify as proficiency tests for different dosimetry systems and radiation types [Grimbergen et al., 2016] including one previous neutron personal dosimeter intercomparison [Fantuzzi et al., 2014a]. Neutron intercomparisons are especially complicated to design because of the limited availability of reference fields and the costs associated with the exposures [Fantuzzi et al., 2014b]. In 2017/2018, the second EURADOS intercomparison for neutron dosimeters (IC2017n) took place. It is an important action because international neutron dosimetry intercomparisons have been performed before only every 8-10 years, even though the problems associated with the design of high quality neutron personal dosimeters are greater than those for photon personal dosimeters.

## Materials and Methods

The intercomparison concerned the performance of neutron dosimeters intended to measure neutron personal dose equivalent,  $H_p(10)$ , as provided by individual monitoring services (IMSS). The neutron dosimeters included in the exercise were restricted to ones routinely used in individual monitoring of occupationally exposed workers. Both passive and active dosimeters were permitted provided they were in routine use. No systems under development were allowed in the intercomparison.

For registration and communication with the participants, an online platform has turned out to be a practicable tool in previous EURADOS intercomparisons for photon dosimeters [Stadtman et al., 2018] and was therefore adapted for IC2017n.

Participants were requested to only apply routine procedures as declared in the application form, where they could also declare whether they needed additional simplified *a priori* information on the energy distribution of the radiation fields to allow correction of the raw results of their neutron personal dosimeters. Especially for albedo systems some information on the radiation field may be necessary for their evaluation algorithm to choose the proper calibration factor.

Application forms and results were received from 32 participants (IMSS) for 33 dosimetry systems (all passive). 6 IMSS participated for the first time in a EURADOS intercomparison for whole body neutron dosimeters, 26 IMSS participated the second time. Most participants were from European countries, but IMSS from Japan, United States, Brazil and India also participated. Values of  $H_p(10)$  were reported by all the participants for all their irradiated dosimeters.

Based on information provided by the participants, the dosimetric systems were divided into two main groups: 15 *Albedo* and 18 *Track*. The *Albedo* systems include 10 systems based on TLD (ThermoLuminescence Detectors) + boron loaded shield, 3 systems based on TLD + cadmium shield, 1 system based on OSL (Optically Stimulated Luminescence) and 1 system based on TLD with no information on shielding of direct thermal neutrons. The *Track* systems include 7 systems with etched track detectors for fast neutrons and TLD for thermal neutrons, 7 systems with etched track detectors for fast neutrons combined with converters for thermal neutrons, 3 systems with etched track detectors for fast neutrons only, i.e. no evidence of a thermal sensor and 1 system based on fission track detection.

The results were provided to the participants in the Certificate of Participation, with the certificates of the irradiating laboratories as annexes. If the *a priori* information was provided to the participant, this was then mentioned on the intercomparison certificate.

## **Irradiations**

The irradiations have been performed in terms of  $H_p(10)$  at two European laboratories accredited to ISO/IEC 17025. Both are National Metrology Laboratories for ionizing radiation: NPL (National Physical Laboratory, UK) and PTB (Physikalisch-Technische Bundesanstalt, D). The irradiation plan of the IC2017n exercise is shown in Table 1. Several different neutron fields, doses, and angles of incidence ( $0^\circ$ ,  $45^\circ$ , and isotropic) were employed. The range of energies of the broad neutron spectra extend from thermal to about 10 MeV.

For IC2017n, each participant was asked to provide 40 dosimeters: 28 to be irradiated, 4 spare dosimeters, and 8 background dosimeters. The dosimeters were attached to the front face of an ISO water slab phantom of outer dimensions 30 cm x 30 cm x 15 cm. The centre of the front face of the phantom was positioned at 75 cm from the center of the neutron source. An exception was the  $D_2O$  moderated  $^{252}Cf$  source behind a shadow block, where a slab phantom with dimensions 30 cm x 30 cm x 15 cm made of PMMA was used at 170 cm from the neutron source. 4 dosimeters were irradiated simultaneously for  $0^\circ$  irradiations, 2 dosimeters (fixed on the rotation axis of the phantom) for  $45^\circ$ , and 8 dosimeters (4 fixed on each 30 cm x 30 cm surface of the slab phantom) in the isotropic field. Most irradiations were performed in neutron fields with no additional photon component, over and above that resulting from the neutron-producing process, i.e. from the radionuclide neutron source. However, for one field, an additional photon component was included. The neutron spectra in

terms of  $H_p(10)$  per unit lethargy are plotted in Figure 1.

