EURADOS Report 2021-06
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S. Mayer[1], M-A. Chevallier[2], E. Fantuzzi[3], M. Hajek[4], M. Luszik-Bhadra[5], R. Tanner[6], D.J. Thomas[7], F. Vanhavere[8]

[1] Paul Scherrer Institute (PSI), CH-5232 Villigen PSI, Switzerland

[2] Institut de Radioprotection et de Sûreté Nucléaire (IRSN), BP 17, 31 avenue de la Division Leclerc, 92260 Fontenay-aux-Roses, France

[3] ENEA-Radiation Protection Institute, via Martiri di Monte Sole 4 – 40129 Bologna, Italy

[4] International Atomic Energy Agency (IAEA), Vienna International Centre, PO Box 100, 1400 Vienna, Austria

[5] Physikalisch-Technische Bundesanstalt (PTB), Bundesallee 100, D-38116 Braunschweig, Germany

[6] Health Protection Agency (UKHPA), Chilton, Didcot, Oxon OX11 0RQ, United Kingdom

[7] National Physical Laboratory (NPL), Hampton Road, Teddington, TW11 0LW, UK

[8] SCK-CEN, Belgian Nuclear Research Centre, Boeretang 200, 2400 Mol, Belgium

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office@eurados.org
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Content

Abstract

EURADOS has carried out a number of different intercomparison exercises for personal dosemeters in the past that qualify as proficiency tests for different dosimetry systems and radiation types including one previous neutron personal dosemeter intercomparison (IC2012n). Neutron intercomparisons are especially complicated to design because of the limited availability of reference fields and the costs associated with the exposures.

IC2017n was the second EURADOS organized intercomparison exercise for neutron personal dosemeters. It was an important and timely exercise because international neutron dosimetry intercomparisons have in the past only been performed every 8-10 years. New dosemeters are currently under development and the problems associated with the design of high-quality neutron personal dosemeters are greater than those for photon personal dosemeters.

IC2017n was carried out by a EURADOS nominated Organization Group (OG) consisting of: Marie-Anne Chevallier (IRSN, F), Elena Fantuzzi (ENEA, I), Michael Hajek (IAEA, UN-Vienna), Marlies Luszik-Bhadra (PTB, D), David J. Thomas (NPL, UK), Rick Tanner (PHE, UK), Filip Vanhavere (SCK-CEN, B), and led by a coordinator, Sabine Mayer (PSI, CH).

32 individual monitoring services (IMSs) registered for the comparison, with 33 dosimetry systems. 6 services participated for the first time in a EURADOS intercomparison for whole body neutron dosemeters, while 26 participated for the second time. Most participants were from European countries, but IMSs from Japan, the United States, Brazil, and India also participated in the intercomparison. In total 924 dosemeters were irradiated in selected neutron fields on an ISO slab phantom. The irradiations were performed at 2 European accredited laboratories which are both national primary metrology laboratories for ionizing radiation: NPL (National Physical Laboratory, UK) and PTB (Physikalisch-Technische Bundesanstalt, D). All irradiations were carried out according to an irradiation plan developed by the OG.

Values of neutron personal dose equivalent, $H_p(10)$, were reported by all the participants for all their irradiated dosemeters. The results show that most, but not all (21 out of 33), of the participating systems fulfilled the ISO 14146:2018 performance criteria for the test.

A meeting was held during the EURADOS Annual Meeting, AM2019, in February 2019 in Łódź, Poland, to allow the participants to discuss with the OG general aspects of this intercomparison and specific systems problems that some IMs have faced.

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.

1 Introduction

The European Radiation Dosimetry Group (EURADOS) has supported working groups investigating harmonisation of individual monitoring in Europe, and these have shown that intercomparison (IC) exercises are a fundamental prerequisite for maintaining and developing the quality of Individual Monitoring Services (IMSs) [1, 2, 3]. Consequently, EURADOS Working Group 2 (WG2), *Harmonisation of Individual Monitoring in Europe,* recommended periodic performance tests or IC exercises within the European Union (EU) and Switzerland to assist with the objective of harmonisation. It was believed that ICs would: stimulate IMSs to improve the quality of their results, provide information on IMS quality throughout the EU, and assist with harmonisation of IMS quality control standards. Further support was provided by the response to questionnaires sent to IMSs in the EU and non-EU countries, which showed very strong interest in participating in the proposed programme of periodic ICs.

The regular participation of IMSs in intercomparison exercises is now considered an essential tool for validating the performance of the dosimetry systems. Participation is a requirement for accreditation in compliance with ISO/IEC 17025 [4] and in some countries is now considered an essential criterion for the approval of an IMS by the national authorities. Participation is strongly advised in the recently updated European Commission's *Technical Recommendations for Monitoring Individuals Occupationally Exposed to External Radiation* [5]. However, regular performance tests or interlaboratory comparisons are carried out only in a few European countries. EURADOS as part of the work performed by WG2 has started a self-sustained programme of regular intercomparisons and has successfully executed six intercomparisons for whole-body photon dosemeters at two-years intervals (IC2008ph, IC2010ph, IC2012ph, IC2014ph, IC2016ph and IC2018ph) and three intercomparisons for extremity dosemeters for photon and beta fields (IC2009ext, IC2015ext and IC2019ext). Results have been published as EURADOS Report for IC2008ph [6], IC2009ext [7], IC2010ph [8], IC2012ph [9], IC2014ph [10] and IC2016ph [11], whilst reports on IC2015ext, IC2018ph and IC2019ext are in progress.

In 2012, as a next step in the programme, EURADOS initiated an intercomparison (IC2012n) for neutron personal dosemeters provided by IMSs to measure neutron personal dose equivalent, $H_p(10)$, for occupationally exposed workers in neutron fields and a EURADOS Report describing the exercise and detailing the results has been published [12].

1.1 Gaps and challenges in neutron personal dosimetry

Relatively few workers are monitored for neutron exposure, compared to those monitored for photons, and the collective dose recorded is relatively small by comparison. However, for individuals working in mixed fields, it is necessary to assess the neutron dose equivalent received to demonstrate compliance with legislation. Further, in several workplaces the neutron component of the dose equivalent comprises a significant component of the total dose received, and in some it can even be an order of magnitude higher than the photon dose [13]. The need for accurate occupational neutron personal dose assessments is hence clear.

Personal dosemeter intercomparisons conducted by EURADOS [6, 7, 8, 9, 10, 11] have shown that in general the performance of photon personal dosemeters is good: very few results have fallen outside the response range 0.5-1.5. Conversely, the EURADOS IC2012n intercomparison [12, 14] for neutron personal dosemeters produced results that showed biases of up to an order of magnitude for overestimates or underestimates. Further, some doses in the low mSv range were reported as zero. About half of the dosemeter systems did perform well in IC2012n for all irradiation fields, i.e. showing response values in the range 0.5 to 2. So, it is evident that good performance is achievable for the fields used in that intercomparison.

Several factors make it harder to produce accurate neutron personal dosemeters, some connected to the workplaces themselves and others related to the detection mechanisms. Whilst most whole-body photon doses in workplaces derive from photons with energies in the 10 keV to 1.5 MeV range, the corresponding energy range for neutrons is 10 meV to 20 MeV, nine orders of magnitude. This wide range of energies poses problems for the dosemeters because the interactions and available detection methods differ across the energy range. Moreover, for accelerator and cosmic radiation fields the upper energy of both these ranges is extended, which increases the difficulties.

Photons deposit most of their energy via either photoelectric or Compton scattering events, both of which produce secondary electrons that can readily be detected. For neutrons, however, energy is deposited by elastic scattering, inelastic scattering, and a range of nuclear reactions, which produce various charged secondaries and photons which can be used to generate the signal in the detection system. For higher energies, more reaction channels contribute which makes detection more complex.

Neutrons deposit dose via secondary particles with a wide range of linear energy transfer, which causes the average quality factor to vary strongly across the neutron energy range [15]. For the protection quantity, effective dose, allowance for the relative biological effectiveness (RBE) is achieved by weighting the absorbed dose by a radiation weighting factor [16]. This weighting leads to strongly energy dependent fluence for dose equivalent conversion coefficients (Figure 1), that increase by a factor of about 50 as the neutron energy increases [17, 18] There are proposals to change these conversion coefficients in the future [19], but for this comparison the currently recommended coefficients of references [17, 18] were used.

This makes it very difficult to design a dosemeter with good energy dependence of response. For lower energies capture reactions dominate the energy deposition, but for higher energies elastic scattering is more important. This means that personal dosemeters are likely to rely on distinct detection mechanisms to produce a reading from neutrons above and below 10 keV: the dose equivalent deposited by neutrons rises rapidly above 10 keV, but below about 200 keV it is deposited mainly by low energy, short range protons, which are hard to detect.

In IC2012n, two types of dosemeter were dominant in terms of numbers entered: etched track and albedo, though some used a combination of the two. Among these each has strengths but suffer from different problems.

- Albedo dosemeters use luminescence that can easily be read out using automated systems and they are reusable, both attractive features. The luminescence derives from energy deposited by secondary charged particles generated in the luminescent material following moderation of the neutron by the workplace / dosemeter / phantom / wearer. Because this is the dominant means by which neutrons below 10 keV deposit their energy in human body, these dosemeters perform well in terms of dose equivalent response below that energy, if an albedo capsule is used which shields thermal neutrons incident on the front or the sides of the dosemeter; but their $H_p(10)$ response falls off rapidly for higher energies. In most workplaces the energy range over which they respond well contributes only a small component of the total dose equivalent, but albedo dosemeters get around this by applying workplace specific correction factors; this causes problems when the field is not known. An additional problem derives from the photon sensitivity of the luminescent elements, though this generally only presents a problem if the detector elements receive varying photon doses, which makes accurate subtraction impossible. If the photon signal cannot be subtracted accurately, the accuracy of the neutron dose assessment will be affected.

- Etched track dosemeters rely mainly on recoil protons to produce damage in plastic detectors that can yield readable tracks. However, this gives them a fast neutron threshold, in the range 50 keV to 300 keV, that depends on the processing method and reading system. The processing and readout are complex, and the detectors are not reusable, which makes them more expensive than albedo dosemeters. However, they generally do not require workplace specific calibration, which is intrinsically more satisfactory. Good performance is seen, however, to depend on finding a method of detection of neutrons below the fast neutron threshold for elastic scattering; this may be achieved using an isotope that emits a charged particle following thermal neutron capture, ^{6}Li, ^{10}B and ^{14}N being commonly used. However, there is often a "gap" in the response between the low energy region and the fast neutron threshold for which the response is very low or even null. An alternative is to add or use in combination a luminescent element to provide the response below the fast neutron threshold.

Given the deficiencies of the existing designs of neutron personal dosemeter, novel designs are needed that address the poor performance of the systems currently in widespread use. Other detection systems such as bubble detectors [20, 21], direct ion storage [22] and fluorescent nuclear track detectors [23] were not entered in IC2012n, though two designs based on silicon diodes did take part. A fission track dosemeter was also entered, but the use of high-*Z* converters means that these are unlikely to ever be widely used.

We can conclude that there is still an urgent need for improved designs and innovation in neutron personal dosimetry.

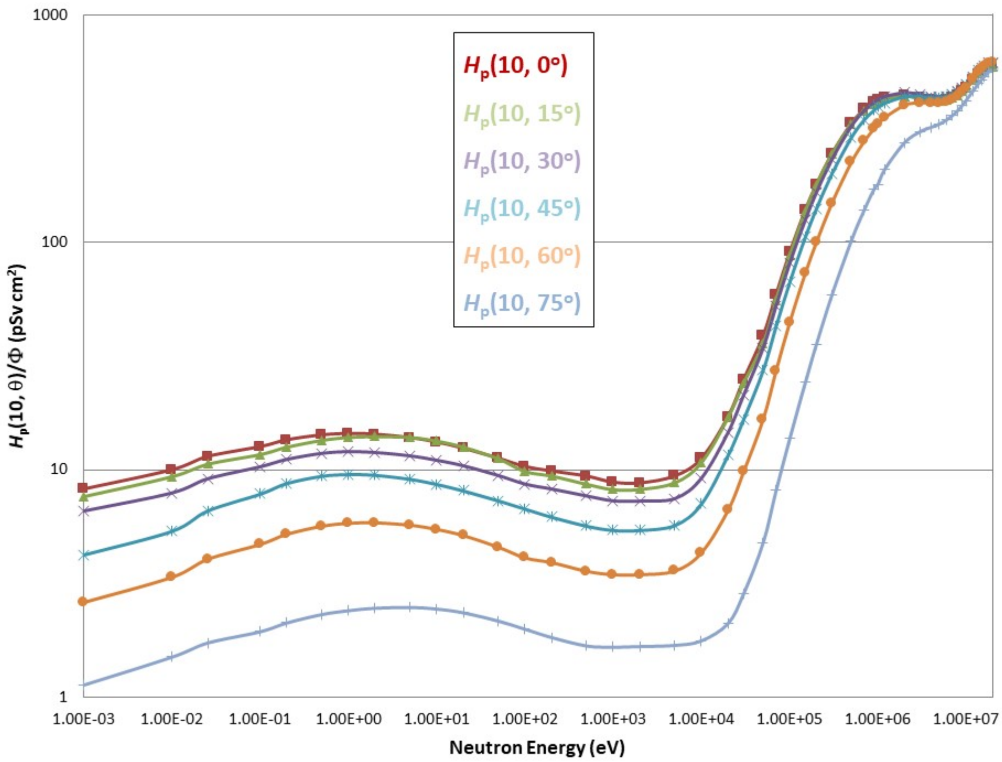

Figure 1: Fluence to personal dose equivalent conversion coefficients vs neutron energy and angle of incidence [17, 18].

Performance standards

Performance standards for personal dosemeters are under constant review and development. Because photons contribute more dose to people, those for photon dosemeters have perhaps been ahead of those for neutron personal dosemeters, but recent years have seen significant improvements in the criteria against which neutron personal dosemeters can be judged. Those standards have been influenced by the recommendations of the EURADOS IC2012n intercomparison. The standards that have been published since IC2012n was carried out are also discussed in this section and in 2.7, to give perspective on the current thinking on personal dosemeter performance.

The added difficulties associated with neutron personal dosimetry are reflected in the available standards, which allow poorer precision on neutron personal dosemeter performance assessments than are permitted in the similar standards for photon personal dosemeters. For example, ISO 14146:2018 [24] which covers “Criteria and performance limits for the periodic evaluation of dosimetry services” permits, for higher doses, a response range of 0.71 ↔ 1.67 for photon whole body dosemeters but 0.5 ↔ 2.0 for neutron whole body dosemeters. EN 62387:2020 [25] for passive whole body photon dosemeters also allows a response range of 0.71 ↔ 1.67for angles of incidence of up to 60°, whereas ISO 21909-1:2015 [26], for passive neutron whole body dosemeters, permits a broader response range of 0.4 ↔ 2.5 for angles of incidence up to 60°, though it is not applicable to albedo dosemeters. The corresponding maximum coefficients of variation are 5% for photon dosemeters but 10% for neutron dosemeters. In all cases, the ranges increase for low personal dose equivalent. More relaxed tolerances on the performance are realistic reflections of the relative difficulty of photon *versus* neutron personal dosimetry.

Intercomparison exercise planning

It is relatively easy to structure a photon personal dosemeter intercomparison, because the range of available calibration fields cover the whole relevant energy range for most applications and can be provided with high dose rates. They are also relatively cheap to generate and widely available. It is comparatively more expensive to conduct a neutron personal dosemeter intercomparison and the range of calibration fields available is limited. The available irradiation fields are more expensive to generate, and the dose rates tend to be relatively low. This is particularly true when accelerators are used, because the accelerators are expensive to buy and operate, and must use thin targets to generate monoenergetic fields, but those targets would be damaged by the high beam currents needed to generate high dose rates. Dose rates from radionuclide sources also tend to be low, and these are far from monoenergetic and cover a relatively limited part of the relevant energy range. Realistic fields tend to have low dose rates, because neutrons need to be scattered down in energy, which lowers the dose rate.

A further problem was highlighted during IC2012n, which used a 250 keV monoenergetic field: some albedo dosemeters could not cope with monoenergetic fields. However, such fields are also very important for determining the fast neutron thresholds of etched track dosemeters. These challenges hence need to be addressed in a way that avoids skewing an intercomparison in favour of one type of dosemeter, whilst ensuring that it provides an adequate test and does not become prohibitively expensive.

Reference radiation fields and workplace fields

Reference neutron fields are detailed in ISO 8529 parts 1 to 3 [27, 28, 29] and simulated workplace fields are described in ISO 12789 parts 1 and 2 [30, 31]. These standards are currently being revised or the revisions are planned, which is particularly important for the simulated workplace fields, many of which are no longer available. The neutron fields described in these standards are a mainly radionuclide source fields or accelerator-generated fields, though there is one reactor field included. Ideally, the intercomparison would have been restricted to fields from these standards, but field availability and dose rate had to be considered. Generation of fields using accelerators is more expensive and the dose rates relatively low, especially for simulated workplaces. Consequently, inclusion of accelerator based simulated workplace fields would require too much accelerator time and the cost would be prohibitive.

One of the most important fields for neutron personal dosemeters is a thermal field. Whilst thermal neutrons can dominate the fluence, they rarely dominate in terms of dose equivalent or effective dose, but dosemeters that do not detect thermal neutrons perform less well in the workplace [32, 33]. It would have been good to use a thermal field in the intercomparison, but this would also have caused a problem similar to monoenergetic neutron field, because some personal dosemeters would not have been able to measure it: This is a particular problem for etched track personal dosemeters that do not have a thermal neutron converter. Moreover, irradiating to a thermal field could also be interesting to check any possible over-response of some dosemeters. Inclusion of the available thermalized fields would also have required a pair of irradiations, one behind a cadmium shield, to allow the fast neutron response to be subtracted.

These difficulties in generating the fields and the cost associated with the exposures limit the number of different fields that can be included. The choice of these fields is problematic because of the contrasting characteristics of neutron workplace and reference fields and the deficiencies of different dosemeter types. Some of these issues are expanded upon below.

Some dosemeters are calibrated via a measurement, using various neutron monitoring instruments, of the dose equivalent in the area where they are actually used, and others use calibration factors which are dependent on information about the energy distribution in the area where they are employed (field-dependent calibration factors). Both of these techniques rely on using data that can be used to determine the $H^{*}(10)$ rate to calibrate a personal dosemeter in terms of $H_{p}(10)$: the former is not affected by the directional distribution of the field, but the latter is affected by the directional distribution of the field and the orientation of the individual. These methods lack the rigour of reference field determination and strictly rely on determination of personal dose equivalent in the specific workplace, which is a difficult problem [32]. They also rely on the field remaining stable.

A desire to investigate the degree to which variations in calibration procedures affect harmonisation of neutron dosimetry, and the question of the suitability of dosemeters for use in neutron fields other than their calibration fields, were amongst the motivations behind the neutron intercomparisons. It was hence important that the fields chosen should provide tests of these factors, that were fair but able to reveal deficiencies in the performance.

High-energy (> 20 MeV) accelerator facilities were excluded because most neutron dosemeters have not been designed for such fields and are not calibrated for use in them. Neutron fields in most terrestrial workplaces have neutrons that range in energy from 10^{-9} MeV to 20 MeV; i.e. over 10 orders of magnitude. The source neutrons are primarily from fission and (α, n) reactions with most of the dose equivalent deriving from neutrons with energies in the range 1-5 MeV, though because of the stochastic nature of these reactions some neutrons will have lower energies and the maximum will be up to 20 MeV. Additionally, fusion reactions for energy generation are characterized by 2.5 MeV and 15 MeV neutrons, for (D, D) and (D, T) respectively, and high-energy photons can also produce neutrons via (γ, n) reactions. Some accelerators may produce neutrons with much higher energies, but those fields are outside the scope of this intercomparison, as are those produced by cosmic ray interactions in the atmosphere or those that are generated as secondary fields in proton therapy facilities.

Workers are rarely exposed to a bare neutron source. In workplace fields the neutrons have, almost invariably, lost energy via a number of scatters, and have a very broad range of energies. Typically, the energy distribution features a thermalized peak (E_{n} < 0.4 eV), a smaller intermediate energy component (0.4 eV < E_{n} < 10 keV) and a residual fast distribution (E_{n} > 10 keV). Examples of workplace fields (Figure 2) show these three distinct components; the examples given are for mainly (α, n) neutrons from fuel rods and fission in a research reactor as measured during the EVIDOS project [33]. Ideally an intercomparison would test dosemeters across this range of energies, though the intermediate energy range is less dosimetrically important.

The primary neutrons used to generate reference fields have fluence to dose equivalent conversion coefficients that are about a factor of 50 times higher than those for thermal and epithermal fields.

Consequently, much higher fluences are required to test adequately the response below the fast threshold: low-energy dose rates can be very low. This problem is exacerbated if there is significant capture taking place in the moderation process. The conversion coefficients also fall, in general, with increasing angle of incidence so irradiations performed at higher angles will need to be longer to ensure that the dose is high enough to produce a measurable signal in the dosemeter.

The photon component of reference neutron fields is not always known with high accuracy. This should be irrelevant for the track detectors, but is an issue for the albedo and electronic dosemeters, but in different ways: albedo dosemeters rely on subtraction to remove the photon background, which statistically impairs the result in a strong photon field; electronic dosemeters must exclude photon pulses from their reading, which is harder if pulse pile-up becomes an issue. In practice, active neutron personal dosemeters have to set a pulse height threshold to exclude photon events, so pile-up can make photon events appear to be due to neutrons.

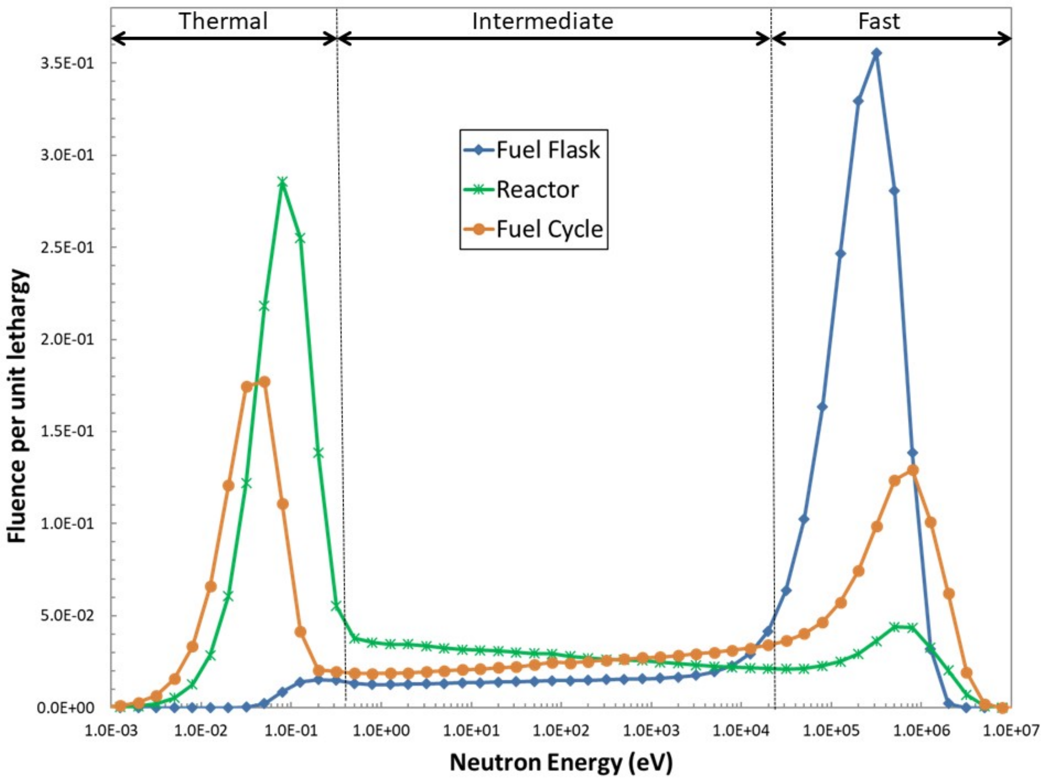

Figure 2: Workplace energy distributions measured at a research reactor, a fuel fabrication plant and near a fuel flask during the EVIDOS project [33]. The fluence is normalized to a total of 1 and then each bin is normalized to its logarithmic energy width, i.e. the plot is of fluence in the i^{th} energy bin (Φ_i) per unit lethargy: $\Phi_i/\ln(E_{i+1}/E_i)$.

The inclusion of angles of incidence other than normal to the reference direction of the dosemeter can also be subjective depending on the type of dosemeters. The best designs of albedo dosemeter should have good angle dependence of response for forward angles, although 90° can be problematic. Track detectors and electronic devices should also perform well for higher angles of incidence for energies below their fast threshold, if they have a thermal neutron converter. Above the fast neutron threshold their angle dependence of response is not so good; for track detectors the dose equivalent response falls with increasing angle of incidence. This is because the recoil protons cannot be detected above a critical angle, which depends on their energy and the etching procedure.