For participants who asked for additional simplified *a priori* information on the energy distribution of the radiation fields, the following information was given:

- “bare radionuclide source”, for irradiations with  $^{252}\text{Cf}$  and  $^{241}\text{Am-Be}(\alpha,n)$ ,
- “radionuclide source, significantly moderated”, for irradiations with a  $\text{D}_2\text{O}$  moderated  $^{252}\text{Cf}$  source with and without shadow block.

Table 1

Irradiation plan. In the  $H_p(10)$  column the values are the reference values for neutron irradiation except the additional irradiation with  $^{137}\text{Cs}$ , where the 1.0 mSv is the exposure to photons.

Quality at irradiation laboratory	$H_p(10)$ (mSv)	Number of dosemeters per dosimetry system	Irradiation laboratory
$^{252}\text{Cf}$ at $0^\circ$	0.3; 1.5; 12	4; 4; 4	NPL
$^{252}\text{Cf}$ at $45^\circ$	1.5	2	NPL
$^{252}\text{Cf}$ at $0^\circ + ^{137}\text{Cs}$	1.5 + 1.0	4	PTB
$^{252}\text{Cf}$ ( $\text{D}_2\text{O}$ moderated) at $0^\circ$	1.2	4	PTB
$^{252}\text{Cf}$ ( $\text{D}_2\text{O}$ moderated) behind a shadow block, isotropic	1.0	2	PTB
$^{241}\text{Am-Be}(\alpha,n)$ at $0^\circ$	1.5	4	NPL
Total number of dosemeters		28	

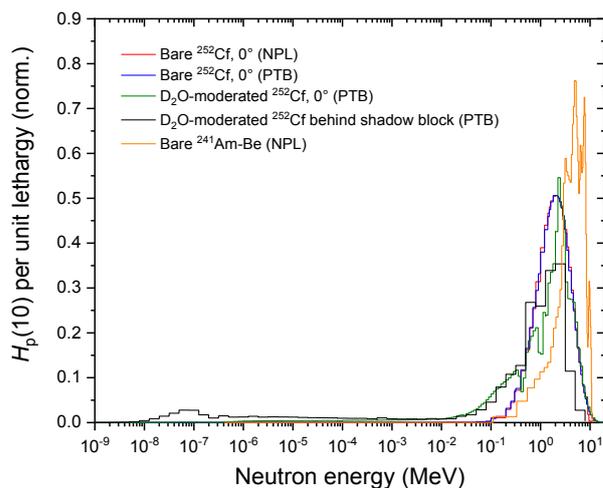


Fig.1.  $H_p(10)$  spectra of the radiation fields. The spectra are normalised to unit  $H_p(10)$ .

## Results

The numerical results of the intercomparison are reported as the response,  $R$ , which is the ratio defined by:

$$R = \frac{H_m}{H_{ref}}$$

where:

$H_m$  is the measured value of  $H_p(10)$  for neutrons as provided by the service,

$H_{ref}$  is the reference value of personal dose equivalent  $H_p(10)$  for neutrons as determined by the irradiation laboratory.

Statistical data for the individual radiation qualities are plotted in Figure 2. In each case the box represents the 50% range, i.e. 25% of the responses were below the lower edge of the box and 25% above the upper edge, and the vertical line is the 90% range. The horizontal line through each box is the median, the circle the mean, and the minimum and maximum values are represented by up and down triangles, respectively. The highest spread in results can be observed in the D<sub>2</sub>O moderated <sup>252</sup>Cf-field behind the shadow block.