Future developments of dose quantities

ICRU have recently published Report 95 [19] which recommends the replacement of *personal dose equivalent* with a new quantity *personal dose*. This proposal has been endorsed by the ICRP. The new quantity better reflects the likely detriment from radiation exposures since it is based on effective dose. Additionally, it does not use the kerma approximation and consequently it is much more relevant for high energy neutron exposures. It will change the magnitude and the energy and angle dependence of response of neutron personal dosemeters, when implemented in legislation. This may require significant redesign of dosemeters and for standards to be revised and intercomparisons to be redesigned accordingly. A EURADOS report is being written on this specific topic.

1.2 Overview and history of IC for neutron dosemeters worldwide, need for and framework

Individual monitoring of workers occupationally exposed to external radiation shall be conducted to verify compliance with the requirements for protection and safety laid down in both the International [34] and the European Basic Safety Standards [35] in accordance with the fundamental principles of justification of activities and optimization of protection, which shall be applied for all exposure situations [36]. The equipment employed is required to be tested at appropriate intervals with reference to national or international standards published, for example, by the International Electrotechnical Commission (IEC) and the International Organization for Standardization (ISO). Apart from standards, several documents of relevance deal with individual monitoring for radiation protection purposes. They are the outcome of deliberations of a group of experts or a commission, who, as a result of their competence and experience, can make highly regarded recommendations in the field of interest. Publications of the International Commission on Radiological Protection (ICRP) and reports from the International Commission on Radiation Units and Measurements (ICRU) belong to this category, along with guides from international organizations such as the European Commission (EC) [5] and the International Atomic Energy Agency (IAEA) [37].

In general, adherence to standards and documents of relevance are not mandatory, and some national framework of guidance is needed. European Union (EU) legislation is in the form of European Council Directives and Regulations. Where radiation protection is concerned, Directives are issued under the Euratom Treaty, requiring member states to implement their provisions nationally for the benefit of the EU as a whole. Regulations directly implement EU policy in member states without the need for member states to enact their own legislation. Directives need to be transposed into national legislation, but member states are left with a certain amount of discretion as to the exact methods of implementation. Although individual monitoring services in Europe may face different legal or regulatory frameworks and widely differing national requirements for dosemeter performance, it is still desirable to achieve a reasonable degree of harmonization in individual monitoring practice.

Accreditation is becoming more and more important in Europe and to comply with ISO/IEC 17025 requirements [4], IMSs need to take part in proficiency testing exercises on a regular basis. Moreover, EC's technical recommendations for individual monitoring [5] also recognize the importance of participating in intercomparisons. In this context, it is essential to make intercomparison exercises available to the IMS community.

1.2.1 Previous Intercomparisons for Neutrons

EURADOS Performance Test 1999

The first performance test for whole-body neutron personal dosemeters broadly representative of those in use in the EU member states and Switzerland was organized by EURADOS in 1999 and aimed at enabling assessment of criteria for the acceptability of routine dosimetry services [38]. The radiation fields were chosen to investigate the energy and angle dependence of different types of personal dosemeter as well as their responses to realistic spectra, simulating, as far as possible, the conditions at workplaces by combining several different energies and angles of incidence. Participants were invited by the *EURADOS Action Group on Harmonization and Dosimetric Quality Assurance in Individual Monitoring for External Radiation*. Participation was on a voluntary basis, without a fee being charged. In all, 17 services from 10 EU member states agreed to take part in the neutron performance test, supplying dosemeters from four different categories: albedo dosemeters, nuclear track detector (NTD)-based high-energy neutron dosemeters, multi-element dosemeters with one detector type (usually etched track or TLD), as well as multi-element dosemeters with at least two different detector types.

Irradiations were performed at the Cadarache Laboratory of the Institut de Radioprotection et de Sûreté Nucléaire (IRSN), France, and included a bare ^{252}Cf source at angles of 0°, 30° and 60°, a graphite-thermalized ^{241}Am-^{9}Be field (Sigma facility), as well as the accelerator-based CANEL+ facility, which delivers a broad spectrum from thermal to 10 MeV and is simulated in detail using MCNP Monte Carlo computations. The dosemeters were mounted at the central area of the front face of an ISO water slab phantom [29] (30 cm × 30 cm × 15 cm), which was placed on a rotating stage. Results were found to be very dependent on the dosemeter type and the dose calculation algorithm. While fast neutron fields were generally measured well, problems were noted in the determination of intermediate energy fields, illustrating the importance of such radiation qualities for calibration purposes. Of particular concern from a radiation protection point of view were the large number of results that underestimated the $H_p(10)$ reference value, which lead to the conclusion that a factor of 1.5 on the response is too tight a criterion to be applied to neutron dosemeter performance. No individual monitoring service had all results within a factor of 1.5, with three services being narrowly outside and a total of seven out of 17 within approximately a factor of 2. The intercomparison identified problems at higher angles of incidence (60°) and low dose values (0.1 mSv).

IAEA Intercomparison 2003/04

The occupational radiation protection programme of the IAEA initiated and funded an international intercomparison exercise of neutron personal dosemeters to assess the capabilities of dosimetry services to measure the quantity personal dose equivalent, $H_p(10)$, in mixed neutron-gamma fields [37]. In addition, the programme aimed to assist IAEA member states in achieving appropriate accuracy requirements in individual monitoring and, where needed, providing guidelines on improvements, rather than simply conducting a performance test. The intercomparison consisted of two phases and focused on passive dosemeters determining neutron and gamma-ray components either separately or in terms of total personal dose equivalent. Out of the 35 participants nominated originally, 32 actually provided dosemeters for phase I and 30 for phase II, including the following systems: 17 albedo TLD dosemeters for neutrons and gamma, eight multi-element dosemeters with one or more detector types, comprising a combination of NTDs, TLDs and radiophotoluminescence (RPL) glass detectors for neutrons and gamma, respectively, as well as one superheated emulsion detector for neutrons. The remaining four participants did not provide any information on the dosemeter type.

Irradiations were performed at the IRSN in Cadarache, France, and the Physikalisch-Technische Bundesanstalt (PTB) in Braunschweig, Germany. Phase I, conducted in 2003, comprised a type-test intercomparison, in which dosemeters were exposed to selected calibration fields of both radiation types as well as mixed neutron-gamma fields. Thermal and accelerator-produced monoenergetic neutrons of 70, 144 and 565 keV as well as 1.2 and 5 MeV were used to investigate the energy dependence of the dosemeter response. The angular dependence was studied using ^{252}Cf at angles of 0°, 45° and 60°. Further irradiations included ^{241}Am-Be, only photon irradiations (W-250 X-rays and ^{60}Co) and mixed neutron-gamma irradiations (^{252}Cf with ^{60}Co and 565 keV neutrons with ^{60}Co). The results were intended to improve the dosimetric procedures of participating laboratories. For phase II, performed in 2004, mixed neutron-gamma fields were selected, which may be considered to be characteristic of workplaces in the nuclear industry, using mixtures of radiation fields from the CANEL+ assembly, a D_2O-moderated ^{252}Cf source with and without shadow cone, W-250 X-rays, ^{137}Cs and 6.6 MeV gamma rays. The exercise revealed clear deficiencies in the methodology used by several laboratories and necessitated a detailed analysis of the existing discrepancies. If a factor of 1.5 was considered as a criterion for the overall uncertainty in the estimation of effective dose for photons, and a factor of 2 for neutrons, nearly 50 % of the participants achieved satisfactory results, defined as not more than one outlier for total $H_p(10)$. 20 % of the participating services, however, achieved very poor results with more than 50 % outliers, particularly for scattered neutrons and mixed neutron-gamma fields. There was no indication that a certain type of dosemeter performed better than another: the results seemed to be mostly influenced by the experience and skills of the laboratory. This observation called for training in the area of mixed neutron-photon dosimetry.

EURADOS Intercomparison 2012

In 2012, EURADOS executed a proficiency test aimed at providing IMSs for external neutron dosimetry with the opportunity to test the performance of their routine active and passive dosemeters, to compare their results with other services and to demonstrate compliance with their quality management systems. At the same time, the intercomparison exercise provided reference calibrations traceable to accredited or primary standard dosimetry laboratories. No systems under research and development were allowed to enter the IC. Since irradiations were restricted to neutrons, no additional photon irradiations were included over and above photon exposures associated with the neutron production mechanism. The radiation fields selected included standard calibration fields described by ISO 8529-1 [27] (bare and D_2O-moderated ^{252}Cf, 250 keV mono-energetic neutrons) and a simulated workplace field produced according to ISO 12789-1 [30] (bare ^{252}Cf behind a shadow cone) with energy range from thermal to several MeV, different dose values (0.3 to 15 mSv) and angles of incidence (0° and 45°) on the dosemeters. The irradiations were performed at accredited National Primary Metrology Laboratories for ionizing radiation: the National Physical Laboratory (NPL), United Kingdom, and PTB, Germany.

For this intercomparison, a total of 36 dosemeters was required of each registered system, comprising 24 dosemeters for irradiation, 8 spares and 4 background dosemeters. A total of 31 IMSs with 34 dosimetry systems participated in the IC: 28 of the IMSs were from 16 European countries, two from Japan and one from the United States. Most of the dosimetry systems were albedo dosemeters based on thermoluminescence or etched track dosemeters, or a combination of these. In addition, two systems were based on optically stimulated luminescence (OSL), one was a fission track dosemeter and two were electronic devices based on silicon diodes. Results were received from 30 participants for 32 dosimetry systems (30 passive and 2 active). One participant withdrew one system after receiving the irradiated dosemeters, but before the reference values had been made available, whilst another participant was unable to provide results due to problems with their reading system. After confirmation of the results submitted by the participating IMSs, EURADOS issued a *Certificate of Participation* to each service, including information on the irradiation qualities, doses, dosemeter responses and overall uncertainties for all irradiations. A summary report was prepared by the Organization Group for publication in the EURADOS Reports series [12, 14].

In view of the lack of international consensus on acceptance criteria for dosemeter performance and the results of previous ICs, the Organization Group decided to consider the relative response of a dosemeter acceptable if it ranged within a factor of two from the reference value for all doses. Except for five systems with low results, all dosemeters met the acceptance criteria for the bare ^{252}Cf irradiations at 0° incidence. Two outliers were observed among track detectors for the bare ^{252}Cf irradiations at 45° incidence. The relative response to D_2O-moderated ^{252}Cf was slightly greater than unity for all dosemeter types. Those for track and other dosemeters were quite tightly grouped and ranged from 0.82 to 1.63. The majority of albedo systems performed well, although three results were identified outside the 0.5 to 2.0 range. The response of albedo and track dosemeters to ^{252}Cf behind a shadow cone, on average, were low while the other systems showed relative responses close to unity. At first sight, it might be surprising that the albedo systems had not performed significantly better than the track dosemeters in a field that was deliberately developed to include lower energy neutrons. Closer analysis revealed that most of the personal dose equivalent was delivered by neutrons with energy of about 1 MeV but included significant contributions from lower energies around 100 keV where both types of dosemeters exhibit some under-response. Unsurprisingly, by far the widest range of responses was reported for 250 keV neutrons. This field falls into the region of neutron energy where the fluence-to-$H_p(10)$ conversion coefficients are changing rapidly and some dosemeter response functions, particularly those of the albedo systems, are poor. In conclusion, it became evident that personal neutron dosimetry still had significant problems. Exercises such as IC2012n are important for making the radiation protection community aware of the present state of the art, and for providing the IMSs with opportunities to demonstrate the capabilities of their dosemeter systems and any recent improvements they have made.

2 Outline of the EURADOS Intercomparison IC2017n

The scope of the intercomparison was to provide Individual Monitoring Services (IMSs) for external neutron dosimetry with the opportunity to test the performance of their dosemeters, to compare their results with other IMSs, to show compliance with their own quality management system, and at the same time to provide reference calibrations traceable to Accredited Laboratories. Participation was on a voluntary basis. A participation fee was charged to cover the expenses for the International Comparison (IC), mainly due to irradiation costs.

The individual results are the property of the participants only, therefore the procedure established for the self-sustained EURADOS intercomparison programme has been set-up in such a way as to assure data integrity and confidentiality.

The 2017 EURADOS Intercomparison for whole-body neutron dosemeters, IC2017n, was designed to accept both active and passive devices, but only routinely used dosemeters. Application forms and results were received from 32 participants (IMSs) for 33 dosimetry systems (all passive). 6 IMS participated for the first time in a EURADOS intercomparison for whole body neutron dosemeters, while 26 participated for the second time. Most participants were from European countries, but IMSs from Japan, United States, Brazil, and India also participated. Values of personal dose equivalent, $H_p(10)$, were reported by all the participants for all their irradiated dosemeters.

An irradiation plan was defined by the Organization Group based on reference radiation calibration fields with different angles of incidence and at different levels of dose.

The results were provided to the participants in the Certificate of Participation with the certificates of the calibrations given by the Irradiation Laboratories as annexes.

As for all EURADOS intercomparisons, a participants' meeting was organized to report and discuss the results and to allow the participants to discuss general aspects of the intercomparison and specific systems' problems with the OG. An overview of the results has been published in [39]. Further and more detailed discussion is given in this dedicated EURADOS report which will be provided to each participant.

The organizational structure for the EURADOS programme for self-sustained ICs for IMS, was laid down in the report of Working Group 2 (WG2) Subgroup 2 which was presented to the EURADOS Council at the annual meeting 2007 [40]. This report provided extensive plans for a self-sustained programme of intercomparisons for IMSs with specific detailed proposals for the technical and organization procedures and financial aspects. The main features of the report are also presented in [41]. The proposed plan was put into practice starting with EURADOS IC2008 and was kept, essentially unaltered, for the following ICs, including IC2017n.

2.1 Organization Group

For each IC an Organization Group (OG) is appointed by the EURADOS Council with the mandate to execute the IC. This group prepares, manages, and controls all planning and operational details of the IC. This includes all material and data transfer between the participating IMS and the irradiation laboratories that perform the irradiations. For efficiency, the OG is limited to a relatively small number of persons which also helps in controlling confidentiality.

For IC2017n the OG was formed by the authors of this report, with PSI (Switzerland) acting as the coordinating institute. The exchange of data and information with the participants and the distribution of the dosemeters between the participants and the irradiation laboratories were performed solely by the OG Coordinator. For registration and communication with the participants, an online platform has proved itself to be a practicable tool in previous EURADOS intercomparisons for photon dosemeters [10] and was therefore adapted for IC2017n.

2.2 Scope

IC2017n was set up to compare neutron dosemeters used to measure neutron personal dose equivalent, $H_p(10)$ as provided by Individual Monitoring Services (IMS) for exposed workers. Routine passive or active dosemeters could be tested, whereas no systems under research and development were allowed. The irradiations, which included exposures to neutrons and mixed fields of neutrons and photons, 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. Most irradiations were performed in neutron fields with no additional photon component, over and above that resulting from the neutron-producing process, e.g. the photons from a radionuclide neutron source. However, for some fields, an additional photon component was included.

The IC2017n allowed IMSs to test their performance and at the same time to provide reference calibrations traceable to Accredited Laboratories.

2.3 Project set-up and phases

For all EURADOS ICs, including IC2017n, four main phases can be defined, i.e.:

1) preparation
2) participant applications
3) execution
4) reporting

In the *preparation phase* the OG decided on the scope, the irradiation plan, a provisional budget and the time schedule. After these details had been established, suitable irradiation facilities had to be identified. This was achieved by approaching a limited number of institutes for formal quotations. These quotes were evaluated for quality and availability. All of the institutes selected from the shortlist fulfilled the minimum quality criteria (ISO 17025 accreditation and also availability). The EURADOS Council decided, in accordance with the protocol contained in the OG proposal, to take an option for two irradiation laboratories that could provide appropriate radiation fields with good characterization. Terms and conditions for the participants were then established with limits set for maximum and minimum number of participants according to the established participation fee. As a sufficient number of applications were received from potential participants, the EURADOS Council approved the budget and gave formal approval to the OG to proceed with IC2017n.

During the *application phase* the IC exercise was formally announced on the EURADOS website and participants were able to send their application forms to a dedicated online platform; these were forwarded to the Coordinator. The Organization Group then evaluated the status of all the applications. Once it became established that the minimum number of participants had been reached to make the IC financially viable, the decision was made to confirm the purchase order for the irradiations and to continue to the next phase.

To clarify the scope of the IC to the candidate participants, the following information was given at the application phase:

> *"The irradiations, which will include exposures to neutrons and mixed fields of neutrons and photons, will be performed in accredited irradiation facilities in terms of $H_p(10)$. The range of energies used in the intercomparison will extend from thermal to several MeV, with different dose values and angles used. Most irradiations will be performed in neutron fields with no additional photon component, over and above that resulting from the neutron-producing process, e.g. the photons from a radionuclide neutron source. However, for some fields, an additional photon component will be included.*
>
> *Participants are requested to only apply routine procedures as declared in the application form, where they can also declare whether they need additional simplified a priori information on the energy distribution of the radiation fields to allow correction of the bare results of neutron personal dosemeters. This information will be provided only to participants who request it. In case this extra information is provided, this will be mentioned on the intercomparison certificate."*

This information was provided to give the candidate participants the opportunity to decide whether this IC would be suitable for their dosimetry systems.

At the start of the *execution phase* all candidate participants received a confirmation of participation, preliminary information, and a set of instructions to deliver the dosemeters to the coordinator. At this stage, the participants were requested to submit the participation fee.

All participants were asked to prepare their dosemeters according to their normal procedures, and to provide the identification codes of the dosemeters to the coordinator using an electronic form (provided by the coordinator). The participants had to dispatch the dosemeters to the coordinating laboratory (PSI, Switzerland) following the guidelines before the set deadline.

The coordinator received and registered all dosemeters. These were then forwarded to the two irradiation laboratories in two separate shipments. For each participant the appropriate number of dosemeters were delivered to each of the two irradiation laboratories plus 4 background dosemeters and 2 spare dosemeters.

Following exposure, the irradiation laboratory returned the dosemeters to the coordinator who returned them to the participants.

In the *reporting phase*, the participants received instructions on reporting their results via the online platform for digital transfer.

The information on radiation fields provided to the participants is reported in Table 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}Cf and ^{241}Am-Be(α,n),
- "radionuclide source, significantly moderated", for irradiations with a D_2O moderated ^{252}Cf source with and without shadow block.

In this respect IC2017n differed from the IC2012n, where a two-step procedure was used with very little information on the radiation fields given to participants in the first step. Then, in a second step, information on the radiation field was given to those participants who had asked for it, to enable them to choose the appropriate calibration factor to be used.

After the dose evaluation was provided by the IMSs, the reported dose values, H_m, were compared with the neutron reference doses, H_{ref}, given by the irradiation laboratories, by calculating the *response value R*:

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

The response values were reported back to all participants individually, with the request to check and to either confirm or comment on the results.

The OG met again and reviewed all the comments received from the participants on their results. Decisions were made on the requests for data amendment and all results were then finalized.

In the reporting phase the Certificates of Participation were prepared, and a scanned version of the Certificate of Participation was made available for download on the online platform. In addition, the signed original of the Certificate of Participation was sent by post. The participants confirmed, either by email or directly via the online platform, the receipt of the certificates.

Table 1: Radiation field information provided to the participants.

Irradiation conditions	Information provided to participants	
	NO *a priori* information requested	with *a priori* information requested
^{252}Cf at 0°, 45° and ^{241}Am-Be(α,n)	irradiated	bare radionuclide source
^{252}Cf at 0° and additional photons	irradiated	bare radionuclide source
^{252}Cf (D_2O moderated) at 0° and ^{252}Cf (D_2O moderated) behind a shadow block	irradiated	radionuclide source, significantly moderated

A participants' meeting was organized to present and discuss the results among the Organization Group and the participants. The meeting was scheduled to coincide with EURADOS Annual Meeting AM2019, held in February 2019 in Łódź, Poland. At the meeting the OG presented detailed information on the irradiation qualities, radiation doses, response values and overall uncertainties. The presentations given at this meeting are available for download at the EURADOS website using the link: https://eurados.sckcen.be/events/intercomparisons.

Finally, the results of the intercomparison are published and fully discussed, with the IMS submitting each set of results being kept anonymous, in a dedicated EURADOS report (present report) and in the open literature as scientific communications presented at conferences and/or papers published by scientific journals.

The time schedule during which IC2017n was performed is reported in Appendix A. The tasks between IC application and sending out of the Certificates of Participation were completed within 17 months in the period from March 2017 until July 2018. Throughout, the work performed by the OG was undertaken under a strict confidentiality agreement (Appendix B).

2.4 Irradiation plan

The irradiation tests were established by the OG with the aim of providing the participants with useful information on their dosimetry systems, i.e. a rough estimation of:

- linearity,
- reproducibility of the system for identical irradiations
- responses for different energies (from thermal to several MeV)
- responses for different angles
- responses for simulated workplace fields

Because of the wide variety of different workplaces in which neutron personal dosemeters are used, with a correspondingly large number of very different neutron spectra, the present exercise could not hope to be comprehensive in covering the effects of all the possible different conditions. Spectra were therefore chosen to investigate a limited number of aspects.

Neutron irradiation qualities as described by the standard ISO 8529, parts 1 to 3, were selected as well as a simulated workplace field, produced according to standard ISO 12789, part 1 and part 2. For more information and references, see Chapter 2.6.

The irradiations have been performed in terms of $H_p(10)$ at two European accredited laboratories which are both National Primary Metrology Laboratories for ionizing radiation: NPL (National Physical Laboratory, UK) and PTB (Physikalisch-Technische Bundesanstalt, D).

The range of energies of the broad neutron spectra used in the intercomparison extended from thermal to about 10 MeV, with different dose values and angles (0°, 45° and isotropic) used. Most irradiations were performed in neutron fields with no additional photon component, over and above that resulting from the neutron-producing process, e.g., photons from a radionuclide neutron source. However, for one field an additional photon component was given.

The chosen fields and the number of dosemeters irradiated in each one are outlined in Table 2. For IC2017n, each participant was asked to provide 40 dosemeters: 28 to be irradiated, 4 spare dosemeters and 8 background dosemeters. During the irradiations, the dosemeters were attached to the front face of an ISO recommended water-filled phantom, which was positioned at 75 cm from the centre of the neutron source. An exception was the D_2O moderated ^{252}Cf source behind a shadow block, where a phantom made of PMMA was used at 170 cm from the neutron source.

Table 2: Irradiation plan for the EURADOS IC2017n intercomparison for whole body neutron dosemeters

Quality at irradiation laboratory	$H_p(10)$ (mSv)	Number of dosemeters	Irradiation distance (cm)	Irradiation laboratory
^{252}Cf at 0°	0.3 1.5 12	4 4 4	75	NPL
^{252}Cf at 0° with ^{137}Cs	1.5 1.0	4	75	PTB
^{241}Am-Be(α,n) at 0°	1.5	4	75	NPL
^{252}Cf at 45°	1.5	2	75	NPL
^{252}Cf (D_2O moderated) at 0°	1.2	4	75	PTB
^{252}Cf (D_2O moderated) behind a shadow block	1.0	2	170	PTB
Total number of irradiated dosemeters		28		
Additional dosemeters: spare and background		4 8		
Total		40		

2.5 Participants and dosemeter types

A total of 32 IMSs participated with 33 dosimetry systems: 26 of the IMSs were from 13 European countries, 2 from Japan, 2 from the USA, 1 from Brazil and 1 from India.

An overview of the dosemeters of the 33 systems taking part in IC2017n is shown in Figure 3.

Results were received for all 33 dosimetry systems, and these were all passive systems.

Table 3 indicates the number of participating systems from different countries. A complete list of the participating IMSs is given in Appendix C.

Figure 3: Dosemeters samples of the systems taking part at IC2017n.

According to the information provided by the participants, most of the dosimetry systems were etched track dosemeters, i.e. proton recoil dosemeters, based on polyallyldiglycol carbonate (PADC) or albedo dosemeters based on thermoluminescence or a combination of the above-mentioned detection techniques. In addition, one system was based on optically stimulated luminescence (OSL) and one was based on fission track detectors.

Table 3: Number of participating systems per country

Country	Number of participating systems per country
Germany, Italy	4
France, United Kingdom	3
Austria, Belgium, Czech Republic, Japan, Switzerland, United States	2
Brazil, Finland, India, Poland, Romania, The Netherlands, Turkey	1

Results are reported according to the following simplified classification: *Track* and *Albedo*. However, each of the categories could be further sub-divided, as shown below.

Track: 18 systems

- 7 with etched track detectors for fast neutrons and TLD for thermal neutrons,
- 7 with etched track detectors for fast neutrons combined with converters for thermal neutrons,
- 3 with etched track detectors for fast neutrons only, i.e. no evidence of a thermal sensor
- 1 based on fission track detection,

Albedo: 15 systems

- 10 based on TLD + boron loaded shield,
- 3 based on TLD + cadmium shield,
- 1 based on OSL with no information on shielding of direct thermal neutrons
- 1 based on TLD with no information on shielding of direct thermal neutrons.

Only three of the etched track dosemeters were based on the detection of charged recoils alone, while all others contained an additional thermal sensor. Depending on the evaluation procedure, recoil protons with energies above a threshold in the range 100 keV to 500 keV, can usually be detected in polyallyldiglycol carbonate. The thermal sensor provides additional response in the thermal neutron region. In most cases, converters containing a material with ^{6}Li, ^{10}B or ^{14}N are used in contact with a sub-area of the track detectors and the track detectors register the charged particles produced by thermal neutron reactions ^{6}Li(n,α), ^{10}B(n,α), or ^{14}N(n,p). In some cases, the thermal neutron converter was an integral part of the holder that does not permit independent estimates of the thermal and fast doses because the whole read area includes a thermal neutron signal.

Alternatively, TLDs, containing ^{6}Li or ^{10}B, are used and their thermal neutron reading is evaluated by a TLD reader. One of the track systems was based on fission track detectors. This dosemeter uses ^{235}U and ^{232}Th, which have a considerable fission cross section ranging from thermal neutrons to fast neutrons. The fission tracks are registered in thin Mylar foils by using chemical etching and a spark counter. Due to the presence of a cadmium cover, thermal neutrons are absorbed and the dosemeter is sensitive to neutrons above 0.5 eV.

Most of the albedo dosemeters used either a cadmium layer in front of the TLDs or they were even more completely surrounded by a boron-loaded shield with an albedo window, containing no boron, on the rear side. In the case of albedo dosemeters, fast neutrons are detected via neutrons thermalized and backscattered by the body. The personal dose equivalent response of these dosemeters decreases strongly for higher-energy neutrons, i.e. for neutrons above 100 keV and – if a cadmium or boron-loaded shield is used – also for thermal neutrons. The cadmium layer or the boron loaded shielding reduces the response to directly incident thermal neutrons. From fundamental principles, there is no difference to be expected if the detection method changes from TLD to OSL.

Albedo dosemeters generally need field-specific calibration factors. For example, in Germany, the field-specific calibration factor for albedo dosimeters is defined for 4 application areas by the standard DIN-6802-4 [42] In this intercomparison exercise, 22 out of 33 participants asked for *a priori* field information. These were mostly albedo systems, but over 40% of the track systems also asked for this information.

2.6 Performance of the irradiations

A total of 924 dosemeters were exposed in accordance with the irradiation plan drawn up by the organising committee. Two laboratories were contracted by EURADOS to perform the exposures; they were NPL and PTB.

Each irradiation laboratory provided certificates to the Coordinator with data for all the irradiations performed at that laboratory. Each participant received the irradiation certificates for the exposures performed for their dosemeters (see example in Appendix D) as an annex of the Certificate of Participation.

All irradiations were performed, on the appropriate phantom, according to the recommendations of ISO 8529 parts 1 to 3 [43, 44, 45], ISO 12789 parts 1 and 2 [46, 47] and ISO 29661 [48]. The dose equivalent reported was the operational quantity, personal dose equivalent, $H_p(10)$, derived from fluence measurements and the use of conversion coefficients recommended by a joint ICRP/ICRU committee [17, 18]. For irradiations at 0°, 4 dosemeters were attached using adhesive tape to the front side of an ISO recommended water-filled phantom, which was positioned at 75 cm from the centre of the neutron source. The phantom consists of a box, with outer dimensions 30 cm × 30 cm × 15 cm, made of PMMA, which is filled with water. The walls are 10 mm thick except on the front face, where the dosemeters are normally attached, which is 2.5 mm thick. An exception was the D_2O moderated ^{252}Cf source behind a shadow block, where a phantom made of PMMA was used at 170 cm from the neutron source (see section 2.6.2). For the ^{252}Cf irradiations at 45° only 2 dosemeters were irradiated, and these were mounted on the vertical rotation axis to minimise the variation in the doses delivered to the dosemeters. As described in ISO 29661 for type tests and calibrations, especially of dosemeters that are substantially sensitive to radiation backscattered from the phantom, the dosemeters were mounted with their rear side (including a clip) attached to the phantom surface. In order to minimize scattered radiation from adjacent dosemeters and attenuation of backscatter, the dosemeters were arranged so that they were not too close to each other, usually within a 20 cm x 20 cm area on the front surface of the phantom (See Figures in Appendix D).

The value for the reference personal dose equivalent was calculated using the fluence at the centre of the phantom front surface, irrespective of the arrangement of the dosemeters on the surface. This is in accordance with procedures suggested in ISO Standard 29661 section 6.6.3 Note 2. Allowance was made for the fact that the dosemeters were not at the centre by an increase in the uncertainty of the reference value.

The fluence and the $H_p(10)$ energy spectra for each radiation field are shown respectively in Figure 4 and Figure 5. Figure 4 shows a considerable fluence contribution at low energies for ^{252}Cf (D_2O moderated) source at 0° and behind a shadow block. These low-energy neutrons make almost no contribution to personal dose equivalent (see Figure 5), but can contribute considerably to the readings of dosemeters that have increasing dose equivalent responses at lower energies, e.g. albedo dosemeters. Spectra for the fields involving a ^{252}Cf source (both bare and D_2O moderated) and also for a ^{241}Am-Be(α,n) source were taken from ISO 8529-1. The spectrum for a ^{252}Cf (D_2O moderated) source and behind a shadow block in a room at PTB which provides a significant scatter component can be found in reference [49]. Numerical data for the ^{252}Cf (D_2O moderated) source behind a shadow block are provided in Annex F.

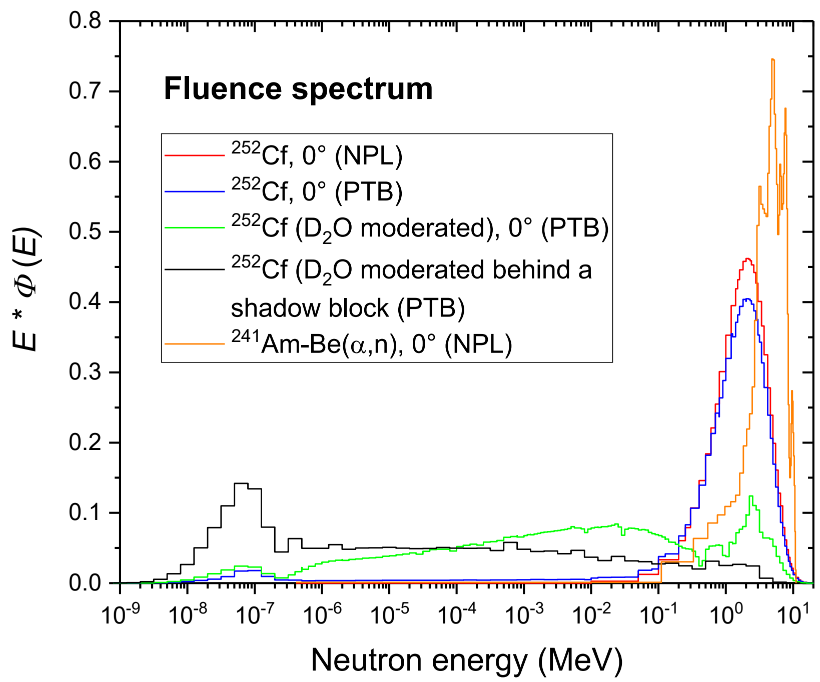

Figure 4: Fluence spectra of the radiation fields. All spectra have been normalised to unit fluence.

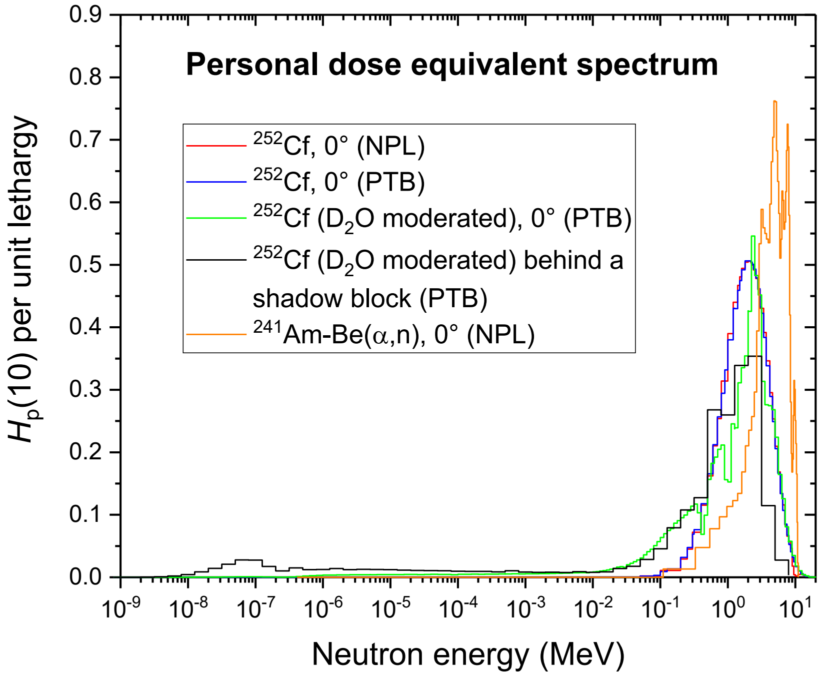

Figure 5: $H_p(10)$ spectra of the radiation fields. All spectra are normalised to unit $H_p(10)$.

The corresponding spectrum-averaged fluence-to-personal dose equivalent coefficients are an indication of the field hardness and are listed in Table 4. The significantly different values given for ^{252}Cf, 0° for the neutron fields at NPL and PTB result from wall-scattered neutrons at PTB which increase considerably the fluence of low-energy neutrons, but only slightly the dose equivalent (see Figures 4 and 5).

Table 4: Fluence to personal dose equivalent conversion coefficients

Neutron radiation field	$h_{p\Phi}(10)$ (pSv cm^2)
^{252}Cf, 0° (NPL)	400
^{252}Cf, 45° (NPL)	389
^{241}Am-Be(α,n), 0° (NPL)	411
^{252}Cf, 0° (PTB, used for irradiation with additional photons)	346
^{252}Cf (D_2O moderated), 0° (PTB)	98
^{252}Cf (D_2O moderated) behind a shadow block, isotropic (PTB)	13.7

More detailed information on the radiation fields and irradiation procedures, as used at NPL and PTB, is given in the following subparagraphs.

2.6.1 The radiation fields at NPL – bare ^{252}Cf and ^{241}Am-Be sources

The ^{252}Cf irradiations at NPL were performed using two physically small cylindrical sources (less than 2 cm high and 1 cm diameter) with different emission rates. The source used for a particular irradiation was determined by the overall dose required; the lower emission rate source being used for the lower total doses to avoid timing uncertainties. For the ^{241}Am-Be irradiations a single source was used, again cylindrical, but somewhat larger with a height of 6 cm and a diameter of 3 cm. The dosemeters were attached to the front face of an ISO water filled slab phantom (see Figure 1 in NPL certificate in Appendix D) the mid-point of which was positioned at 75 cm from the centre of the source. Each irradiation time was assumed to have a standard timing uncertainty of ± 4 seconds.

Fluence values at NPL were derived from a measurement of the source total emission rate into 4π steradians plus a determination of the source anisotropy. The measurement of the total emission rate is one which can be performed to a high accuracy (< 1%) by using the manganese bath technique [50]. Emission from the source is not, however, isotropic, and needs to be measured. This is done at NPL using a long counter [51]. Because the ^{252}Cf sources used at NPL are cylindrical and physically small, anisotropy factors, defined as the ratio of the fluence in a plane at 90° to the capsule axis and passing through the centre of the capsule to the average fluence over all angles, are close to one. The larger ^{241}Am-Be source has a greater degree of anisotropy in its emission, the anisotropy factor having been measured as 1.041. The uncertainties in the reference quantities are outlined in Table 5.

Irradiations were performed in a low-scatter area which has dimensions of 24 m × 18 m × 18 m. The neutron source was positioned about 6 m above the floor and 12 m below the ceiling near the centre of the room and material near the source was kept to a minimum. No corrections were applied for scattered neutrons, which were estimated to be slightly lower than 1% both in terms of fluence contribution and in terms of personal dose equivalent contribution [52]. Fluence to dose equivalent conversion coefficients were taken from ISO 8529-3 which provides spectrum-averaged values based on the recommended coefficients in references [17, 18].

After the dosemeters had been returned to the participants, the OG identified a potential problem with an unwanted photon irradiation during transit for a small number of the albedo dosemeters irradiated at NPL. Consequently, all the affected participants were offered substitute irradiations, free of charge. Only the results of the repeated irradiations have been used in the certificates and in this EURADOS report although the problems proved to be largely negligible.

Table 5: Percentage standard uncertainties associated with the determination of the personal dose equivalent values from bare ^{252}Cf and ^{241}Am-Be sources

Uncertainty component	**Relative uncertainty for radiation quality**				
	^{252}Cf $\theta = 0°$ 0.3 mSv	**^{252}Cf $\theta = 0°$ 1.5 mSv**	**^{252}Cf $\theta = 0°$ 12 mSv**	**^{241}Am-Be $\theta = 0°$ 1.5 mSv**	**^{252}Cf $\theta = 45°$ 1.5 mSv**
Type B (non-random)					
Reference irradiation distance*	± 0.55%	± 0.55%	± 0.55%	± 0.55%	± 0.55%
Source emission rate ($MnSO_4$ bath) including component for half-life	± 0.53%	± 0.53%	± 0.53%	± 0.69%	± 0.53%
Source anisotropy correction	± 0.26%	± 0.26%	± 0.26%	± 0.25%	± 0.26%
Timing	± 0.74%	± 0.15%	± 0.02%	± 0.06%	± 0.14%
Scatter	± 2.0%	± 2.0%	± 2.0%	± 2.0%	± 2.0%
$H_p(10,\theta)$ conversion coefficient†	± 1.0%	± 1.0%	± 1.0%	± 4.0%	± 1.0%
Total standard uncertainty Components added in quadrature	**± 2.5%**	**± 2.4%**	**± 2.4%**	**± 4.6%**	**± 2.4%**
Expanded uncertainty ✠	**± 5.0%**	**± 4.8%**	**± 4.8%**	**± 9.1%**	**± 4.8%**

* The figures quoted for the uncertainty in the reference irradiation distance includes a sensitivity factor of 2, taking into account the inverse square dependence of the neutron fluence rate on the distance between the source centre to reference point.

† The conversion coefficients of references [17] and [18] are by convention taken to be exact. The uncertainties quoted derive from ISO 8529-2 [29], are spectrum averaged, and hence allow for uncertainty in the neutron spectra.

✠ Obtained by multiplying the total standard uncertainty by a coverage factor k=2. (This provides an uncertainty estimate with a coverage probability of approximately 95%.)

2.6.2 The radiation fields at PTB - ^{252}Cf (with additional photons) and ^{252}Cf (D_2O moderated) at 0° and behind a shadow block

The neutron source facility of the PTB was used for the irradiation with ^{252}Cf (with additional photons) and ^{252}Cf (D_2O moderated) at 0° and behind a shadow block. The size of the concrete-shielded irradiation room is 7 m x 7 m x 6.5 m, and the source is located at the centre. The irradiation conditions are listed in Table 6.

Table 6: Irradiation conditions at PTB for the EURADOS neutron intercomparison IC2017n.

Neutron source	Angle α	Distance (cm)	($H_p(10)_{insc}$§/ $H_p(10)$) (%)	$H_p(10)$ (mSv)	Number of dosemeters
^{252}Cf *	0°	75	2.24 ± 0.32	1.50 ± 0.06	4
^{252}Cf (D_2O mod., 1 mm Cd)	0°	75	2.40 ± 0.40	1.20 ± 0.11	4
^{252}Cf (D_2O mod., 1 mm Cd) behind a shadow block	isotropic	170	100	1.00 ± 0.15	2

*: Additional irradiation with photons from a ^{137}Cs source ($H_p(10)$ = 1 mSv).

§ The dose equivalent contribution from in-scattered neutrons

The first two irradiations were performed on an ISO-water phantom. The distance between the centre of the neutron source and the centre of the front face of the phantom was 75 cm. The dosemeters were attached to the front surface of the phantom in an area of about 20 cm x 20 cm. Four dosemeters (two each from two different participants) were irradiated together to provide irradiation cross checks.

In the case of the D_2O moderated ^{252}Cf source behind a shadow block, the distance between the centre of the neutron source and the centre of the phantom was 170 cm and a PMMA phantom was used. It was directed with its side face towards the source and four dosemeters were fixed on each of the 30 cm x 30 cm planes of the phantom, see Figure 6. Thus, eight dosemeters (two per participant) were irradiated together. The phantom was changed from an ISO water phantom to a PMMA one in order to have two identical surfaces (left and right) which can be used for irradiation of dosemeters. Both large surfaces are considered to receive an isotropic field of wall-scattered neutrons with the same dose. The isotropy is caused by use of an almost cubic irradiation room with the source at the centre. Additional data on this field are given in Appendix F.

The first two irradiations, bare ^{252}Cf and D_2O moderated ^{252}Cf, were performed at 0° with chiefly directly incident neutrons. The $H_p(10)$ contribution of neutrons in-scattered from the walls of the irradiation room was only about 2% (see values of ($H_p(10)_{insc}$/$H_p(10)$) in column 4 of Table 6).

Figure 6: The neutron irradiation geometry for irradiations with ^{252}Cf (D_2O moderated) behind a shadow block

The measurement quantity, neutron personal dose equivalent $H_p(10)$, was calculated from the fluence of the direct and in-scattered neutrons with the fluence to personal dose equivalent conversion coefficients $h_{p\Phi,dir}(10; 0°)$ and $h_{p,\Phi,ins}(10; isotropic)$. The spectral fluence distributions of the direct and in-scattered neutrons were measured with the PTB Bonner-sphere spectrometer [53, 54] and values for $h_{p\Phi,dir}(10; 0°)$ and $h_{p,\Phi,ins}(10; isotropic)$ have been calculated using the measured fluence distributions and the energy dependent fluence to personal dose equivalent conversion coefficients for normal and isotropic incidence on the phantom according to references [45] and [16, 17]. The numerical values of $h_{p\Phi,dir}(10; 0°)$ and $h_{p,\Phi,ins}(10; isotropic)$ are given in the irradiation certificates of PTB (see Annex D).

The relative uncertainties of the $H_p(10)$ values were 4%, 9% and 15% (see absolute values as given in column 5 of Table 6), and are the expanded measurement uncertainties which are obtained by multiplying the standard uncertainty by the coverage factor $k = 2$.

2.6.3 Quality control of irradiation fields

Both PTB and NPL are included in the Calibration and Measurement Capability (CMC) lists at the Bureau International des Poids et Mesures (BIPM). NPL is also accredited by the UK national accreditation body UKAS (UK Accreditation Service) for personal dosemeter calibrations. The neutron emission rates of the sources used have been determined using manganese-bath measurements, a technique that has been validated in key international comparisons.

2.7 Relevance of existing standards to the IC2017n Intercomparison

The basic principle of a dosimetry intercomparison is to expose dosemeters to accurately known doses in reference fields and to evaluate the responses. To evaluate the intrinsic quality of the response of a dosimetry system and to quantify the difference between systems, criteria are needed to specify what can be considered in terms of an acceptable under-response or an acceptable over-response.

To perform a fair and accurate analysis of the results it is more appropriate to conduct it on the basis of procedures and criteria agreed by the scientific community. Setting up such procedures and criteria is typically the objective of standards such as those established by ISO (International Organization for Standardization) or IEC (International Electro technical Commission) at an international level or organizations such as, for example, DIN (Deutsches Institut für Normung, D) or the SSK (Strahlenschutzkommission, D), HSE (Health and Safety Executive, UK) and ANSI (American National Standard Institute, US) at a national level. Other organizations such as ICRU (International Commission on Radiation Units and Measurements) or ICRP (International Commission on Radiological Protection) also give guidelines and recommendations.

At an international level, the standards which are relevant for personal dosimetry are of two kinds. There are standards related to the realization and the use of reference radiation fields, and standards giving the requirements and recommendations for testing the performance of personal dosemeters.

2.7.1 Resume of the situation during the IC2012n intercomparison exercise

At the time of the EURADOS intercomparison of neutron dosemeters performed in 2012 (IC2012n), there was no internationally agreed document that answered precisely the question: "which procedures and criteria should be applied for overall dosimetric performances and comparison between different kind of personal neutron dosemeters?"

Indeed, among all the documents related to personal neutron dosimetry, only three gave criteria that applied to the response: ICRP Report n°75 [55], IEC Standard 61526 [56] and ISO Standard 21909:2005 [57]. But the criteria defined in these three documents were different, and depended also on the dosimetry techniques. Moreover, they did not take into account the fact that the criteria need to be less constraining for low dose levels. And, last but not least, they described performance tests as full type tests aimed at characterising a dosimetry system, which is a very different goal to the one of an intercomparison exercise.

Considering all this, criteria used at previous international intercomparisons were analysed. Here again, it was shown that there had been a variety of approaches and criteria.

Finally, the Organization Group decided to use a factor of 2 as a general criterion for the response, *R,* for all dose values following the ICRP 75 recommendation on neutron dosimetry. Therefore, the criterion for an "acceptably good" response used for the IC2012n EURADOS neutron intercomparison was:

$$0.5 \leq \frac{H_m}{H_{ref}} \leq 2$$

It should be clear that this criterion was considered only as a guideline to the performance of the personal dosimetry system.

2.7.2 Evolution of international standards for neutron personal dosemeters since IC2012n

Since 2012, in the field of individual neutron dosimetry, two main documents were revised within ISO working groups.

The first one was ISO 14146:2000 which gives test procedures, but also criteria, to be used for the periodic verification of the performance of dosimetry services supplying personal dosemeters. Some modifications in the test procedures were made, and above all, the performance criteria were enlarged to include neutron dosemeters.

In addition to the revision of the ISO Standard 14146, a second document concerning passive neutron dosimetry was also revised during recent years. This was ISO Standard 21909 giving performance and test requirements for personal dosimetry, specifically for the case of passive neutron dosimetry systems.

Both standards are described in the following in more detail.

2.7.3 Revision of the 21909 ISO standard

ISO Standard 21909, published in 2005, was the international document establishing type tests and requirements for passive neutron personal dosemeters. This standard was revised from 2011 to 2015. This new version is split into two parts. The first one, 21909-1, was published in 2015 [26]. The second one, 21909-2 is in progress, and publication is planned to be in 2021.

The objective of the revision of the standard was to rectify the weaknesses of the document published in 2005. Indeed, the former version (ISO 21909:2005) defined tests and criteria which differed for five different measurement techniques. Thus, for instance, the performance criteria could hardly be compared for solid state nuclear track dosemeters and thermoluminescence albedo dosemeters, which are the two main techniques used nowadays to perform neutron personal dosimetry. Moreover, this standard was not constraining enough to ensure that personal dosimetry is reliable in most of the usual work situations, i.e. low dose levels and neutron energy ranges representative of those encountered in workplaces.

The first part of the new version of this standard gives performance and test requirements for passive dosimetry systems to be used for the determination of personal dose equivalent, $H_p(10)$, in neutron fields with energies ranging from thermal to approximately 20 MeV. No distinction between the different techniques available in the marketplace is made in the description of the tests. The main objective of this document is to achieve correspondence between performance tests and conditions of use at workplaces, in terms of dose levels and neutron spectra. That is why many tests are added, by comparison with the former version. The document has lower constraining criteria at low doses to assure the quality of the dosimetry without being unachievable.

To conclude, dosimetry systems complying fully with this part 1 of the 21909 ISO standard should give consistent dosimetry in workplace environments without the requirement of precise information on the neutron energy and direction characteristics of the radiation field.

The second part of this standard deals with dosimetry systems that, because of the variability of their energy responses, do not fulfil all the requirements of part 1 but are able to give consistent and reliable dosimetry at selected workplaces by applying corrections when needed. In this case, a specific study of the workplace where the dosimetry systems are used is necessary to demonstrate that the dosimetry systems are suited for the workplace of application; and, if needed, to determine the appropriate corrections to be applied. This second part will give recommendations on how to undertake this demonstration and thereby to qualify the dosimetry system for specific workplaces.

2.7.4 Revision of ISO 14146:2000 and criteria for an intercomparison of the performance of personal neutron monitoring

This standard gives test procedures, and also criteria, to be used for the periodic verification of the performance of dosimetry services supplying personal dosemeters. That is why it is used as a reference document for the EURADOS photon intercomparisons. Unfortunately, for the IC2012n exercise, the 14146:2000 ISO standard [58], was not applicable to neutrons. But a revision of this document was conducted recently, and a new version was published in 2018 [24]. This new document applies not only to photons but also for beta radiation and neutrons with (fluence weighted) mean energies between 25.3 meV (i.e. thermal neutrons with a Maxwellian energy distribution with kT = 25.3 meV) and 200 MeV.

The performance criterion for the neutron dosemeter response, *R*, is expressed in terms of a trumpet curve defined by the following equation:

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

where H_{ref} is the irradiated dose, defined as the conventional quantity value of the dose to which the dosemeters are irradiated.