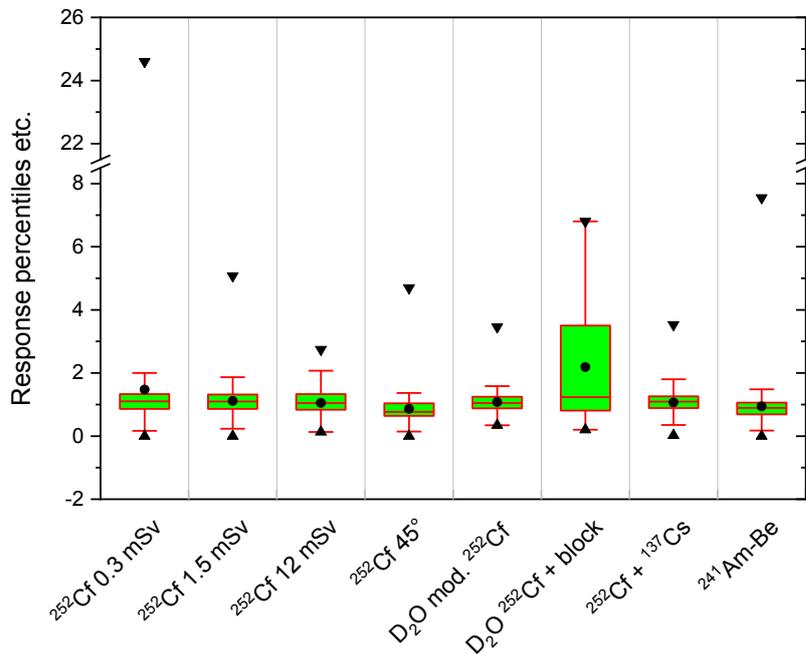


Fig. 2. Distribution of response values  $R$  for irradiations with different radiation qualities. Circle = mean value, box = 50% range, vertical red line = 90% range, horizontal red line inside the box = median, up and down triangles = minimum and maximum values.

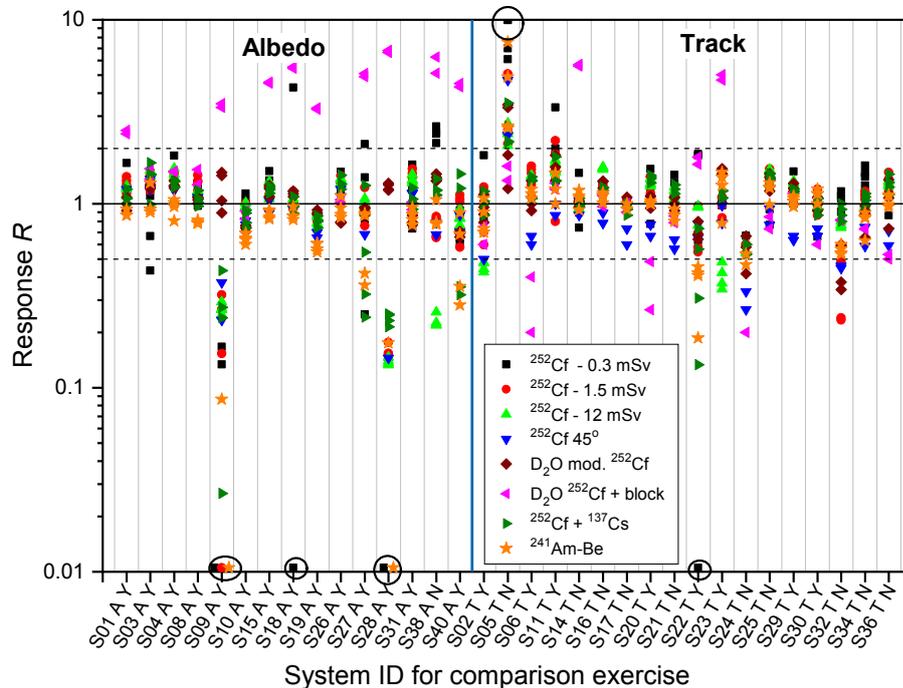


Fig. 3. Summary of all reported response values. On the X-axis captions: A stands for *Albedo*, T for *Track*, Y indicates additional *a priori* field information was requested, N indicates no additional field information requested. Points at  $R=0.01$  with a ring around them were actually reported as zero. The other point at  $R=10$  with a ring around it was higher than 10.

Figure 3 shows the responses,  $R$ , for all radiation fields, all systems, and all dosimeters, i.e. 28 responses are plotted per system. They are ordered with *Albedo* on the left, and *Track* on the right. The dotted line at  $R=2$  corresponds to the upper performance limit of ISO 14146:2018, where the dotted line at  $R=0.5$  serves only as an eye guide line since the limit depends on the reference dose. Figure 3 essentially allows all results to be compared and individual results for any system to be picked out.

In addition, the X-axis captions show that 22 out of 33 participants systems asked for *a priori* field information (Y following the identification code means they asked for this additional information). These were mostly albedo systems, but over 40% of the track systems also asked for this information.