H_0 is defined as the "lower dose limit", which is the "dose below which irradiations should not be performed", according to the definition in the ISO document. The exact interpretation of this parameter is not well defined in the standard, but it can be taken to be the "minimal reporting level" used by a dosimetry service. For neutron personal dosemeters, these are likely to be set to avoid spurious backgrounds, but typically 0.1 - 0.2 mSv might be anticipated.

This equation shows that the high value for the performance limit is always the same whatever the considered dose for the different tested configurations during an intercomparison exercise. An over-estimation of maximum +100% of the reference value is accepted.

However, the low limit depends on the values of both H_{ref} and H_0. For the IC2017n intercomparison the value of H_0 was set by the organisation group, and a value of 100 µSv was chosen. The performances limits are then the ones shown in Figure 7.

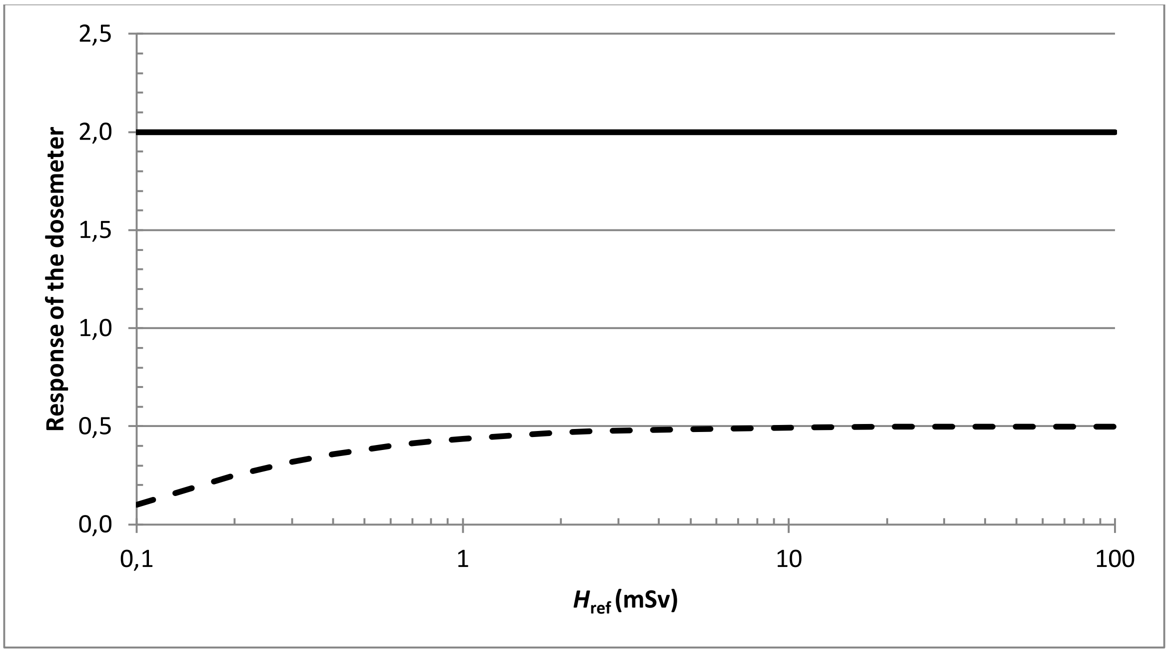

Figure 7: Performance limits for neutrons, according to the 14146:2018 ISO standard, with H_0 = 100 µSv.

It is important to underline that the performance criteria are not the same for neutron dosimetry in the ISO Standard 21909-1 and in 14146. The differences can be explained by the fact that the philosophy and the aim of the tests of these two documents are very different. In ISO Standard 21909-1, the tests are type tests used for the characterization of the dosimetry system. For this objective, it is important to check the reliability of the dosimetry provided by the system for many configurations, that is why a large number of irradiations is required in order to know the behaviour for a large range of neutron doses, energies and angles. The behaviour of the dosimetry system is tested using several dosemeters for one irradiation quality. What is tested is the mean behaviour of the dosimetry system.

ISO Standard 14146 covers intercomparison exercises; not characterizations. The aim is to check whether the system gives reliable dosimetry measurement for only a few samples of neutron radiation qualities. Only a few dosemeters (it can be one) are exposed for a given radiation quality. The mean behaviour of the dosimetry system is not determined by such an exercise. Each value given by each dosemeter is regarded according to the trumpet curve performance criteria. The way to test whether the dosimetry system is reliable enough for neutron dosimetry, is then imposed by limiting the number of outliers. That is why there is in this document an approval criterion.

This approval criterion states that "a maximum of one-tenth of the dosemeters irradiated may exceed the limits" [section 7.2 of ISO 14146:2018]. This means that for the IC2017n exercise, where a total of 28 measurements were performed, the approval criterion was considered fulfilled by an IMS if no more than 2 measurements exceed the limits.

2.7.5 Conclusion: criteria for the IC2017n intercomparison exercise

Thanks to the evolution of the standard since 2012, an internationally agreed document is now available giving procedures and criteria that should be applied for a comparison between different kinds of personal neutron dosemeters. The new version of the ISO Standard 14146, published in 2018 provides, guidance on the criteria to be applied to the results. It will be, from now on, the document that the organisation group for EURADOS neutron intercomparisons will refer to when deriving tests to measure whether dosimetry systems can be considered as adequately reliable or not.

Moreover, for the overall performance of a dosimetric system for neutron dosimetry, there is now a new version of the ISO Standard 21909 giving criteria that are independent of the dosimetry techniques. The performance criteria from the ISO Standard 14146:2018 are less restrictive than 21909-1 requirements, but this can be easily explained by the fact that the aim of the two documents is different, especially in the way the dosemeters are tested.

To sum up, the performance limits chosen for this intercomparison exercise are the ones tabulated in Table 7. And a dosimetry system fulfils the approval criterion if a maximum of 2 measurements on the 28 performed, are exceeding the limits.

It is then possible to analyse the results (c.f. section 3) stating how many IMSs had, during this exercise, no outliers from the "trumpet curve" criteria; and how many fulfilled the ISO Standard 14146 approval criteria.

Table 7: Performance criteria to quantify neutron personal dosimetry performance, used for IC2017n intercomparison exercise. H_0 = 100 µSv.

H_{ref} = Irradiation dose (mSv)	Performance criteria	
	Low limit	High limit
0.3	0.32	
1	0.44	
1.2	0.45	2
1.5	0.46	
12	0.49	

2.8 Background and transit dose control

For each dosimetry system 8 dosemeters were reserved as "background and transit dose controls" to allow for background and transfer dose corrections. In addition, 4 dosemeters were assigned as "spare" dosemeters to be used by the irradiation laboratory in the event of damage or errors with the irradiations. The dosemeters were sent in one shipment to each of the irradiation laboratory.

The IMSs had information on which dosemeters were unexposed, and thus had the option of subtracting their background readings if they chose to do so.

2.9 Confidentiality of the data and the results

The procedure established for the self-sustained EURADOS intercomparison programme was set-up in such a way as to ensure data integrity and confidentiality.

Each member of the Organization Group signed a confidentiality clause (see Appendix B) prior to her/his participation in the work of the intercomparison. The exchange of data and information with the participants (e.g. application forms, instructions, results, and dose reports, etc.) and the distribution of the dosemeters and exchange of data with the irradiation laboratories were performed solely by the OG Coordinator.

The data processed by the OG had to be treated confidentially for two reasons:

- Firstly, the IC was designed to be a blind test for all the participants. This meant that all participants had to report their results without knowing the details of the irradiation plan, in particular the dose values. The dose values were reported to the participants only after the coordinator had received the dose values evaluated by the participant. At the time of application for the IC, only the ranges of dose, energies and angles were known to the participants. Direct communication between participants and irradiation facilities was not allowed and the coordinator transferred all necessary information between participants and irradiation laboratories. It was known that some IMS might participate with more than one dosimetry system and it was also considered that some IMS might have access to results of other participants. In order to prevent these participants guessing dose values by combining results, the irradiation plan was executed selecting in a random order the dosemeters for each irradiation conditions for each participant.
- Secondly, the individual results are the property of the participants only and thus have to be kept confidential. To assure this confidentiality the coordinator separated all information which could possibly lead to the identity of the participants from the published results. In the overviews of the results the participating dosimetry systems are only referenced by a randomized code (system code). The link between the "system code" and the participant's identity is only known by the coordinator. All participants received their own code to be able to look up their own results in the overviews.

During the IC exercises significant quantities of data had to be exchanged. In order to assure data integrity, it was decided to use an online platform as in the photon intercomparisons.

2.10 EURADOS Certificates of Participation and Participants Meeting

Since EURADOS itself is not accredited for the evaluation of IMSs, the results issued by EURADOS cannot be regarded as an official test report. As an alternative, it was decided to report back the results to the individual participants in the form of a "Certificate of Participation" (see Appendix E), with the irradiation reports of the accredited irradiation laboratories as an annex.

These certificates consist of a number of pages. The front page shows the certificate number, the details of the participant, the description of the system as given by the participant, and a summary of the IC procedure. The front page was signed by both the EURADOS Chairperson and the IC coordinator. The second page shows the actual results: ID code, irradiation laboratory, reference value of $H_p(10)$ as reported by the irradiation laboratory, radiation field, value of $H_p(10)$ as reported by participant, remark of participant and the ratio of the participant's value to the reference value. In the certificates, no performance limits are indicated.

A scan of the Certificate of Participation was available for download on the online platform on 29 June 2018. The signed original of the Certificate of Participation was sent by post in July 2018. The participants confirmed either per email or directly via the online platform the receipt of the certificates.

The OG organized a participants' meeting, held during the EURADOS Annual Meeting AM2019, in February 2019 in Łódź, Poland to show and discuss the results among the OG and the participants.

3 Results and Discussion

3.1 Basic statistical results

Results were received from all 32 participants (IMSs) for 33 dosimetry systems (only passive ones). The breakdown of the analyzed systems was *Albedo* 15 and *Track* 18. Values for $H_p(10)$ were reported by the IMSs for all of the irradiated dosemeters.

Individual results for each system, using an assigned randomized code (system code) are reported in Appendix G.

The numerical results are reported as the response, *R,* which is the ratio of the measured value of $H_p(10)$ due to neutrons as provided by the service - H_m, divided by the reference value as determined by the irradiating laboratory - H_{ref}.

Table 8 shows the total number of values reported for $H_p(10)$, together with estimates for the central value of the distribution of the responses (arithmetic mean, median value) and measures for the spread in the response values (standard deviation, 2.5th and 97.5th percentiles). The data presented in this table were derived using all the reported values for the dosemeters from all the services.

The estimates of the central values for the arithmetic mean and median for the responses were 1.18 and 1.02 respectively. The spread (standard deviation) in the values for *R* was 1.23. From the percentiles the 95% coverage interval of the responses for all results of all participants together can be derived: this was 0.13 to 4.52.

More dosemeters were irradiated for the present exercise than for the previous one; 924 compared to 816, and results were delivered for all of these in contrast to the case previously where only 750 results were forthcoming.

The values for the mean, median, and standard deviation are slightly higher than they were for IC2012n where they were 1.06, 1.00, and 0.80 respectively.

Removing the two largest outlier results, *R* values of 24.6 and 14.8, both of which occurred for one particular track-based service for ^{252}Cf at 0.3 mSv, gave mean, median, and standard deviation values of 1.14, 1.02, and 0.85, i.e. a significant reduction in the standard deviation.

For the particular service with the two largest outliers all values, at all doses, were high and removing all these results gave *mean*, *median*, and *standard deviation* values of 1.07, 1.00, and 0.72. These are very little different to the IC2012n values, although there are differences in the details, and these are discussed in the sections below.

Figure 8 shows the distribution of all response values, for all dosemeter types, for the eight different radiation qualities.

Table 8: Total number of values reported for $H_p(10)$ and some statistical quantities indicating the central values and the spread of the results for the overall response values *R*

	Number of values reported for $H_p(10)$
Number of irradiated dosemeters	924
Number of reported values	924
	Statistical data on *R*
Arithmetic mean	1.18
Median	1.02
Standard deviation	1.23
2.5^{th}-percentile	0.13
97.5^{th}-percentile	4.52

In each individual field the box represents the 50% range, i.e. 25% of responses to 75% of responses, and the vertical line the 90% range. The horizontal line through each box is the median, the circle is the mean, and the minimum and maximum values are represented by up and down triangles respectively.

The 50% range boxes are similar in size for all fields, varying from 0.37 to 0.5, except for the results for the D_2O moderated ^{252}Cf source plus shadow block where the range is 2.7. The standard deviation for this field is 1.9, which is not, however, the largest value. That occurs for the 0.3 mSv ^{252}Cf field where the value is 2.5. This is largely due to the service with the high values including extreme outliers at 14.8 and 24.6. On removing the results for this service from the calculations the standard deviation for the 0.3 mSv dose rate drops to 0.61 compared to an average of 0.33 for all the other fields except the D_2O moderated ^{252}Cf plus shadow block which remains at about 1.9.

It would appear then that some services are still struggling to provide good results at low doses and in broad range fields with low energies.

Statistical data for individual radiation qualities are presented in Table 9 and give quantitative information for the results plotted in Figure 8. The values of 0.0 in the table for the 2.5^{th}-percentile for two of the fields reflects the fact that there were a number of zero values for the responses in these fields.

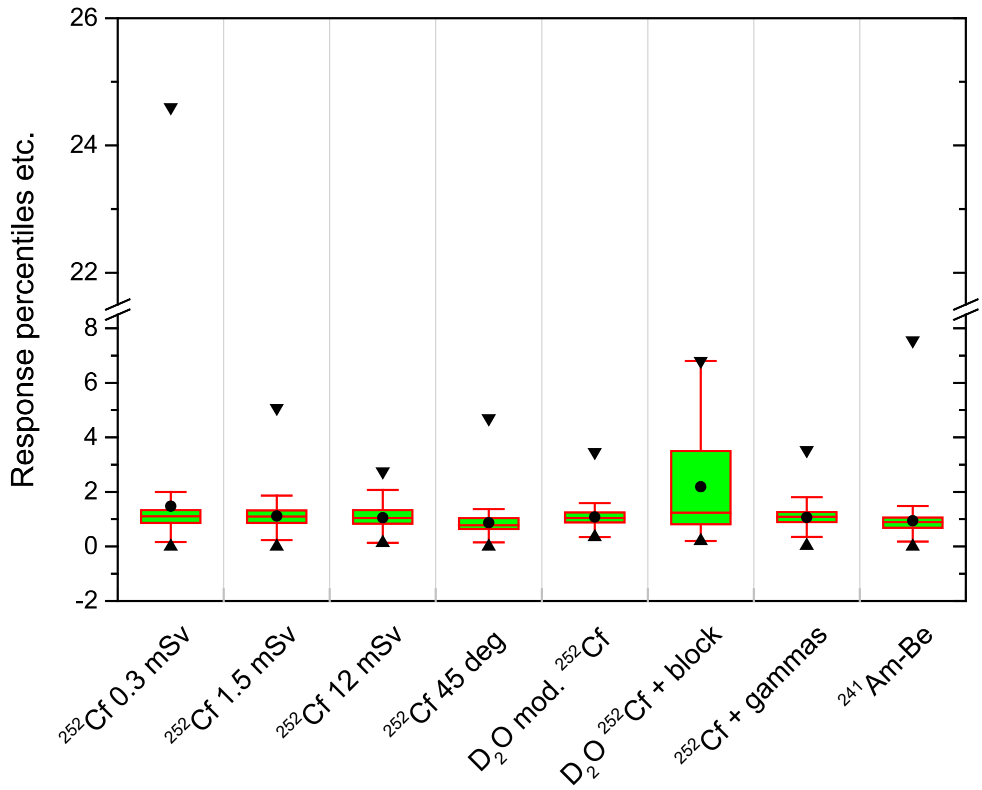

Figure 8: Distribution of response values *R* for irradiations with different radiation qualities. Circle = mean value, box = 50% range (25% to 75%), vertical red line = 90% range, horizontal red line inside the box = median, up and down triangles = minimum and maximum values

The large range between the 2.5th and the 97.5th percentile values for the 0.3 mSv ^{252}Cf field and the D_2O moderated ^{252}Cf source plus shadow block fields reinforce the message from the standard deviations that some services had difficulties with these fields, and the mean values being greater than 1 indicate that the problem was mostly overreading.

Besides that, the 0.3 mSv ^{252}Cf field also had the largest number (10) of reported results where the value was zero. Nine of the ten zero results for the 0.3 mSv ^{252}Cf field were for albedo dosemeters.

Perhaps surprisingly, in view of the relatively large dose of 1.5 mSv, there were 6 values reported as zero for the ^{241}Am-Be field. All of these were for albedo dosemeters.

To present information on how the statistical data vary for the different dosemeter types, the mean and standard deviation values for all dosemeters are listed separately in Table 10 for the different irradiation fields.

Table 9: Statistical data for the individual radiation qualities

Statistical values	0.3 mSv ^{252}Cf 0°	1.5 mSv ^{252}Cf 0°	12 mSv ^{252}Cf 0°	1.5 mSv ^{252}Cf at 45°	1.2 mSv D_2O ^{252}Cf	D_2O ^{252}Cf + block	1.5 mSv ^{252}Cf + ^{137}Cs	1.5 mSv ^{241}Am-Be
No. of reported values	132	132	132	66	132	66	132	132
Mean	1.47	1.11	1.05	0.86	1.08	2.19	1.07	0.94
Median	1.10	1.10	1.05	0.77	1.05	1.23	1.09	0.89
Standard deviation	2.52	0.63	0.46	0.59	0.40	1.94	0.45	0.78
2.5th.-percentile	0.00	0.15	0.14	0.10	0.42	0.20	0.22	0.00
97.5th.-percentile	6.71	2.41	2.29	3.12	1.84	6.69	2.18	2.62

Table 10: Mean and standard deviation, *s*, values for the responses reported for the different types of dosemeters in the different exposure fields.

Irradiation field	All		*Albedo*		*Track*	
	Mean	*s*	Mean	*s*	Mean	*s*
0.3 mSv ^{252}Cf at 0°	1.47	2.52	1.06	0.78	1.82	3.31
1.5 mSv ^{252}Cf at 0°	1.11	0.63	0.99	0.40	1.21	0.75
12 mSv^{252}Cf at 0°	1.05	0.46	0.95	0.42	1.13	0.48
^{252}Cf all 0° data	1.21	1.53	1.00	0.56	1.39	1.99
1.5 mSv ^{252}Cf at 45°	0.86	0.59	0.88	0.34	0.85	0.74
D_2O mod ^{252}Cf	1.08	0.40	1.04	0.23	1.11	0.50
D_2O ^{252}Cf + block	2.19	1.94	3.22	1.96	1.33	1.47
^{252}Cf + ^{137}Cs gammas	1.07	0.45	0.94	0.40	1.17	0.47
^{241}Am-Be	0.94	0.78	0.70	0.32	1.14	0.97

The mean values for the albedo dosemeters tend to be slightly smaller than 1, whereas the mean values for the track dosemeter types tend to be higher than 1.

An exception amongst the albedo results is the response in the D_2O moderated ^{252}Cf + shadow block field, where the mean overestimates the reference by more than a factor of 3. In this field the average for the track dosemeter results shows only an overestimation of about 30 %. This is close to the average for this dosemeter type.

In the case of the ^{252}Cf field at 45° both dosemeter types have a low mean value, as they did in the IC2012n exercise, indicating that the angle dependence of the response is still a problem for personal dosemeters.

3.2 Distribution of response values with radiation quality

Figure 9 shows the mean responses for all radiation fields and for all systems. They are ordered with *Albedo* on the left, and *Track* on the right.

All but one of the albedo services and eight out eighteen of the track services asked for the additional field information.

To simplify the plot, in view of the very large number of individual responses, mean values are plotted for each radiation field for each individual service. The error bars represent one *standard error of the mean* and are included simply to give an indication of the spread of results rather than the absolute accuracy.

Thus, for services S09 and S28 the ^{241}Am-Be results can be seen to be both low and variable. For these two albedo services a comparison of the data for the various fields clearly indicate that there are problems in fast neutron fields where there are no lower energy neutrons.

This plot allows all results to be compared and individual mean responses for any system to be picked out. Some general features can clearly be seen, e.g. the fact that a significant number of albedo dosemeter responses were high for the D_2O ^{252}Cf plus shadow block field, and for the track dosemeters this field tended to give some of the highest responses and the lowest. Reasons for some specific problems can also be surmised. Except for the result at 0.3 mSv the results for S05 are reasonably well bunched, but are all high, implying a problem with the underlying calibration.

Figure 9 includes two dotted lines. One is at a value of 2.0 which corresponds to the upper performance limit recommended by ISO Standard 14146. The recommended lower limit is dose dependent, and the specific values for the doses used in the exercise were used throughout the subsequent analysis, but as a rough indication of where this limit occurs a line has been drawn at 0.44 which is an average of the values (0.32 to 0.49) for the different doses used.

As shown in Figure 9 and the results given in Appendix G, just under half of the systems, 14 out of 33, have all response values within the performance limits (6 *Albedo* and 8 *Track*). A total of 21 systems had 2 or fewer results outside the limits (9 *Albedo* and 12 *Track*).

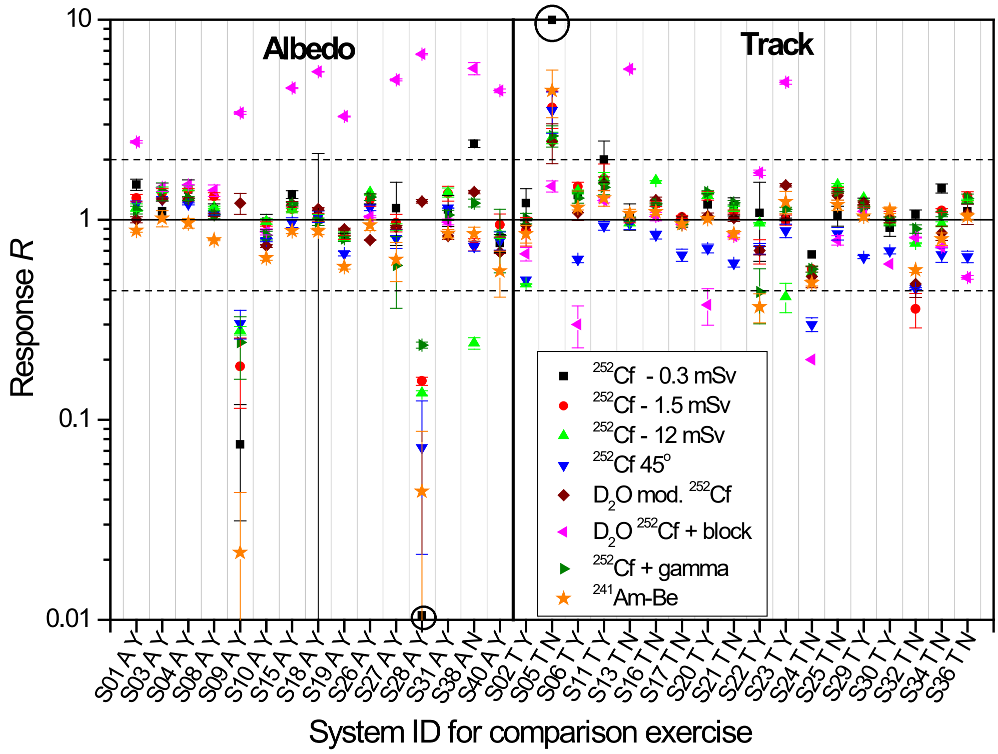

Figure 9: Summary of all reported responses. The values plotted are mean responses for each radiation field for each individual service, and the error bars are one standard error of the mean. In the X-axis captions: A stands for *Albedo*, T for *Track*, Y for service having asked for additional field information, N for no additional field information requested. For the point at R=0.01 with a ring around it all results for that field were reported as zero. For the situation when the service reported some zero values, then the error bar reflects this. For the point at R=10 with a ring around it the mean for this field was higher than 10.

3.3 Distribution of response values for individual irradiation field

To investigate the results for the individual radiation fields the relevant responses are plotted in Figures 10 to 17. The recommended performance limits shown in these figures are those from ISO Standard 14146 for the dose delivered.

Figure 10 shows the results for irradiations with a bare ^{252}Cf source to 0.3 mSv at 0° incidence. Several services reported a value of zero for one or more of their dosemeters irradiated to this dose and the overall standard deviation for R was the highest at 2.5. This is not surprising as 0.3 mSv is close to the lower detection limit for some systems and this dose, while equal to or above the stated lower limit for all services, had been chosen when planning the exercise to provide a test of the low dose measurement capabilities. The responses are on average greater than one with a mean of 1.47 and a median of 1.10. This would appear to be a poorer result than in IC2012n where the mean and standard deviation were 1.08 and 0.49 respectively, but Figure 10 illustrates one of the reasons for this. Many of the services had very good results, but the small number of services with significant outliers produced the higher standard deviation of the current exercise.