## Discussion of Results

At the time of IC2012n no internationally agreed document existed defining performance criteria: the development of such criteria was one of the main recommendations of IC2012n [Fantuzzi et al., 2014b]. The International Organization for Standardisation (ISO) endorsed this recommendation and published a revised version of the ISO 14146 standard in 2018 [ISO 14146:2018]. This standard deals with the criteria and performance limits for the periodic evaluation of dosimetry services, and was formerly only for photon radiation (publication of 2000). The revised standard now provides the performance limits for neutron irradiations, which are as follows:

$$0.5 \cdot \left( 1 - \frac{2 \cdot H_0 / 1.5}{H_0 / 1.5 + H_{ref}} \right) \leq R \leq 2$$

where:

$H_0$  is the lower dose limit, chosen to be 0.1 mSv in the IC2017n,  
 $H_{ref}$  is the reference value as determined by the irradiation laboratory.

The lower performance limit proposed in this standard depends on both the choice of the lower dose limit,  $H_0$ , and on the reference dose equivalent,  $H_{ref}$ . The value  $H_0 = 0.1$  mSv is specified for whole-body dosimeters measuring  $H_p(10)$ , although it notes that other values of  $H_0$  may be chosen by the evaluation organization, if found to be appropriate. To simplify analysis and allow comparison of the systems within IC2017n, a value of 0.1 mSv has been adopted to specify the performance limits summarized in Table 2.

Table 2

Performance limits according to ISO 14146:2018 for the irradiation doses used in IC2017n

Irradiation dose (mSv)	Lower limit of response	Upper limit of response
0.3	0.32	2
1.0	0.44	2
1.2	0.45	2
1.5	0.46	2
12	0.49	2

ISO 14146 also states in its approval criterion that a maximum of one-tenth of the dosimeters irradiated may exceed the limits. For IC2017n, where 28 measurements under reference conditions have been carried out, the approval criterion is fulfilled when a maximum of two

dosemeters exceed the limits.

Most, but not all, participants performed acceptably well for all irradiation conditions. In fact, applying the approval criterion and performance limits from ISO 14146:2018, 9 out of 15 *Albedo* and 12 out of 18 *Track* passed with not more than two outliers. Good results were obtained in most radionuclide source radiation fields. The spread of the low dose (0.3 mSv) response values was, in general, not much larger than for higher doses, although there were some significant outliers; 4 services being unable to measure this dose. The overall spread of the results is influenced by the results of three systems (S09, S28 and S05) which only gave good results for the D<sub>2</sub>O moderated <sup>252</sup>Cf-field, with much too high or too low values in all other fields. S28 showed the highest spread and was a system based on TLD with no information on shielding of direct thermal neutrons. Most problems were observed in the D<sub>2</sub>O moderated <sup>252</sup>Cf-field behind the shadow block for albedo doseimeters. This field contains a high contribution from intermediate and thermal neutrons, and the field is isotropic. Albedo readings usually showed a high over-response, unless a field-dependent correction factor was used. Slightly lower response values have been observed for track doseimeters for this field and the irradiation at higher angle (45°). Such an under-response for higher angles is well known for track detectors. This is due to geometrical constraints which have been successfully taken into account by some of the track systems.

## **Conclusion**

Regular neutron intercomparisons under standard laboratory conditions with ISO reference fields [ISO 8528-1], and also with simulated workplace neutron radiation fields [ISO 12789:2008] provide an essential tool to test the performance of neutron doseimeters and to inform the radiation protection community about the present state of the art in neutron dosimetry. Such intercomparisons are usually not achievable in only one country and therefore the EURADOS intercomparison for whole-body neutron doseimeters (EURADOS IC2017n) was an important action. IC2017n was the second neutron dosimetry intercomparison within EURADOS, organized 5 years after the first. For the first time in a neutron intercomparison the registration and communication with the participant was established via an online platform. The intercomparison results can assist participants in showing compliance with their quality management systems. Moreover, they allow comparisons of individual results with those of other participants and, if required, help in developing action plans for improving their systems.

IC2017n results show that most, but not all (21 out of 33), of the participating systems fulfilled the ISO14146 performance criteria for the test. Full details of the intercomparison

IC2017n will be given in a forthcoming EURADOS report.

### **Acknowledgement**

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