For a bare ^{252}Cf dose of 1.5 mSv the results, shown in Figure 11, have improved compared to a dose of 0.3 mSv. The mean has come down to 1.11 and the standard deviation to 0.63. Some of the features from the 0.3 mSv plot can also be seen at 1.5 mSv, e.g. the low results for S09 and S28, and the generally high results for S05. However, some results do not follow this pattern and are hard to explain, e.g. the low result for S32 where their results at 0.3 mSv were very good.

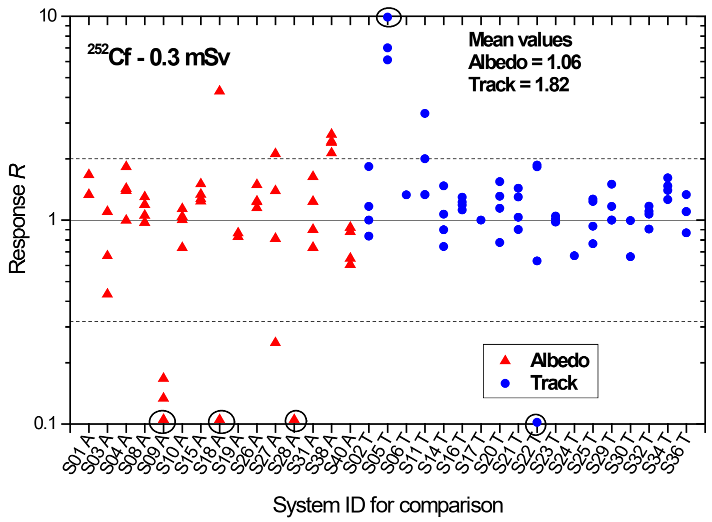

Figure 10: Summary of all responses for irradiations in the bare ^{252}Cf field with a dose of 0.3 mSv for 0° incidence. Four dosemeters were irradiated per service. For the points at R=0.01 with rings around them one or more result for that service were reported as zero. For the point at R=10 with a ring around it one or more values were greater than 10.

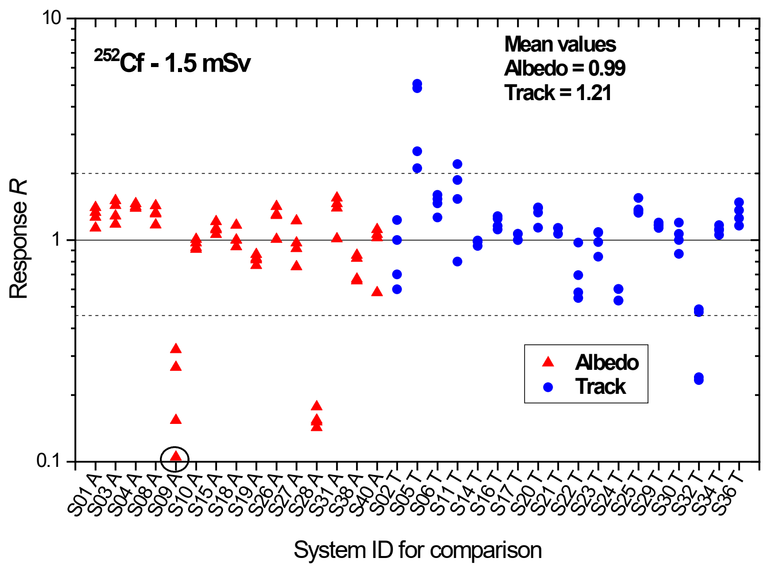

Figure 11: Summary of all responses for irradiations in the bare ^{252}Cf field with a dose of 1.5 mSv for 0° incidence. Four dosemeters were irradiated per service. The point at R=0.01 with a ring around it indicates that one result for this service was zero at this dose.

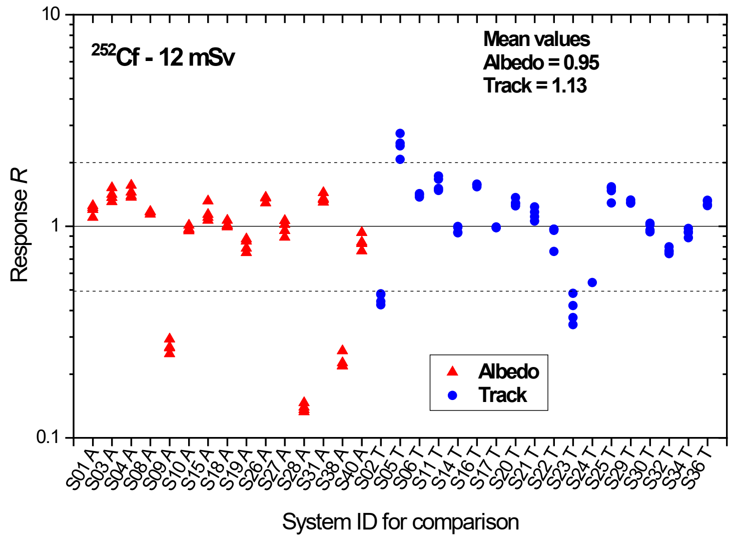

Figure 12: Summary of all responses for irradiations in the bare ^{252}Cf field with a dose of 12 mSv for 0º incidence. Four dosemeters were irradiated per service.

Figure 12 shows the results for ^{252}Cf at 12 mSv. The trends for S09, S28, and S05 persist, although there is some improvement. Two track services, S02 and S23 whose results were good at the lower doses are beginning to show signs of under-reading This could possibly be the result of overlapping tracks being difficult to count at this higher dose.

Figure 13 shows the response values for the irradiations with ^{252}Cf neutrons incident at 45° to the dosemeters. The personal dose equivalent delivered to the dosemeters was 1.5 mSv. A more detailed discussion of the results for irradiations with ^{252}Cf neutrons at 0° and 45° is given in the section on the angle dependence of the responses.

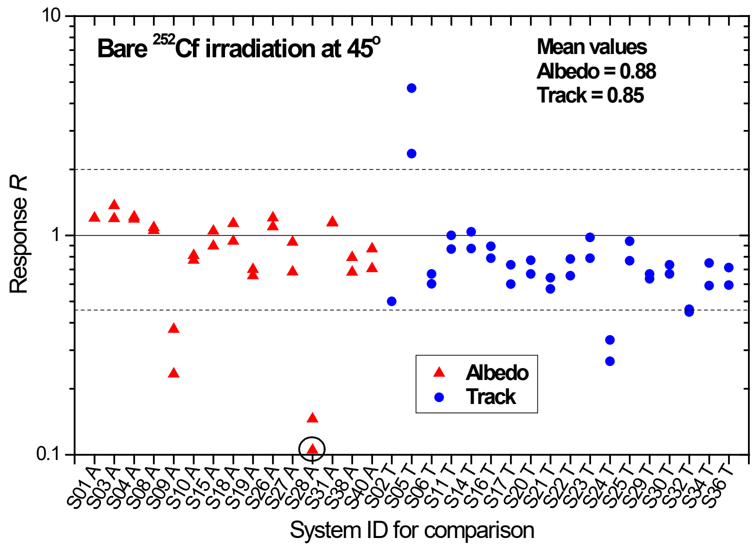

Figure 13: Responses for all dosemeters irradiated with 1.5 mSv of ^{252}Cf neutrons at 45º. Only two dosemeters were irradiated for each system. The circled result was a zero value and not 0.1

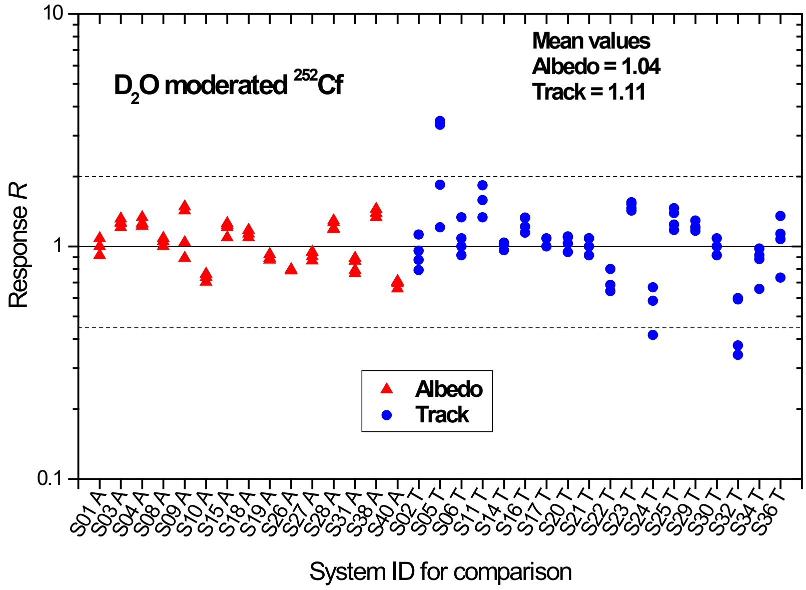

Figure 14: Responses for all dosemeters irradiated with1.2 mSv D_2O moderated ^{252}Cf neutrons. Four dosemeters were irradiated for each system.

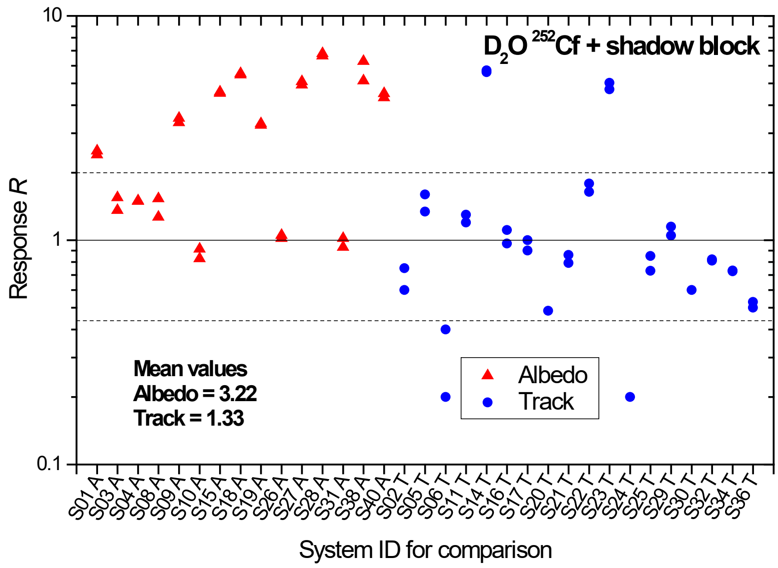

Figure 15: Responses for all dosemeters irradiated in a field produced by a D_2O moderated ^{252}Cf source shielded by a shadow block in a room which provided scattered neutrons. Two dosemeters were irradiated with a dose of 1.0 mSv for each system.

Results for the responses to D_2O moderated ^{252}Cf are shown in Figure 14. At a value of 1.08 the average response is close to unity, and the standard deviation of 0.40 is the smallest for any of the fields used. The overall good precision of the results is highlighted by the fact that only 6 out of 132 results are outside the ISO 14146 performance limits. These are all for track based dosemeters. The personal dose equivalent delivered was 1.2 mSv so the results can be compared almost directly with irradiation to 1.5 mSv bare ^{252}Cf neutrons.

Figure 15 presents the results for irradiation of the dosemeters with a D_2O moderated ^{252}Cf source behind a shadow block. These results have a mean value (2.19), which is the furthest from unity of all the fields, and a standard deviation (1.94) that is the second largest after the 0.3 mSv results for ^{252}Cf. The albedo dosemeters seem to over-respond, with a mean response of 3.22 compared to 1.33 for track. At first sight it is perhaps surprising that the albedo dosemeters do not perform significantly better than the track dosemeters in a field which has been deliberately developed to include lower energy neutrons. It also has a range of angles, and the angle dependence of the response of albedo dosemeters seems better than for track. However, an inspection of the fluence and dose equivalent distributions, as plotted in Figures 4 and 5, shows that although most of the fluence is at thermal and intermediate energies, most of the personal dose equivalent occurs in the high energy region around 1 MeV.

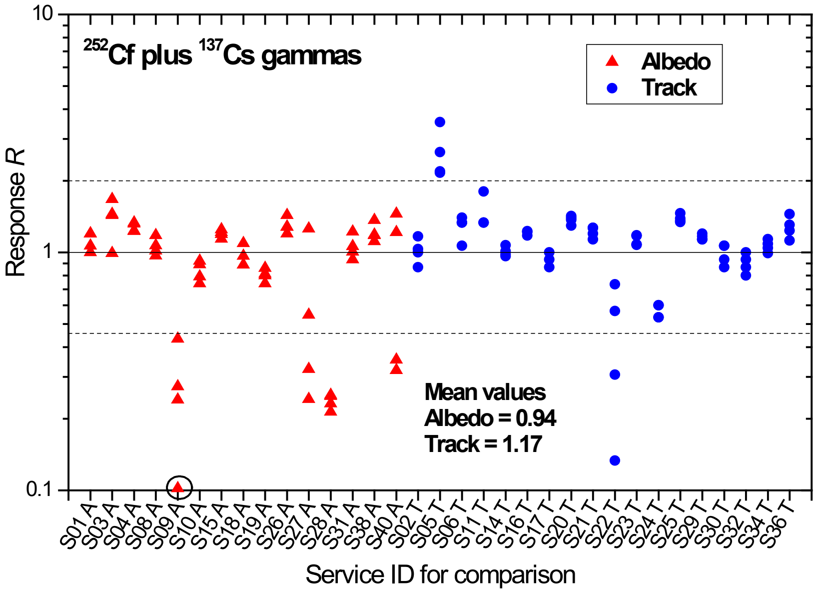

Figure 16: Responses for all dosemeters irradiated with 1.5 mSv neutrons from a ^{252}Cf source and additional gammas from a ^{137}Cs source. Four dosemeters were irradiated for each system.

The results for 1.5 mSv of ^{252}Cf neutrons with 1.0 mSv of ^{137}Cs gammas are shown in Figure 16. There are distinct similarities with Figure 11 where the neutron dose was the same but there were no additional gammas. In view of the need in TLD-based albedo dosemeters to correct for the gamma response, via a subtraction technique involving TLDs with ^{6}Li and ^{7}Li, it might be expected that dosemeters of this type would be more prone to problems with an additional gamma field. There is evidence that this might have been the case for services S27 and S40 where the spread of results is wider than for the case of a pure neutron 1.5 mSv dose. For the track dosemeters, which one would have expected to be insensitive to gammas, there are two oddities. Service S22, whose results were all within the performance limits for the field without additional gammas, has two low results when the gammas were present; while service S32, that had generally low results in the absence of additional gammas, has four results very close to unity with the additional gammas present.

Finally, Figure 17 shows the results for irradiation with ^{241}Am-Be neutrons to 1.5 mSv. There are clear similarities with the ^{252}Cf irradiations to this dose. Services S09 and S28 again have very low values, and two other albedo services, S27 and S40, have results below the low dose performance limit. In general, the albedo results are lower than for ^{252}Cf, presumably because of the higher mean energy of the ^{241}Am-Be neutrons. For the track dosemeters service S05 is high, as it is for most of the fast neutron fields, and S22 has some low results that are hard to explain in view of the good results of this service for ^{252}Cf.

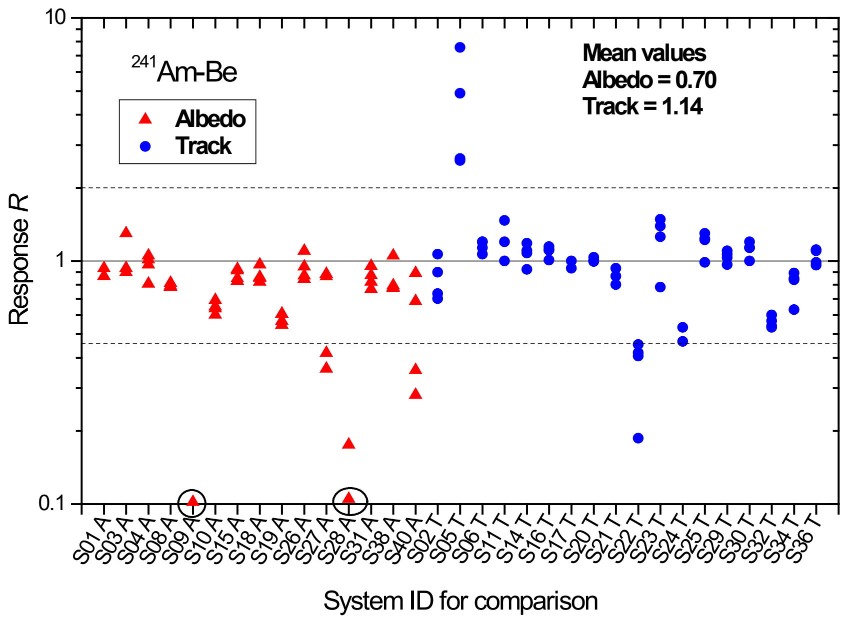

Figure 17: Responses for all dosemeters irradiated with a ^{241}Am-Be source. Four dosemeters were irradiated with a dose of 1.5 mSv for each system.

3.4 Distribution of response values with dosemeter type

The responses are shown in Figure 18 in a format intended to allow the results for different dosemeter types to be compared for each irradiation condition. Figure 19 complements Figure 18 and shows the data as a series of histogram frequency distributions for the two types of dosemeters for the eight different radiation qualities.

Comments on the results for individual fields can be found in the section above, and these include some analysis of the performance of the two dosemeter types.

Deriving comparative information from Figures 18 and 19 is hampered by the fact that results for a dosemeter type are often affected by the results for one or two individual services being high or low for a number of fields. Thus, the apparent tendency for albedo dosemeters to read low for bare ^{252}Cf neutrons in Figure 18 is the result of two services which were low in these fields and were in fact low in all fields that did not include low energy neutrons. Similarly, many of the track results that are above the ISO 14146 upper performance limit come from a single service.

Features which are evident in Figure 18 are the generally low values for the ^{252}Cf irradiation at 45°, particularly for track dosemeters, also the generally tight bunching of the results for the D_2O moderated ^{252}Cf field around a value of 1.

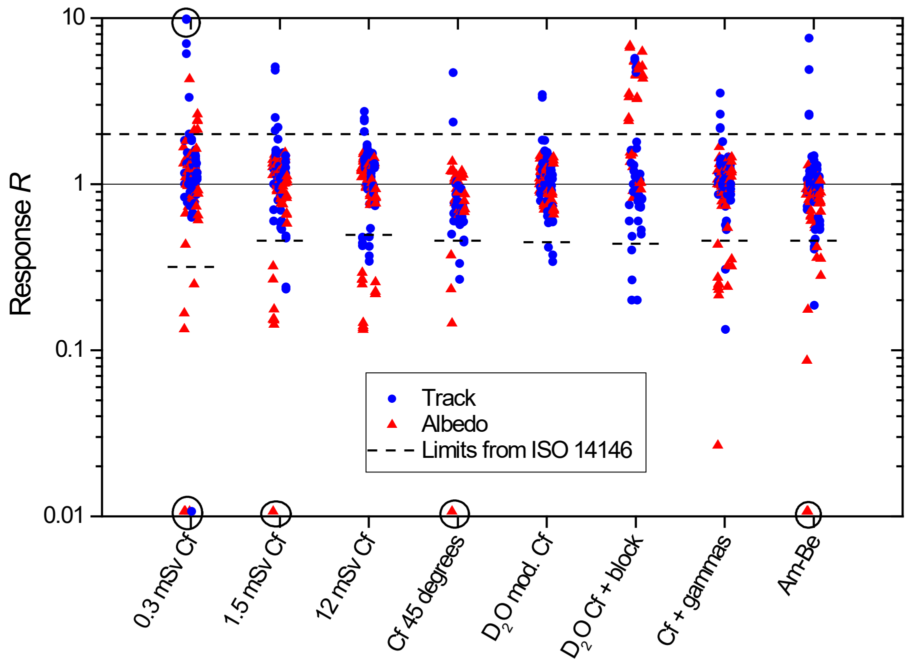

Figure 18: Individual response values for all dosemeters for the two different dosemeter types in the seven radiation fields used

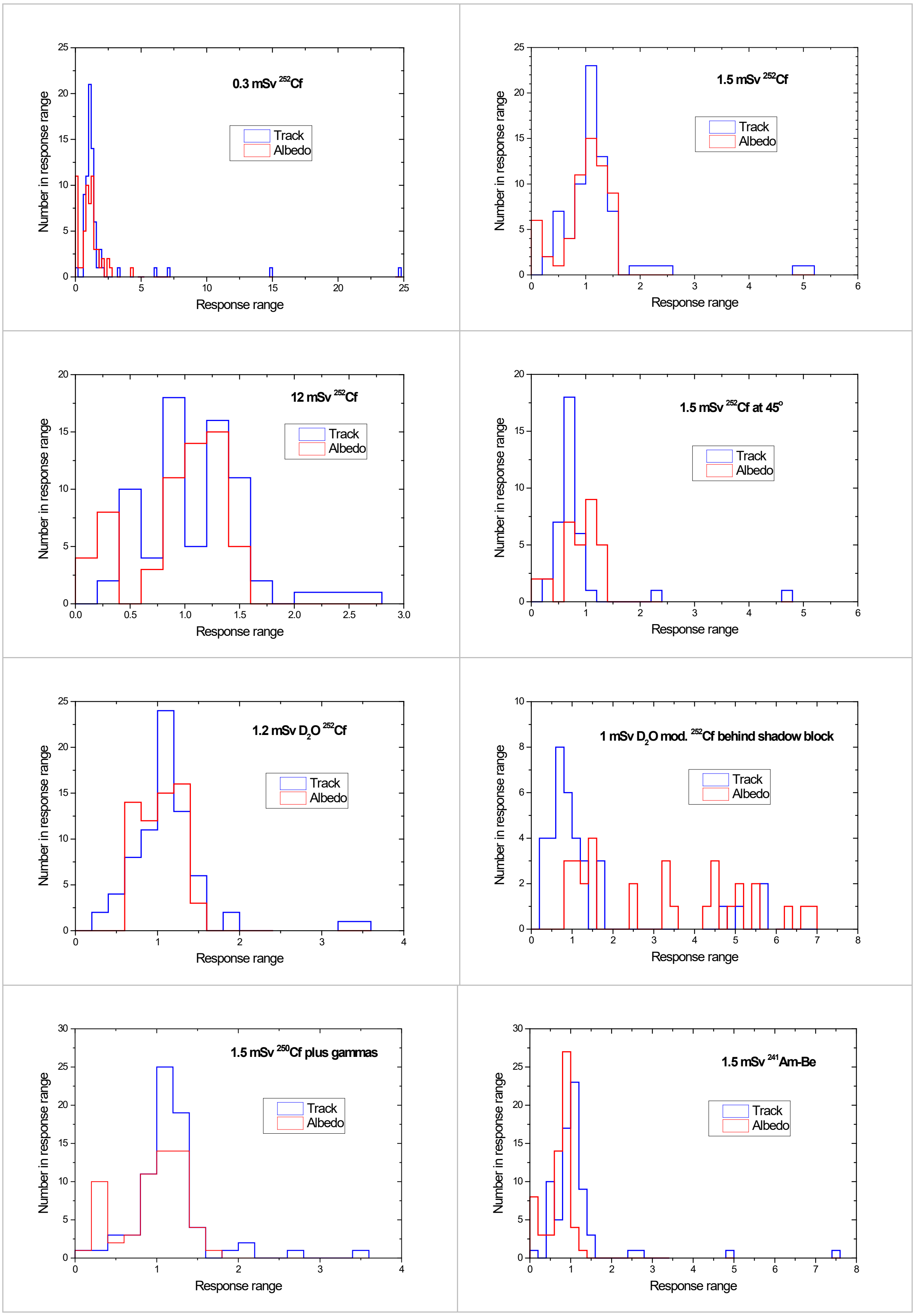

Figure 19: Frequency distribution for responses of different dosemeter types

3.5 Angular response and linearity

Only a limited amount of information about the angle dependence of the responses can be extracted from this exercise, and this is derived from a comparison of the results for irradiation with ^{252}Cf neutrons at 0° and at 45°. A comparison of Figures 11 and 13 shows that the responses for 1.5 mSv of ^{252}Cf neutrons incident at 45° tend to be lower than for the same dose of neutrons incident at 0°. The low response is more prominent for the track dosemeters than for the albedo ones which, except for two outliers that are very low, show very good responses on average for 45° incidence. Removing the outliers increases the mean response for albedos for 45° incidence from 0.88 to 0.99 and reduces the standard deviation from 0.34 to 0.21. For the track dosemeters all average values at 45° are less than 1 except for S05. The results are generally what would be expected as track devices are more likely to have a poor angle dependence of response than albedo devices simply from the mechanism of neutron detection.

No information on the angle dependence of the responses of the dosemeters can be derived from the irradiations with a ^{252}Cf source behind a shadow block. Although the neutrons are incident from angles other than normal, the spectrum of the neutrons differs significantly to that from a bare source and it is not possible to separate angle effects from spectrum effects.

The three irradiations to different integral doses for 0° incidence from a ^{252}Cf source provide information on the linearity of the systems. The presence of outliers in Figure 18 make it difficult to identify trends with dose, but the data in Tables 9 and 10 show that, on average, the dosemeter responses were linear and that there was a decrease in the spread of the results with increasing dose over this range. For both dosemeter types the mean values progressively approach 1 as the dose increases and the standard deviation decreases. As noted earlier, the group of track dosemeter results around the lower performance limit at 12 mSv may be evidence of tracks being missed by the read system due to overlapping at higher doses.

3.6 Reproducibility

In plots such as Figure 9, the standard errors on the mean values of a set of results for a particular system and irradiation field are plotted as an error bar to indicate the variation of the results within a set, i.e. as an indication of the reproducibility of the results for a particular irradiation condition. To present these data quantitatively the average values for the different irradiation fields are tabulated in Table 11 for all dosemeters and for the two different types separately, both before and after removal of three services (2 *Albedo* and 1 *Track*) that had large outliers which distorted the data.

When these three services are removed the standard error of the mean is reduced in the majority of cases, and by a large amount in some cases. We choose to report the values with the outliers removed as they probably present a more accurate estimate of the present state of the art. The only one case where removing the three services does not improve matters is for the D_2O ^{252}Cf + block field, reflecting the fact that the results are not outliers for this field.

Table 11: Average values of the standard errors of the means for the different irradiation fields and dosemeter types. Results are given for all the data and after removal of three services which had large outliers (2 *Albedo* and 1 *Track*)

Irradiation field	Average values for the standard errors of the means					
	Albedo + Track		*Albedo*		*Track*	
	All	All - 3	All	All - 2	All	All - 1
^{252}Cf 0.3 mSv	14.9%	4.2%	9.5%	4.4%	21.4%	8.1%
^{252}Cf 1.5 mSv	4.9%	2.6%	5.2%	2.6%	7.3%	3.1%
^{252}Cf 12 mSv	3.8%	3.0%	5.7%	3.0%	5.0%	4.2%
^{252}Cf at 45° 1.5 mSv *	8.4%	3.8%	7.1%	3.8%	14.5%	4.2%
D_2O mod ^{252}Cf 1.2 mSv	3.2%	2.4%	2.8%	2.4%	5.3%	3.0%
D_2O ^{252}Cf + block 1.0 mSv *	10.9%	11.7%	11.1%	11.7%	18.5%	12.3%
^{252}Cf 1.5 mSv + ^{137}Cs 1.0 mSv	3.7%	2.5%	5.5%	2.5%	4.7%	4.0%
^{241}Am-Be 1.5 mSv	7.2%	2.6%	5.9%	2.6%	10.1%	3.3%

* Note that only two dosemeters were irradiated for each service in these fields so the uncertainty on the standard error of the mean may be higher than for the other fields where four dosemeters were irradiated per service.

3.7 Response values as a function of reference doses

In an attempt to investigate the responses as a function of the reference dose delivered all the reported responses are plotted together in Figure 20. A dose of 1.5 mSv was delivered for four radiation fields: bare ^{252}Cf at 0°, bare ^{252}Cf at 45º, bare ^{252}Cf +additional ^{137}Cs gammas and ^{241}Am-Be. This makes it difficult to distinguish the fields when data are plotted against dose, but an attempt has been made to provide different symbols for all fields at 1.5 mSv.

The fact that, except for the three 0° irradiations with a bare ^{252}Cf source, different angles and different spectra were used makes it is difficult to extract very meaningful data on the dose dependence of the dosemeters except to say that there is no clear upward or downward trend with increasing dose over the dose range considered.

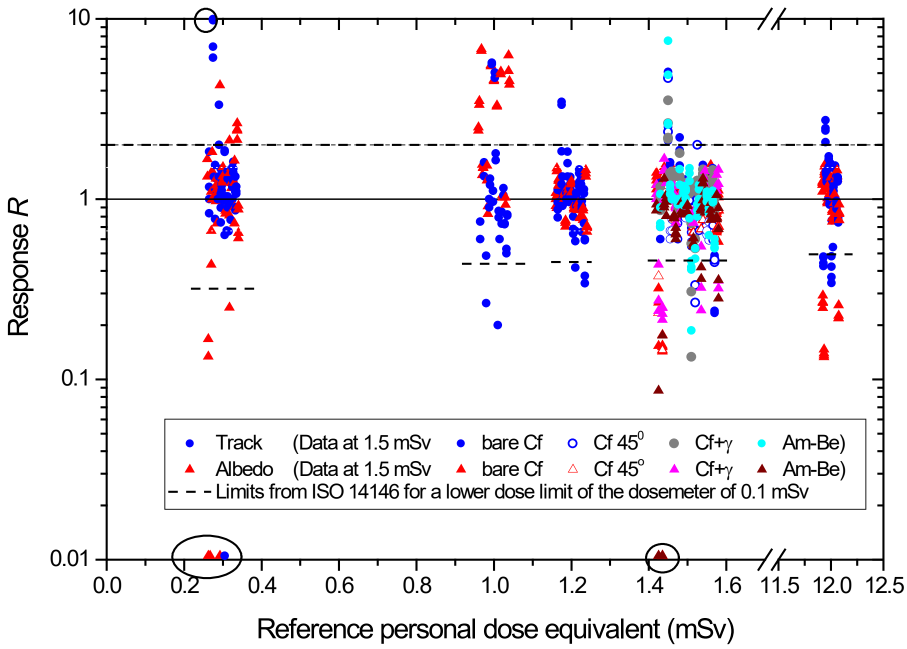

Figure 20: All reported responses plotted against the reference dose delivered. There were four irradiation fields where the reference dose was 1.5 mSv and the fields are identified by different symbols at this dose.

3.8 Values outside the ISO 14146 upper and lower limit

Table 12 details the number of reported responses that were greater than the ISO 14146 upper limit of 2 or less than the variable lower limit for the eight irradiation fields. Data are given for the albedo and track dosemeters separately and for all reported results.

In total 16% of the results were outside the prescribed range.

One aspect of obvious concern is the number of responses below the lower limit; there were 89 of these in total compared to 54 with responses greater than the upper limit. Although over-reading is undesirable, under-reading is of even greater concern. The field with the largest number of results below the lower limit (20) was for the 12 mSv ^{252}Cf field. This number is made up of the albedo results for the two services that are low for most fields plus a group of track services where the results fall below the lower limit possibly because of loss of signal due to overlapping tracks. The ^{241}Am-Be field had the next largest number below the lower limit (16).

Table 12: Values for all data where *R* was > upper limit (UL) or < lower limit (LL) for the different radiation fields and for the different dosemeter types

	^{252}Cf 0.3 mSv 0°	^{252}Cf 1.5 mSv 0°	^{252}Cf 12 mSv 0°	^{252}Cf 1.5 mSv 45°	D_2O ^{252}Cf 1.2 mSv 0°	D_2O ^{252}Cf + block 1.0 mSv	^{252}Cf + γ rays 1.5 mSv 0°	^{241}Am-Be 1.5 mSv 0°	Total
Albedo									
Total	60	60	60	30	60	30	60	60	420
>UL	6	0	0	0	0	18	0	0	24
<LL	12	8	12	4	0	0	12	12	60
Track									
Total	72	72	72	36	72	36	72	72	504
>UL	5	5	4	2	2	4	4	4	30
<LL	1	2	8	3	4	5	2	4	29
All dosemeters									
Total	132	132	132	66	132	66	132	132	924
>UL	11	5	4	2	2	22	4	4	54
<LL	13	10	20	7	4	5	14	16	89

4 Conclusions

The main observed features can be summarized in the following way.

IC2017n differed from IC2012n in having a one-step procedure for delivering results, not a two-step one as in IC2012n. Only very general information about the fields was provided *a priori*.

Participants could declare at the registration step whether they need additional *a priori* field information according to their system. Additional field information was requested by 22 out of the 33 participants; all but 1 of the 15 albedo services and 8 of the 18 track services.

Because the additional field information was made available to the services before they analysed their dosemeter results, in contrast to the IC2012n exercise where this information was only supplied after the results had been submitted and services were then allowed to change their results on the basis of this information, it was not possible in the current exercise to estimate the influence of this field information on the results.

Just under half of the systems (14 out of 33) gave results where the response value for every dosemeter was within the limits set by ISO Standard 14146; 6 of these were albedo systems and 8 were track detector systems.

A total of 21 systems out of 33 had 2 or fewer results outside the limits (9 out of 15 *Albedo* and 12 out of 18 *Track*) which is the maximum number of outliers accepted by the ISO Standard 14146 "approval" criterium.

The overall mean value for all systems and all fields was 1.18. This number is influenced by the high value of 2.19 for the D_2O moderated ^{252}Cf + shadow block field. Removing this result gave an overall mean of 1.084. Two fields had mean values below 1. These were 0.86 for ^{252}Cf at 45°, the low value being mainly due to the track systems, and 0.94 for the ^{241}Am-Be field, the low value being mainly due to the albedo systems.

No obvious problems were observed with linearity over the limited range covered. At the low dose of 0.3 mSv, as delivered by a bare ^{252}Cf source, a high standard deviation value of 2.51 was observed, mainly due to few significant outliers or zero values (4 services reported a value of zero for the dose measured by one or more of their dosemeters for this dose). Instead, the standard deviation decreased significantly to 0.46 at a dose of 12 mSv.

Results for the field with additional gammas surprisingly did not show a clear difference between the performance of the 2 types of dosemeters.

Most, but not all, participants performed acceptably well (within, or nearly within, the ISO Standard 14146 performance limits) for all irradiation conditions. A few participants reported poor results.

Two albedo systems showed poor results with low values for all bare-source fields. For one track detector system all reported response values were high with a mean for all fields of 4.46 and a standard deviation of 4.80.

The poor results obtained for the dosemeters irradiated in a field produced by a D_2O moderated ^{252}Cf source shielded by a shadow block raise the question of the relevance of the *a priori* information on the neutron field. Indeed, the noted over-response especially for albedo systems might come from an inappropriate choice of the calibration factor. However, the choice of fields for exercises such as the current one is always likely to be contentious. The OG tried to be fair to all IMSs by giving enough data for IMSs which need *a priori* information, and ensuring the data are representative of the reality in the workplace.

Some of the IMSs are very small operations, supplying dosimetry to as few as one establishment and calibrating their systems accordingly. Although they may be supplying adequate dosimetry to their customer(s), their performance in comparisons such as the present one may be poor thus distorting the picture of the current state of the art and any comparison between albedo and etched-track devices. Their inclusion in the final analysis of the comparison needs careful consideration in future.

EURADOS IC2012n and IC2017n were two important actions in the field of regular performance testing in neutron dosimetry informing the radiation protection community about the present state of the art in neutron dosimetry. In the past intercomparisons at international level tended to be performed only every 8-10 years by different organizations in various way.

At the time of the IC2012n exercise no internationally agreed standards were available to guide the choice of acceptance criteria. By the time of IC2017n standards were available and the performance criteria from ISO Standard 14146 were used in evaluating the current exercise. The results of intercomparisons provide valuable input data to help when writing ISO or IEC standards.

5 Recommendations

The exercise has emphasised once again the need for development work on neutron personal dosemeters.

Participation in intercomparisons is an essential step to test and verify the performance of neutron dosemeters.

Such intercomparisons should be performed regularly and EURADOS should make every effort to keep to the 5-year frequency in future.

Analysis of the results of the two EURADOS ICn intercomparisons is recommended in order to provide actual data and check the applicability of the requirements stated by international standards, published or in development.

For the next intercomparison:

- Test again the performance at low doses, which seems to be still a problem for some, though not all, services. All services should be able to measure doses as low as the declared lower limit of their dose range. Such tests are essential as workers are usually routinely exposed to low levels of dose, near the low limit of a dosimetry system's dose range.
- Neutron and gamma discrimination performance needs further investigations for both types of dosemeters (i.e. *Albedo* and *Track*)
- Although one can understand the reason why services requested *a priori* additional information, even though not strictly needed by their systems, further attempts might be made to have results from the services as they perform routinely, which is most often without any *a priori* field information.

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Appendix A: Time schedule

Realized time schedule of IC2017n:

10 March 2017	Announcement - Call for participants
31 March 2017	Deadline for IMS sending Application Forms with information on their dosemeters
5 April 2017	Confirmation of participation by OG coordinator and instructions to provide dosemeters
5 May 2017	Deadline for IMS sending dosemeters to OG coordinator
June – September 2017	Irradiations at NPL and PTB and irradiation data to the OG coordinator
9 October 2017	Dosemeters received by coordinator from the irradiation laboratories
13 October 2017	Dosemeters sent back to IMSs for readout
17 October 2017	Instructions for readout to IMSs
15 November 2017	Deadline for IMS to send results
12 December 2017	Asking for photon doses
12 January 2018	Deadline for IMS for submission of photon doses
February 2018	Irradiation repeated for some IMSs
5 March 2018	Dosemeters sent back to IMSs, where irradiation have been repeated
15 March 2018	Instructions to IMS, where irradiation have been repeated
30 March 2018	Deadline for IMS with repeated irradiation to send results
9 April 2018	Draft report including final and reference results available for download on the online platform
30 April 2018	Deadline to confirm the results by IMS
29 June 2018	Download of Certificate of Participation via online platform available
4 July 2018	Certificate of Participation to all IMSs via post
12th February 2019	Participant's meeting

Appendix B: Confidentiality clause template

European Radiation Dosimetry Group EURADOS

CONFIDENTIALITY UNDERTAKING FOR INTERCOMPARISON ORGANISATION GROUP MEMBERS

1. I hereby undertake, as part of the terms and conditions of my participation in the Organisation Group (OG) of IC2017n - Intercomparison of neutron dosemeters to be performed by EURADOS, not to disclose at any time during or after my participation any confidential information which may come to my knowledge in connection with my activity, including any commercial, technological or industrial secrets to which I have had access in the course of my work and involvement in the **Organisation Group for the IC2017n - Intercomparison for neutron dosimetry (OG2017n)** to any person, or organisation not authorised to receive such information.

2. I further undertake that I shall:

a. restrict any use I make of such information, both within and outside the OG, to the proper execution of the organisation, analysis, and reporting of the comparison;

b. refrain from any unauthorised use of such information to my private advantage or to that of any third party.

c. prevent emails from being automatically forwarded to or read by individuals other than the intended recipient.

3. I undertake that, at all times following the termination of my involvement within the OG2017n, I shall not use, disclose or disseminate any of the information referred to in paragraph 1 above. I also undertake to take no action that may lead to such information being disclosed or exploited to the detriment of EURADOS, of a EURADOS Voting Member or a natural or legal person of such Member, or of a participant to the EURADOS intercomparisons exercises.

4. I understand:

that a breach of my obligation not to disclose confidential information without appropriate authorisation, may result in the initiation of legal proceedings against me, and that, the EURADOS Chairperson may exclude myself from EURADOS activities.

Date and Place: ______________________________

Signature: ________________________________

Printed name: ______________________________

Institution: _________________________________

Address: ___________________________________

E-mail for correspondence: ______________________

Werner Rühm (Chairperson)
Helmholtz Zentrum München GmbH
Ingolstädter Landstr. 1
85764 Neuherberg, Germany
Phone: +49 89 3187 3359
werner.ruehm@eurados.org

Filip Vanhavere (Vice Chairperson)
SCK•CEN, RDC
Boeretang 200
2400 Mol, Belgium
Phone: +32 14 332859
filip.vanhavere@eurados.org

EURADOS e.V.
www.eurados.org
office@eurados.org

USt-IdNr. (VAT Reg.No.): DE283696163

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Version 3.1 – July 2015

Appendix C: List of participants

Participants sorted alphabetically by country and place. The order thus has no resemblance to the ordering of services in terms of the randomized codes (S numbers) used in this document.

Name of the IMS	*Place*	*Country*
Seibersdorf Labor GmbH - Dosimetry Service	Seibersdorf	AUSTRIA
International Atomic Energy Agency	Vienna	AUSTRIA
Vinçotte Controlatom	Vilvoorde	BELGIUM
Serviço de Monitoração Individual de Nêutrons	Rio de Janeiro	BRAZIL
Sluzba osobni dozimetrie VF	Cerna Hora	CZECH REPUBLIC
NUVIA Dosimetry, s.r.o.	Praha	CZECH REPUBLIC
Fortum, Loviisa Nuclear Power Plant	Loviisa	FINLAND
Service de Protection Radiologique des Armées (SPRA) - French Army - Radiation Protection Service	Clamart Cedex	FRANCE
Laboratoire de Dosimétrie de l'IRSN	Croissy-sur-Seine	FRANCE
LANDAUER	Vélizy-Villacoublay	FRANCE
LPS, Landesanstalt für Personendosimetrie und Strahlenschutzausbildung	Berlin	GERMANY
Personendosismessstelle Berlin	Berlin	GERMANY
Materialprüfungsamt Nordrhein-Westfalen	Dortmund	GERMANY
Auswertungsstelle	München	GERMANY
Fast Neutron Monitoring Service, BARC, India	Mumbai	INDIA
ENEA - Radiation Protection Institute - Individual Monitoring Service	Bologna	ITALY
EUROPEAN COMMISSION - JOINT RESEARCH CENTRE-Nuclear decommissioning Unit - Radiation Protection Sector - Dosimetry Service	Ispra (Varese)	ITALY
L.B. Servizi per le Aziende Srl	Roma	ITALY
Tecnorad s.r.l.	Verona	ITALY

Name of the IMS	*Place*	*Country*
Chiyoda Technol Corporation	Ibaraki	JAPAN
Nagase-Landauer, Ltd. Japan	Tsukuba-shi	JAPAN
Institute of Nuclear Physics PAN	Krakow	POLAND
DOZIMED S.R.L.	Magurele, Ilov	ROMANIA
CERN Dosimetry Service	Geneva	SWITZERLAND
Paul Scherrer Institut	Villigen PSI	SWITZERLAND
NRG	Arnhem	THE NETHERLANDS
Turkish Atomic Energy Authority Saraykoy Nuclear Research and Training Center	Ankara	TURKEY
Berkeley Approved Dosimetry Service	Berkeley, Gloucestershire	UNITED KINGDOM
Dstl Approved Dosimetry Services	Gosport, Hampshire	UNITED KINGDOM
Public Health England, Personal Dosimetry Service	Oxfordshire	UNITED KINGDOM
Mirion Technologies (GDS), Inc.	Irvine, California	USA
Landauer	Glenwood	USA

Appendix D: Example irradiation certificates

NATIONAL PHYSICAL LABORATORY

Teddington Middlesex UK TW11 0LW Telephone +44 20 8977 3222

Certificate of Calibration

UKAS CALIBRATION 0478

Calibration of the personal dose equivalent delivered during irradiation of personal dosemeters with bare ^{252}Cf and ^{241}Am-Be radionuclide neutron sources

This certificate is issued in accordance with the laboratory accreditation requirements of the United Kingdom Accreditation Service. It provides traceability of measurement to the SI system of units and/or to units of measurement realised at the National Physical Laboratory or other recognised national metrology institutes. This certificate may not be reproduced other than in full, except with the prior written approval of the issuing laboratory.

FOR:

For the attention of

On behalf of IC2017n Participant S0xx

DESCRIPTION: Irradiation of personal dosemeters to accurately known neutron fluences, and hence dose equivalent values, with bare ^{252}Cf and ^{241}Am-Be radionuclide neutron sources at incident angles of either 0° or 45°

IDENTIFICATION: Each neutron dosemeter individually identified

BASIS OF MEASUREMENTS: ISO Standard 8529, *Reference neutron radiations –*
Part 1: (2001) Characteristics and methods of production,
Part 2: (2000) Calibration fundamentals of radiation protection devices related to the basic quantities characterizing the radiation field,
Part 3: (1998) Calibration of area and personal dosimeters and determination of their response as a function of neutron energy and angle of incidence.

DATE OF RECEIPT: 6th June 2017

DATES OF IRRADIATIONS: 9th August – 14th September 2017

Reference: N1525 (2016070332) Participant S0xx Page 1 of 6

Date of issue: 31st October 2017 **Signed:** (Authorised Signatory)

Checked by: **Name:** Dr David J Thomas on behalf of NPLML

CIPM MRA

This certificate is consistent with the capabilities that are included in Appendix C of the MRA drawn up by the CIPM. Under the MRA, all participating institutes recognise the validity of each other's calibration and measurement certificates for the quantities, ranges and measurement uncertainties specified in Appendix C (for details see http://www.bipm.org).

NATIONAL PHYSICAL LABORATORY
Continuation Sheet

IRRADIATIONS

Irradiations of the personal neutron dosemeters provided by EURADOS IC2017n participant S0xx were performed in the low-scatter facility in the Chadwick Building at the UK National Physical Laboratory. The dosemeters were irradiated to accurately known neutron fluence values. From these fluences, personal dose equivalent values, $H_p(10)$, were determined using internationally accepted fluence to dose equivalent conversion coefficients. Irradiations were performed using techniques recommended by the International Organization for Standardization (ISO) [1].

Irradiations were performed using a bare ^{252}Cf radionuclide neutron source at 0° and 45°, and a ^{241}Am-Be radionuclide neutron source at 0°, mounted at the centre of the irradiation area in the low-scatter facility. All irradiations were performed using a 30 cm × 30 cm × 15 cm ISO water phantom. The dosemeters were mounted on the phantom exactly as supplied by the customer. The dosemeters were attached to the surface of the phantom using double-sided tape and then secured using single-sided tape.

All irradiations were performed at a fixed distance of 75.0 ±0.2 cm between the centre of the radionuclide neutron source and the centre of the front face of the phantom.

The neutron fluence rates were determined by absolute neutron source emission rate measurements, performed in the NPL manganese sulphate bath. The anisotropy factors for the source encapsulations had been previously determined at NPL using precision long counter measurements. No correction was applied for neutron in- or out-scatter effects, the assumption being that, at this distance in the NPL low-scatter facility, the two effects are small and to some extent cancel each other. An additional uncertainty component was, however, included to allow for this. The total integrated neutron fluence was then derived from the fluence rate and the total irradiation time.

For the 0° irradiations, four dosemeters were mounted as illustrated in Figure 1. This rotationally-symmetric arrangement ensured that any variation in radiation field due to beam divergence would be the same across every dosemeter. Also shown is an electronic personal dosemeter, which was used as a reference monitor during the irradiation.

Reference: N1525 (2016070332) Participant S0xx Page 2 of 6

Checked by:

NATIONAL PHYSICAL LABORATORY

Continuation Sheet

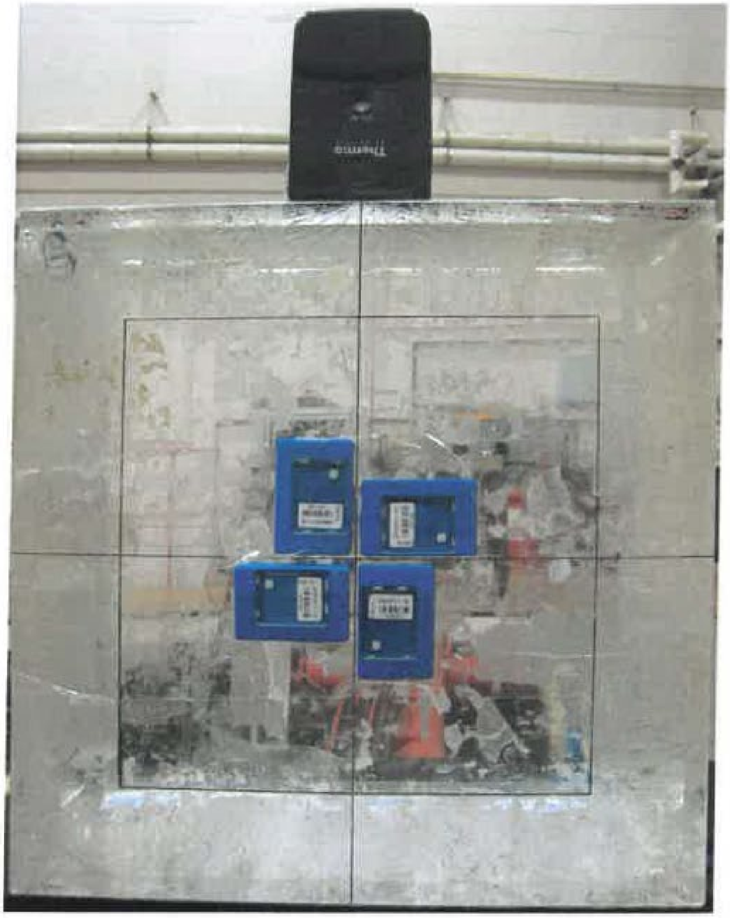

***Figure 1:** Rotationally symmetric arrangement employed for the irradiations of groups of four dosemeters.*

For the 45° irradiation, two dosemeters were mounted on the axis of rotation, *i.e.* in line with the electronic personal dosimeter shown in Figure 1.

RESULTS

Table 1 quotes the nominal exposure, dosemeter numbers, source-to-phantom distance (measured from the centre of the source capsule to the centre of the front face of the phantom) and the neutron personal dose equivalent that the dosemeters received (subject to the above assumptions).

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NATIONAL PHYSICAL LABORATORY

Continuation Sheet

FLUENCE TO DOSE EQUIVALENT CONVERSION COEFFICIENTS

The spectrum-averaged fluence to personal dose equivalent [2] conversion coefficient ($h_p(10,\theta°)$) for bare ^{252}Cf has a value of 400 pSv cm^2 at $\theta = 0°$ and a value of 389 pSv cm^2 at $\theta = 45°$ [1]. The ($h_p(10,\theta°)$) for ^{241}Am-Be at $\theta = 0°$ has a value of 411 pSv cm^2. These values have been derived using the spectra published in ISO 8529-1:2001 [3].

UNCERTAINTIES

The uncertainties have been treated as recommended in UKAS publication M3003 [4], and are given in Table 2. The standard uncertainties associated with the spectrum-averaged fluence to dose equivalent conversion coefficients, needed to convert fluence response to dose equivalent response, are ±1% for bare ^{252}Cf and ±4% for ^{241}Am-Be [5], and originate from uncertainties in the source spectra rather than uncertainties in the conversion coefficients, which are assumed to be exact.

REFERENCES

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Continuation Sheet

TABLE 1: Neutron personal dose equivalent at the reference distance for the irradiation of personal dosemeters using ^{241}Am-Be and ^{252}Cf neutron sources. The uncertainties are quoted with a coverage probability of approximately 95%

Nominal $H_p(10)$	Dosemeter Reference Number	Source - Phantom Distance* (cm)	NPL $H_p(10)$ (mSv)		
1.5 mSv Am-Be 0°	S0xx/2017-01 S0xx/2017-08 S0xx/2017-12 S0xx/2017-20	75.0	1.50	+/-	0.14
12 mSv Cf (bare) 0°	S0xx/2017-04 S0xx/2017-09 S0xx/2017-13 S0xx/2017-16	75.0	12.00	+/-	0.58
1.5 mSv Cf (bare) 0°	S0xx//2017-03 S0xx/2017-06 S0xx/2017-10 S0xx/2017-14	75.0	1.501	+/-	0.072
0.3 mSv Cf (bare) 0°	S0xx/2017-02 S0xx/2017-05 S0xx/2017-15 S0xx/2017-18	75.0	0.301	+/-	0.015
1.5 mSv Cf (bare) 45°	S0xx/2017-07 S0xx/2017-11	75.0	1.499	+/-	0.072

*This figure represents the perpendicular distance from the centre of the source capsule to the centre of the front face of the phantom.

Reference: N1525 (2016070332) Participant S0xx Page 5 of 6

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NATIONAL PHYSICAL LABORATORY
Continuation Sheet

Table 2: Percentage standard uncertainties associated with the determination of the personal dose equivalent at the reference distance.

Uncertainty component	Irradiation				
	^{241}Am-Be 0° 1.5 mSv	^{252}Cf, 0° 12 mSv	^{252}Cf 0° 1.5 mSv	^{252}Cf 0° 0.3 mSv	^{252}Cf 45° 1.5 mSv
Type B (non-random)					
Reference irradiation distance*	±0.55%	±0.55%	±0.55%	±0.55%	±0.55%
Source emission rate ($MnSO_4$ bath) (includes component for half-life)	±0.69%	±0.53%	±0.53%	±0.53%	±0.53%
Source anisotropy correction	±0.25%	±0.26%	±0.26%	±0.26%	±0.26%
Timing	±0.06%	±0.02%	±0.15%	±0.74%	±0.14%
Scatter	±2.0%	±2.0%	±2.0%	±2.0%	±2.0%
$H_p(10,\theta)$ conversion coefficient	±4.0%	±1.0%	±1.0%	±1.0%	±1.0%
Total Standard Uncertainty Components added in quadrature	**±4.6%**	**±2.4%**	**±2.4%**	**±2.5%**	**±2.4%**
Expanded uncertainty •	**±9.1%**	**±4.8%**	**±4.8%**	**±5.0%**	**±4.8%**

* The figures quoted for the uncertainty in the reference irradiation distance includes a sensitivity factor of 2, taking into account the inverse square dependence of the neutron fluence rate on the distance between the source centre to reference point.

• Obtained by multiplying the total standard uncertainty by a coverage factor $k=2$. (This provides an uncertainty estimate for a coverage probability of approximately 95%.)

Reference: N1525 (2016070332) Participant S0xx Page 6 of 6

Checked by:

Physikalisch-Technische Bundesanstalt
Braunschweig und Berlin
Nationales Metrologieinstitut

Bericht

Report

Irradiation of whole body dosemeters in neutron reference fields at PTB in the framework of the EURADOS intercomparison 2017 of neutron dosemeters IC 2017n

Applicant:
EURADOS e. V.
Working Group 2 " Harmonisation of individual monitoring"
Attn. Sabine Mayer, Paul Scherrer Institut (PSI)
European Radiation Dosimetry Group
Ingolstädter Landstraße 1
85764 Oberschleißheim
Germany

For:
IC2017n Participant S0xx

Date of irradiation:
2017-06-02 to 2017-07-10

Anzahl der Seiten: 8
Number of pages:

Geschäftszeichen: PTB - 6.4-2017/35_S0xx
Reference No.:

393 00B o

Im Auftrag
On behalf of PTB

Dr. D. Radeck

Braunschweig, 2017-12-18

Siegel
Seal

PHYSIKALISCH-TECHNISCHE BUNDESANSTALT 15

Im Auftrag
On behalf of PTB

S. Koch

Physikalisch-Technische Bundesanstalt
Braunschweig und Berlin
Nationales Metrologieinstitut

Seite 2 zum Bericht vom 2017-12-18 — Geschäftszeichen: PTB - 6.4-2017/35_S0xx
Page 2 of the Report dated 2017-12-18 — *Reference No.: PTB - 6.4-2017/35_S0xx*

1. Irradiation conditions

This report deals with the irradiation of ten whole body dosemeters in neutron reference fields at PTB in the framework of the EURADOS intercomparison 2017 of neutron dosemeters IC2017n.

The uncertainty stated in this report is the expanded measurement uncertainty obtained by multiplying the standard uncertainty by the coverage factor $k = 2$. It has been determined in accordance with the "Guide to the Expression of Uncertainty in Measurement" (GUM) [1]. The value of the measurand then normally lies, with a probability of 95%, within the attributed coverage internal.

The irradiations were performed in a low scattering room (7 m x 7 m x 6.5 m) of PTB in a height of 3.25 m above the floor. For the irradiations, reference radiation fields from a ^{252}Cf neutron source were used in accordance with [2-4]. The irradiation conditions at PTB are listed in Tab. 1.

Tab. 1: Irradiation conditions at PTB for the EURADOS neutron intercomparison IC2017n.

Neutron source	Angle	Distance / cm	Number of dose-meters	$H_{p,ins}(10)/H_p(10)$ / %	$H_p(10)$ / mSv
^{252}Cf	0°	75	4	2.24 ± 0.32	1.50 ± 0.06 *
^{252}Cf (D_2O mod., 1 mm Cd)	0°	75	4	2.40 ± 0.40	1.20 ± 0.11
^{252}Cf (D_2O mod., 1 mm Cd) behind a shadow block	iso-tropic	170	2	100	1.00 ± 0.15

*: Additional irradiation with photons of a ^{137}Cs source ($H_p(10)$ = 1 mSv).

The measurement quantity is the neutron personal dose equivalent $H_p(10)$. This quantity was calculated from the fluence of the direct and the inscattered neutrons and the mean fluence-to-personal-dose-equivalent conversion coefficients $h_{p\Phi,dir}(10; \alpha)$ and $h_{p\Phi,ins}(10;\text{isotropic})$. The value $h_{p\Phi,dir}(10; 0°)$ for ^{252}Cf is taken from [4]. The value $h_{p\Phi,dir}(10; \alpha)$ for the moderated ^{252}Cf source takes into account that the PTB moderator differs slightly from the ISO moderator [5]. The mean fluence-to-dose-equivalent conversion coefficients for the inscattered neutrons $h_{p\Phi,ins}(10;\text{isotropic})$ have been determined from the spectral distribution of the scattered neutrons measured with the PTB Bonner-sphere spectrometer [6] and the monoenergetic fluence-to-personal-dose-equivalent conversion coefficients in accordance with [7]. The contribution of inscattered neutrons to the neutron personal dose equivalent is listed in Tab. 1 for each irradiation condition. The fluence-to-personal-dose-equivalent conversion coefficients as used are listed in Tab. 2. The spectral neutron fluence rate in the three reference fields is shown in the figures Fig. 2 to Fig. 4.

The first two irradiations were performed on an ISO water phantom (size: 30 cm x 30 cm x 15 cm). The distance between the centre of the neutron source and the centre of the front face of the phantom was 75 cm. Four dosemeters were attached to the front surface of the phantom on an area of about 20 cm x 20 cm. Dosemeters from different participants were mixed. For the irradiations behind a shadow block, a PMMA phantom was used. It was directed with its side face towards the source and four dosemeters were fixed on each of the 30 cm x 30 cm faces of the phantom, see Fig. 1. Thus, eight dosemeters were irradiated together. The dosemeter ID codes and the corresponding irradiation conditions are given in Tab. 3.

Tab. 2: Fluence-to-personal-dose-equivalent conversion coefficients for the direct and the in-scattered neutron contribution.

Neutron source	$h_{p\Phi,dir}(10;0°)$ / (pSv·cm²)	$h_{p\Phi,ins}(10;$ isotropic) / (pSv·cm²)
^{252}Cf (D_2O mod., 1 mm Cd)	114.8 ± 7.2	13.7 ± 1.7
^{252}Cf	400 ± 8	50 ± 7

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Reference No.: PTB - 6.4-2017/35_S0xx

2. Results

Tab. 3: Information on the irradiations of whole body dosemeters at PTB in the framework of the EURADOS neutron intercomparison IC2017n for participant S0xx.

ID code	$H_p(10)$ / mSv	Neutron source	Date of irradiation
S0xx-2017-25	1.20 ± 0.11	^{252}Cf(D_2O mod., 1 mm Cd)	07.06.2017
S0xx-2017-26	1.20 ± 0.11	^{252}Cf(D_2O mod., 1 mm Cd)	07.06.2017
S0xx-2017-27	1.20 ± 0.11	^{252}Cf(D_2O mod., 1 mm Cd)	07.06.2017
S0xx-2017-28		not irradiated	
S0xx-2017-29	1.50 ± 0.06	^{252}Cf (with additional 1.0 mSv of ^{137}Cs)	15.06.2017
S0xx-2017-30	1.00 ± 0.15	^{252}Cf(D_2O mod., 1 mm Cd) behind a shadow block	23.06.2017
S0xx-2017-31	1.50 ± 0.06	^{252}Cf (with additional 1.0 mSv of ^{137}Cs)	15.06.2017
S0xx-2017-32	1.20 ± 0.11	^{252}Cf(D_2O mod., 1 mm Cd)	07.06.2017
S0xx-2017-33		not irradiated	
S0xx-2017-34		not irradiated	
S0xx-2017-35		not irradiated	
S0xx-2017-36		not irradiated	
S0xx-2017-37	1.50 ± 0.06	^{252}Cf (with additional 1.0 mSv of ^{137}Cs)	15.06.2017
S0xx-2017-38	1.50 ± 0.06	^{252}Cf (with additional 1.0 mSv of ^{137}Cs)	15.06.2017
S0xx-2017-39		not irradiated	
S0xx-2017-40	1.00 ± 0.15	^{252}Cf(D_2O mod., 1 mm Cd) behind a shadow block	23.06.2017

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3. Figures

Fig. 1: Illustration of the irradiation conditions of whole body dosemeters on a PMMA phantom in a ^{252}Cf (D_2O mod., 1 mm Cd) reference field behind a shadow block.

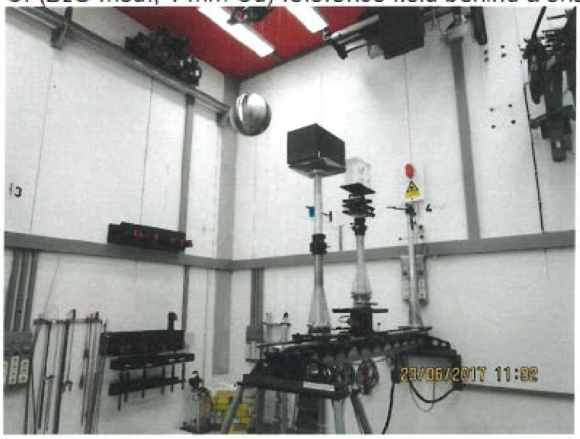

Fig. 2: Spectral neutron fluence rate of the direct and inscattered contribution and the total spectral neutron fluence rate (without phantom) at 75 cm distance for the ^{252}Cf source.

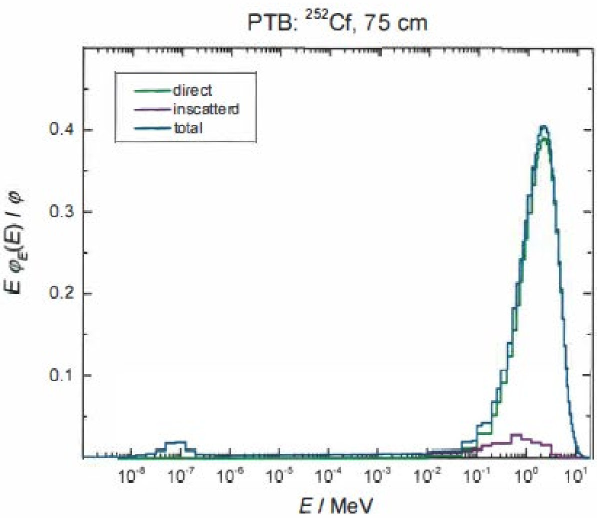

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Fig. 3: Spectral neutron fluence rate of the direct and inscattered contribution and the total spectral neutron fluence rate (without phantom) at 75 cm distancefor the ^{252}Cf (D_2O mod., 1 mm Cd) source.

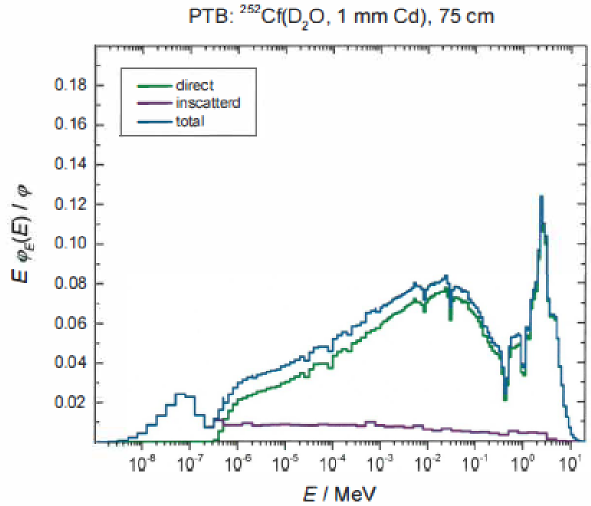
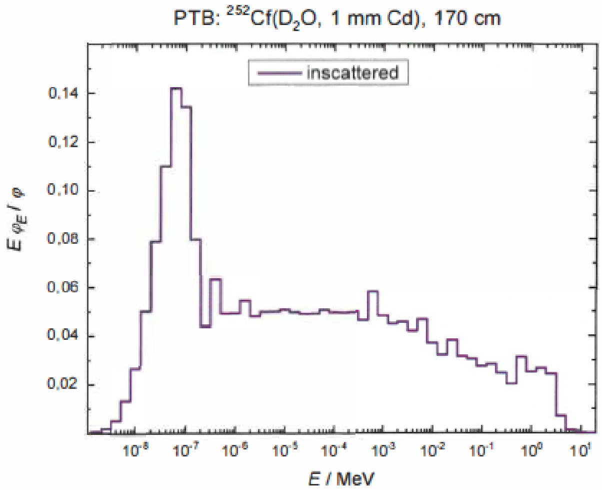


Fig. 4: Spectral fluence rate of the inscattered neutrons (without phantom) at 170 cm distance for the ^{252}Cf (D_2O mod., 1 mm Cd) source.



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Reference No.: PTB - 6.4-2017/35_S0xx

4. Bibliography

[1] JCGM 100:2008, *Evaluation of measurement data – Guide to the expression of uncertainty in measurement* Joint committee for Guides in Metrology.

[2] International Standard ISO 8529-1 (2001) *Reference neutron radiations – Part 1: Characteristics and methods of production.*

[3] International Standard ISO 8529-2 (2000) *Reference neutron radiations – Part 2: Calibration fundamentals of radiation protection devices related to the basic quantities characterizing the radiation field.*

[4] International Standard ISO 8529-3 (1998) *Reference neutron radiations – Part 3: Calibration of area and personal dosimeters and determination of their response as a function of neutron energy and angle of incidence.*

[5] Jetzke, S. and Kluge, H. (1997) *Characteristics of the* ^{252}*Cf neutron fields in the irradiation facility of the PTB*, Radiat. Prot. Dosim. 69, 247.

[6] Kluge, H., Alevra, A.V., Jetzke, S., Knauf, K., Matzke, M., Weise, K., and Wittstock, J. (1997) *Scattered neutron reference fields produced by radionuclide sources* Radiat. Prot. Dosim. 70, 327.

[7] ICRP Publication 74 (1996) *Conversion Coefficients for use in Radiological Protection against External Radiation*, Ann. ICRP 26 (3-4).

[8] Kluge, H. (1998) *Irradiation facility with radioactive reference neutron sources: Basic principles* PTB Report, PTB-N-34, ISBN: 3-89701-192-1.

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Die Physikalisch-Technische Bundesanstalt (PTB) in Braunschweig und Berlin ist das nationale Metrologieinstitut und die technische Oberbehörde der Bundesrepublik Deutschland für das Messwesen. Die PTB gehört zum Geschäftsbereich des Bundesministeriums für Wirtschaft und Energie. Sie erfüllt die Anforderungen an Kalibrier- und Prüflaboratorien auf der Grundlage der DIN EN ISO/IEC 17025.

Zentrale Aufgabe der PTB ist es, die gesetzlichen Einheiten in Übereinstimmung mit dem Internationalen Einheitensystem (SI) darzustellen, zu bewahren und weiterzugeben. Die PTB steht damit an oberster Stelle der metrologischen Hierarchie in Deutschland. Die Kalibrierscheine der PTB dokumentieren eine auf nationale Normale rückgeführte Kalibrierung.

Dieser Ergebnisbericht ist in Übereinstimmung mit den Kalibrier- und Messmöglichkeiten (CMCs), wie sie im Anhang C des gegenseitigen Abkommens (MRA) des Internationalen Komitees für Maße und Gewichte enthalten sind. Im Rahmen des MRA wird die Gültigkeit der Ergebnisberichte von allen teilnehmenden Instituten für die im Anhang C spezifizierten Messgrößen, Messbereiche und Messunsicherheiten gegenseitig anerkannt (nähere Informationen unter http://www.bipm.org).

CIPM MRA

The Physikalisch-Technische Bundesanstalt *(PTB) in Braunschweig and Berlin is the National Metrology Institute and the supreme technical authority of the Federal Republic of Germany for metrology. The PTB comes under the auspices of the Federal Ministry of Economics and Energy. It meets the requirements for calibration and testing laboratories as defined in DIN EN ISO/IEC 17025.*

The central task of PTB is to realize, to maintain and to disseminate the legal units in compliance with the International System of Units (SI). PTB thus is at the top of the metrological hierarchy in Germany. The calibration certificates issued by PTB document a calibration traceable to national measurement standards.

This certificate is consistent with the Calibration and Measurement Capabilities (CMCs) that are included in Appendix C of the Mutual Recognition Arrangement (MRA) drawn up by the International Committee for Weights and Measures (CIPM). Under the MRA, all participating institutes recognize the validity of each other's calibration and measurement certificates for the quantities, ranges and measurement uncertainties specified in Appendix C (for details, see http://www.bipm.org).

Physikalisch-Technische Bundesanstalt
Bundesallee 100
38116 Braunschweig
DEUTSCHLAND

Abbestraße 2-12
10587 Berlin
DEUTSCHLAND

Appendix E: Example "Certificate of Participation"

European Radiation Dosimetry Group

EURADOS

IC2017n - EURADOS Intercomparison 2017 for whole body neutron dosemeters

Certificate of Participation EURADOS-2017n-S0XX

Certificate of Participation

in the EURADOS Intercomparison 2017 for whole body neutron dosemeters

Certificate number:	EURADOS-2017n-S0XX
Number of pages:	3
Date of Issue:	Example
Participating institute:	Name of the IMS
Dosimetry system:	S0XX (system code): description of the dosemeter as provided by the participant
Requested a priori information:	Yes or No
Intercomparison procedure:	The EURADOS Intercomparison 2017 for whole body neutron dosemeters (IC2017n) was managed and co-ordinated on behalf of EURADOS by the WG2-Intercomparison Organization Group for neutron dosimetry (OGn). The OGn established the irradiation plan and announced the intercomparison, including the range limits of the doses and radiation qualities, in March 2017. On the application form candidate participants were asked to indicate details of the dosemeter, including its reference point. After completing subscription procedures the participant sent its dosemeters to the OGn coordinator (May/June 2017). Each participant provided 40 dosemeters: 28 dosemeters were irradiated, 8 were kept as spares and 4 were transit controls. The coordinator sent all dosemeters, along with the instructions to 2 irradiation laboratories. Each laboratory irradiated a certain number of dosemeters of each set of dosemeters according to the irradiation plan and then sent all the dosemeters back to the coordinator (October 2017). The coordinator then returned the dosemeters to the participant for assessment and indicated which dosemeters were not irradiated. The participant was instructed to follow normal routine procedures as much as possible. Those participants, who indicated a need to receive a priori information on the radiation fields for the evaluation procedure ('yes'), were provided the following description: (i) bare radionuclide source, and (ii) radionuclide source, significantly moderated. All other participants ('no') received no information on the radiation fields. The participant then sent the results of the dosemeter readings to the coordinator. Within one month after receiving the dosemeters, the participant had to submit the results in terms of $H_p(10)$ in an online response form provided by the Organization Group. After receipt of the participants' results, the coordinator sent the reference values for $H_p(10)$ together with detailed information on the radiation field used (April 2018).
Number of participants:	32 Institutes participated in EURADOS IC2017n with a total of 33 systems.
Irradiation data:	See attached certificates of the irradiation laboratories , Reference No.: N1525 (xxxxxxxxxx) Participant S0XX PTB – 6.4-2017/35_S0XX
Intercomparison results:	See the table on page 2 - 3 of this certificate

On behalf of the IC2017n Organization Group:

Dr. Sabine Mayer
Coordinator

On behalf of EURADOS:

Prof. Dr. Werner Rühm
Chairperson

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European Radiation Dosimetry Group

EURADOS

IC2017n - EURADOS Intercomparison 2017 for whole body neutron dosemeters

Certificate of Participation EURADOS-2017n-S0XX

Result of the intercomparison

ID code	Irradiation laboratory	$H_p(10)$ Reference value mSv	Radiation field	$H_p(10)$ Participant's value mSv	Remark of participant	Ratio (Participant's value/ Reference value)
S0XX-2017-1	NPL	1.50	Bare AmBe source at 0°	1.8		1.20
S0XX-2017-2	NPL	0.301	Bare Cf-252 source at 0°	0.4		1.33
S0XX-2017-3	NPL	1.501	Bare Cf-252 source at 0°	2.2		1.47
S0XX-2017-4	NPL	12.00	Bare Cf-252 source at 0°	17.1		1.43
S0XX-2017-5	NPL	0.301	Bare Cf-252 source at 0°	0.4		1.33
S0XX-2017-6	NPL	1.501	Bare Cf-252 source at 0°	2.3		1.53
S0XX-2017-7	NPL	1.499	Bare Cf-252 source at 45°	0.9		0.60
S0XX-2017-8	NPL	1.50	Bare AmBe source at 0°	1.7		1.13
S0XX-2017-9	NPL	12.00	Bare Cf-252 source at 0°	16.5		1.38
S0XX-2017-10	NPL	1.501	Bare Cf-252 source at 0°	2.4		1.60
S0XX-2017-11	NPL	1.499	Bare Cf-252 source at 45°	1		0.67
S0XX-2017-12	NPL	1.50	Bare AmBe source at 0°	1.6		1.07
S0XX-2017-13	NPL	12.00	Bare Cf-252 source at 0°	16.5		1.38
S0XX-2017-14	NPL	1.501	Bare Cf-252 source at 0°	1.9		1.27
S0XX-2017-15	NPL	0.301	Bare Cf-252 source at 0°	0.4		1.33
S0XX-2017-16	NPL	12.00	Bare Cf-252 source at 0°	16.9		1.41
S0XX-2017-17	NPL		not irradiated			-
S0XX-2017-18	NPL	0.301	Bare Cf-252 source at 0°	0.4		1.33
S0XX-2017-19	NPL		not irradiated			-
S0XX-2017-20	NPL	1.50	Bare AmBe source at 0°	1.8		1.20

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European Radiation Dosimetry Group

EURADOS

IC2017n - EURADOS Intercomparison 2017 for whole body neutron dosemeters

Certificate of Participation EURADOS-2017n-S0XX

ID code	Irradiation laboratory	$H_p(10)$ Reference value mSv	Radiation field	$H_p(10)$ Participant's value mSv	Remark of participant	Ratio (Participant's value/ Reference value)
S0XX-2017-21	NPL		not irradiated			-
S0XX-2017-22	NPL		not irradiated			-
S0XX-2017-23	NPL		not irradiated			-
S0XX-2017-24	NPL		not irradiated			-
S0XX-2017-25	PTB	1.2	Cf-252 (D_2O moderated, 1 mm Cd)	1.6		1.33
S0XX-2017-26	PTB	1.2	Cf-252 (D_2O moderated, 1 mm Cd)	1.2		1.00
S0XX-2017-27	PTB	1.2	Cf-252 (D_2O moderated, 1 mm Cd)	1.3		1.08
S0XX-2017-28	PTB		not irradiated			-
S0XX-2017-29	PTB	1.5	Cf-252 (with additional 1.0 mSv of Cs-137)	2		1.33
S0XX-2017-30	PTB	1.0	Cf-252 (D_2O moderated, 1 mm Cd) behind a shadow block	0.4		0.40
S0XX-2017-31	PTB	1.5	Cf-252 (with additional 1.0 mSv of Cs-137)	2.1		1.40
S0XX-2017-32	PTB	1.2	Cf-252 (D_2O moderated, 1 mm Cd)	1.1		0.92
S0XX-2017-33	PTB		not irradiated			-
S0XX-2017-34	PTB		not irradiated			-
S0XX-2017-35	PTB		not irradiated			-
S0XX-2017-36	PTB		not irradiated			-
S0XX-2017-37	PTB	1.5	Cf-252 (with additional 1.0 mSv of Cs-137)	2		1.33
S0XX-2017-38	PTB	1.5	Cf-252 (with additional 1.0 mSv of Cs-137)	1.6		1.07
S0XX-2017-39	PTB		not irradiated			-
S0XX-2017-40	PTB	1.0	Cf-252 (D_2O moderated, 1 mm Cd) behind a shadow block	0.2		0.20

Appendix F: Additional data

Values of group fluence rate and personal dose equivalent rate of in-scattered neutrons produced in the PTB bunker room by a ^{252}Cf (D_2O moderated) source with source strength 1 s^{-1} behind a shadow block at a distance of 170 cm.

Neutron energy (lower limit) (MeV)	Δφ (cm^{-2} s^{-1})	ΔH_p(10) (pSv s^{-1})
7.94E-10	1.88E-10	3.40E-10
1.26E-09	7.16E-10	1.35E-09
2.00E-09	2.04E-09	4.00E-09
3.16E-09	5.56E-09	1.13E-08
5.01E-09	1.40E-08	2.96E-08
7.94E-09	2.75E-08	6.09E-08
1.26E-08	5.23E-08	1.23E-07
2.00E-08	8.22E-08	2.06E-07
3.16E-08	1.15E-07	2.99E-07
5.01E-08	1.48E-07	4.00E-07
7.94E-08	1.40E-07	3.94E-07
1.26E-07	8.31E-08	2.49E-07
2.00E-07	4.62E-08	1.46E-07
3.16E-07	6.61E-08	2.17E-07
5.01E-07	5.16E-08	1.75E-07
7.94E-07	5.17E-08	1.81E-07
1.26E-06	5.70E-08	2.01E-07
2.00E-06	5.03E-08	1.77E-07
3.16E-06	5.22E-08	1.82E-07
5.01E-06	5.22E-08	1.78E-07
7.94E-06	5.30E-08	1.76E-07
1.26E-05	5.19E-08	1.66E-07
2.00E-05	5.13E-08	1.58E-07
3.16E-05	5.13E-08	1.52E-07
5.01E-05	5.29E-08	1.50E-07
7.94E-05	5.19E-08	1.41E-07
1.26E-04	5.17E-08	1.37E-07

Neutron energy (lower limit) (MeV)	Δφ (cm^{-2} s^{-1})	ΔH_p(10) (pSv s^{-1})
2.00E-04	5.20E-08	1.34E-07
3.16E-04	4.84E-08	1.23E-07
5.01E-04	6.04E-08	1.50E-07
7.94E-04	5.03E-08	1.21E-07
1.26E-03	4.69E-08	1.12E-07
2.00E-03	4.76E-08	1.15E-07
3.16E-03	4.36E-08	1.08E-07
5.01E-03	4.87E-08	1.28E-07
7.94E-03	3.85E-08	1.13E-07
1.26E-02	3.35E-08	1.23E-07
2.00E-02	3.97E-08	2.03E-07
3.16E-02	3.30E-08	2.54E-07
5.01E-02	3.19E-08	4.11E-07
7.94E-02	2.86E-08	6.53E-07
1.26E-01	2.95E-08	1.14E-06
2.00E-01	2.57E-08	1.55E-06
3.16E-01	2.11E-08	1.83E-06
5.01E-01	3.26E-08	3.85E-06
7.94E-01	2.62E-08	3.73E-06
1.26E+00	2.78E-08	4.87E-06
2.00E+00	2.54E-08	5.08E-06
3.16E+00	7.35E-09	1.65E-06
5.01E+00	1.48E-09	3.93E-07
7.94E+00	1.45E-10	4.60E-08
1.26E+01	7.51E-13	3.03E-10
2.00E+01		

Appendix G: Datasheets with results for individual participants

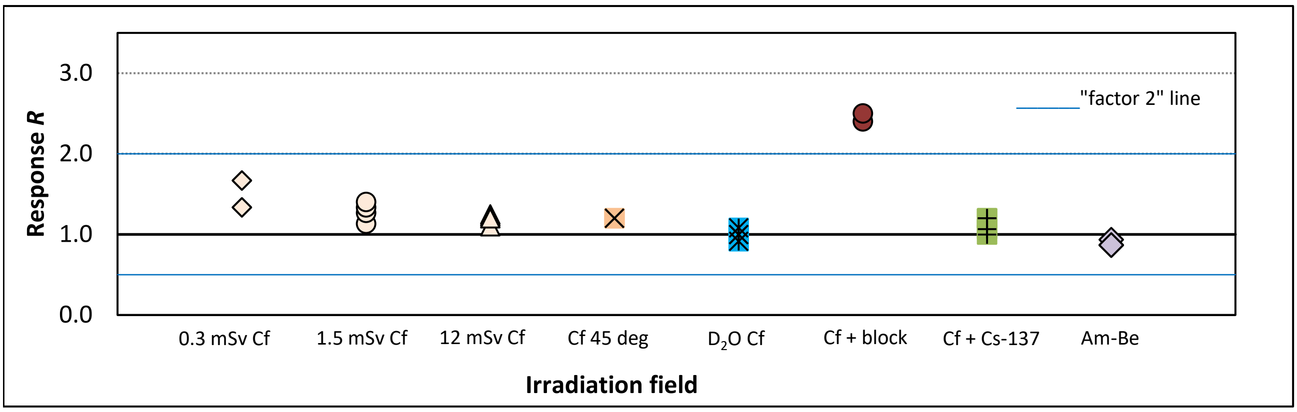
In this annex all individual results are given for all participating systems using an assigned randomized code (system code). Classification of the system (i.e. *Track* or *Albedo*) was done by the Organization Group (see paragraph 2.5).

S001, dosemeter type: Albedo

Reference values reported by the irradiating laboratory			Results		
Radiation quality	Dosemeter code	$H_p(10)$ Reference value (mSv)	$H_p(10)$ Participant's value (mSv)	R Response (Participant/Reference)	OK / outlier
Cf-252; 0°	S001-2017-03	0.3	0.50	1.67	
	S001-2017-08	0.3	0.50	1.67	
	S001-2017-13	0.3	0.40	1.33	
	S001-2017-16	0.3	0.40	1.33	
	S001-2017-01	1.499	1.70	1.13	
	S001-2017-06	1.499	1.90	1.27	
	S001-2017-11	1.499	2.00	1.33	
	S001-2017-17	1.499	2.10	1.40	
	S001-2017-02	12	15.00	1.25	
	S001-2017-12	12	14.70	1.23	
	S001-2017-20	12	13.20	1.10	
	S001-2017-22	12	14.40	1.20	
Cf-252; 45°	S001-2017-07	1.5	1.80	1.20	
	S001-2017-14	1.5	1.80	1.20	
Cf-252 (D_2O); 0°	S001-2017-25	1.2	1.10	0.92	
	S001-2017-32	1.2	1.20	1.00	
	S001-2017-33	1.2	1.20	1.00	
	S001-2017-34	1.2	1.30	1.08	
Cf-252 + shadow block; 0°	S001-2017-31	1	2.40	2.40	outlier
	S001-2017-39	1	2.50	2.50	outlier
Cf-252 + Cs-137; 0°	S001-2017-27	1.5	1.80	1.20	
	S001-2017-30	1.5	1.80	1.20	
	S001-2017-36	1.5	1.50	1.00	
	S001-2017-38	1.5	1.60	1.07	
Am-Be; 0°	S001-2017-05	1.5	1.30	0.87	
	S001-2017-10	1.5	1.40	0.93	
	S001-2017-15	1.5	1.30	0.87	
	S001-2017-18	1.5	1.30	0.87	

Radiation quality	Number of values	Median of R	Mean of R
Cf-252; 0°	12	1.30	1.33
Cf-252; 45°	2	1.20	1.20
Cf-252 (D_2O); 0°	4	1.00	1.00
Cf-252 + block; 0°	2	2.45	2.45
Cf-252 + Cs-137; 0°	4	1.13	1.12
Am-Be; 0°	4	0.87	0.88
All	28	1.20	1.26

Number of outliers:	2 of 28
Fraction of outliers:	7%

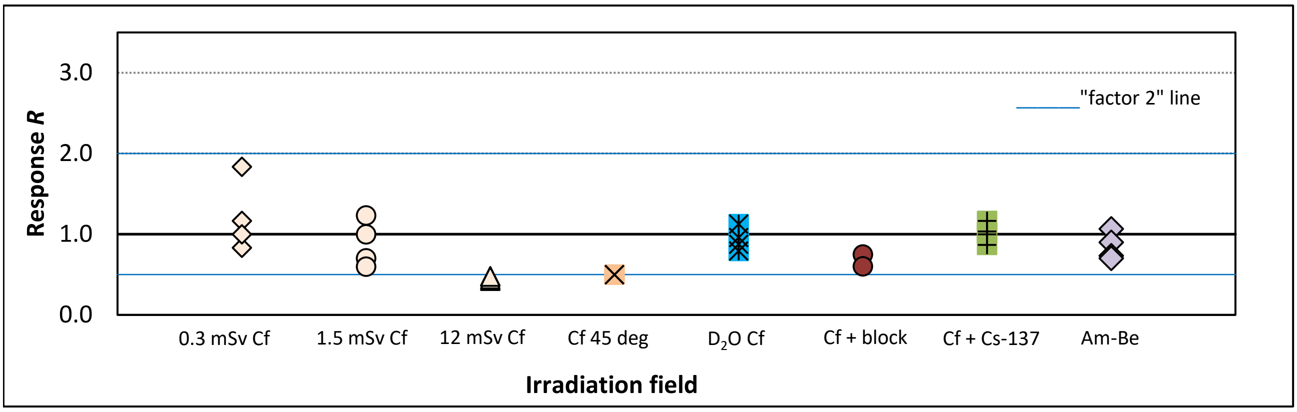


S002, dosemeter type: Track

Reference values reported by the irradiating laboratory			Results		
Radiation quality	Dosemeter code	$H_p(10)$ Reference value (mSv)	$H_p(10)$ Participant's value (mSv)	R Response (Participant/Reference)	OK / outlier
Cf-252; 0°	S002-2017-01	0.3	0.55	1.83	
	S002-2017-04	0.3	0.25	0.83	
	S002-2017-06	0.3	0.35	1.17	
	S002-2017-14	0.3	0.30	1.00	
	S002-2017-07	1.501	1.50	1.00	
	S002-2017-11	1.501	1.85	1.23	
	S002-2017-16	1.501	1.05	0.70	
	S002-2017-18	1.501	0.90	0.60	
	S002-2017-02	12.00	5.10	0.43	outlier
	S002-2017-05	12.00	5.30	0.44	outlier
	S002-2017-13	12.00	5.75	0.48	outlier
	S002-2017-17	12.00	5.70	0.48	outlier
Cf-252; 45°	S002-2017-20	1.5	0.75	0.50	
	S002-2017-21	1.5	0.75	0.50	
Cf-252 (D_2O); 0°	S002-2017-25	1.2	1.05	0.88	
	S002-2017-28	1.2	0.95	0.79	
	S002-2017-30	1.2	1.15	0.96	
	S002-2017-34	1.2	1.35	1.13	
Cf-252 + shadow block; 0°	S002-2017-27	1	0.75	0.75	
	S002-2017-29	1	0.60	0.60	
Cf-252 + Cs-137; 0°	S002-2017-31	1.5	1.50	1.00	
	S002-2017-33	1.5	1.30	0.87	
	S002-2017-35	1.5	1.75	1.17	
	S002-2017-38	1.5	1.55	1.03	
Am-Be; 0°	S002-2017-03	1.50	1.60	1.07	
	S002-2017-08	1.50	1.35	0.90	
	S002-2017-12	1.50	1.10	0.73	
	S002-2017-15	1.50	1.05	0.70	

Radiation quality	Number of values	Median of R	Mean of R
Cf-252; 0°	12	0.77	0.85
Cf-252; 45°	2	0.50	0.50
Cf-252 (D_2O); 0°	4	0.92	0.94
Cf-252 + block; 0°	2	0.68	0.68
Cf-252 + Cs-137; 0°	4	1.02	1.02
Am-Be; 0°	4	0.82	0.85
All	28	0.85	0.85

Number of outliers:	4 of 28
Fraction of outliers:	14%

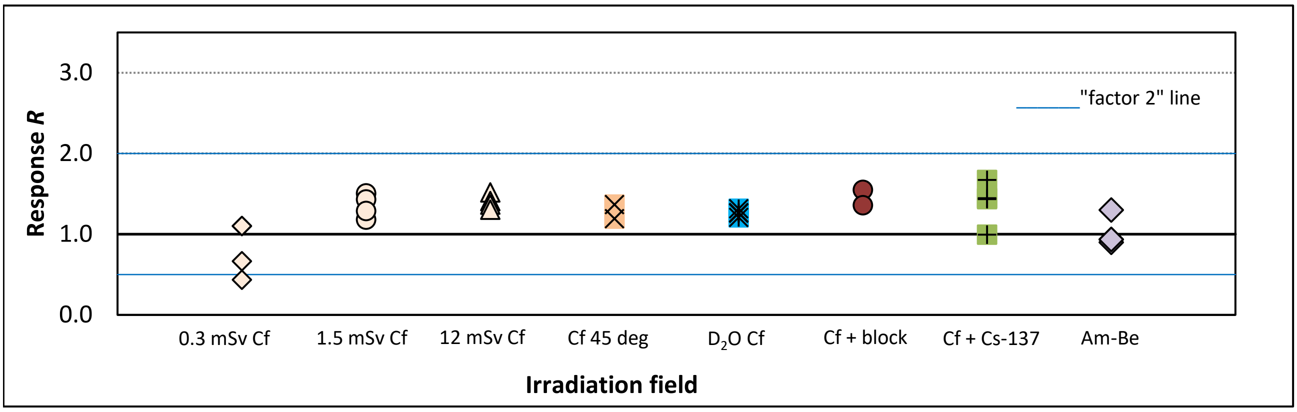


S003, dosemeter type: Albedo

Radiation quality	Dosemeter code	$H_p(10)$ Reference value (mSv)	$H_p(10)$ Participant's value (mSv)	R Response (Participant/Reference)	OK / outlier
Cf-252; 0°	S003-2017-43	0.3	0.13	0.43	outlier
	S003-2017-45	0.3	0.33	1.10	
	S003-2017-51	0.3	0.33	1.10	
	S003-2017-54	0.3	0.20	0.67	
	S003-2017-42	1.501	2.26	1.51	
	S003-2017-49	1.501	1.77	1.18	
	S003-2017-55	1.501	2.15	1.43	
	S003-2017-58	1.501	1.93	1.29	
	S003-2017-47	12.00	18.22	1.52	
	S003-2017-57	12.00	16.95	1.41	
	S003-2017-60	12.00	16.39	1.37	
	S003-2017-64	12.00	15.66	1.31	
Cf-252; 45°	S003-2017-50	1.5	1.79	1.19	
	S003-2017-63	1.5	2.05	1.37	
Cf-252 (D_2O); 0°	S003-2017-29	1.2	1.45	1.21	
	S003-2017-32	1.2	1.52	1.27	
	S003-2017-34	1.2	1.58	1.32	
	S003-2017-39	1.2	1.51	1.26	
Cf-252 + shadow block; 0°	S003-2017-28	1	1.55	1.55	
	S003-2017-38	1	1.36	1.36	
Cf-252 + Cs-137; 0°	S003-2017-31	1.5	2.15	1.43	
	S003-2017-33	1.5	1.49	0.99	
	S003-2017-36	1.5	2.51	1.67	
	S003-2017-37	1.5	2.17	1.45	
Am-Be; 0°	S003-2017-48	1.50	1.95	1.30	
	S003-2017-56	1.50	1.40	0.93	
	S003-2017-59	1.50	1.35	0.90	
	S003-2017-62	1.50	1.40	0.93	

Radiation quality	Number of values	Median of R	Mean of R
Cf-252; 0°	12	1.30	1.19
Cf-252; 45°	2	1.28	1.28
Cf-252 (D_2O); 0°	4	1.26	1.26
Cf-252 + block; 0°	2	1.46	1.46
Cf-252 + Cs-137; 0°	4	1.44	1.39
Am-Be; 0°	4	0.93	1.02
All	28	1.29	1.23

Number of outliers:	1 of 28
Fraction of outliers:	4%

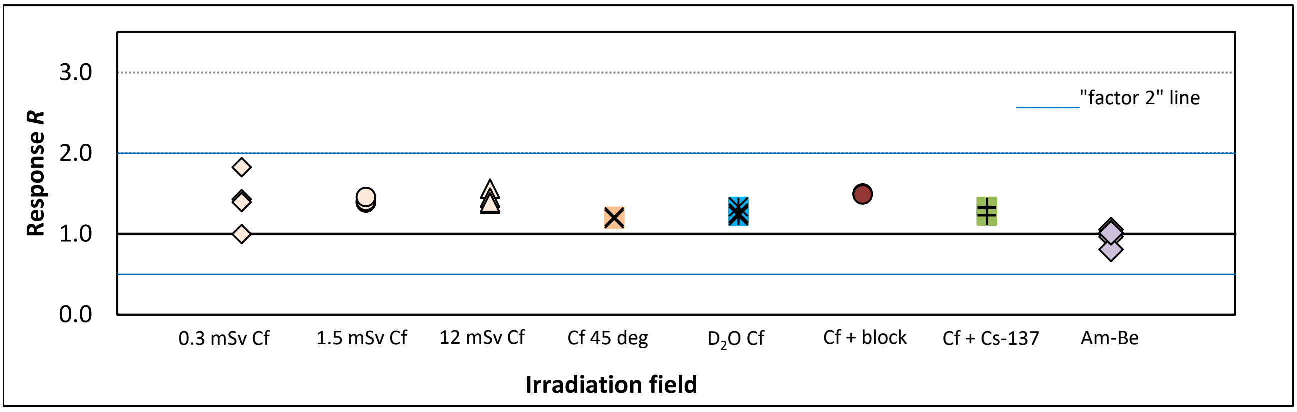


S004, dosemeter type: Albedo

Reference values reported by the irradiating laboratory			Results		
Radiation quality	Dosemeter code	$H_p(10)$ Reference value (mSv)	$H_p(10)$ Participant's value (mSv)	R Response (Participant/Reference)	OK / outlier
Cf-252; 0°	S004-2017-48	0.301	0.55	1.83	
	S004-2017-50	0.301	0.43	1.43	
	S004-2017-59	0.301	0.42	1.40	
	S004-2017-63	0.301	0.30	1.00	
	S004-2017-45	1.501	2.09	1.39	
	S004-2017-52	1.501	2.09	1.39	
	S004-2017-55	1.501	2.12	1.41	
	S004-2017-58	1.501	2.19	1.46	
	S004-2017-44	12.00	16.44	1.37	
	S004-2017-53	12.00	18.73	1.56	
	S004-2017-56	12.00	17.38	1.45	
	S004-2017-64	12.00	16.71	1.39	
Cf-252; 45°	S004-2017-46	1.499	1.82	1.21	
	S004-2017-61	1.499	1.78	1.19	
Cf-252 (D_2O); 0°	S004-2017-27	1.2	1.50	1.25	
	S004-2017-29	1.2	1.51	1.26	
	S004-2017-34	1.2	1.60	1.33	
	S004-2017-38	1.2	1.47	1.23	
Cf-252 + shadow block; 0°	S004-2017-26	1	1.50	1.50	
	S004-2017-40	1	1.49	1.49	
Cf-252 + Cs-137; 0°	S004-2017-28	1.5	1.98	1.32	
	S004-2017-31	1.5	1.84	1.23	
	S004-2017-33	1.5	1.85	1.23	
	S004-2017-39	1.5	2.00	1.33	
Am-Be; 0°	S004-2017-41	1.50	1.45	0.97	
	S004-2017-51	1.50	1.21	0.81	
	S004-2017-57	1.50	1.58	1.05	
	S004-2017-62	1.50	1.52	1.01	

Radiation quality	Number of values	Median of R	Mean of R
Cf-252; 0°	12	1.40	1.42
Cf-252; 45°	2	1.20	1.20
Cf-252 (D_2O); 0°	4	1.25	1.27
Cf-252 + block; 0°	2	1.50	1.50
Cf-252 + Cs-137; 0°	4	1.28	1.28
Am-Be; 0°	4	0.99	0.96
All	28	1.33	1.30

Number of outliers:	0 of 28
Fraction of outliers:	0%

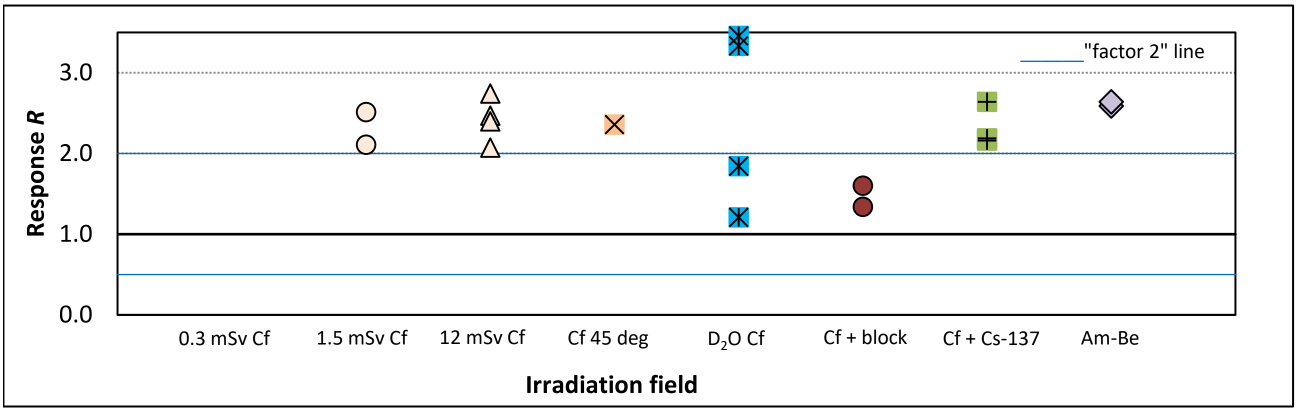


S005, dosemeter type: Track

Reference values reported by the irradiating laboratory			Results		
Radiation quality	Dosemeter code	$H_p(10)$ Reference value (mSv)	$H_p(10)$ Participant's value (mSv)	R Response (Participant/Reference)	OK / outlier
Cf-252; 0°	S005-2017-03	0.3	7.38	24.60	outlier
	S005-2017-06	0.3	2.10	7.00	outlier
	S005-2017-13	0.3	1.83	6.10	outlier
	S005-2017-17	0.3	4.45	14.83	outlier
	S005-2017-02	1.5	7.26	4.84	outlier
	S005-2017-05	1.5	3.77	2.51	outlier
	S005-2017-09	1.5	3.16	2.11	outlier
	S005-2017-12	1.5	7.61	5.07	outlier
	S005-2017-01	12.00	29.65	2.47	outlier
	S005-2017-08	12.00	24.86	2.07	outlier
	S005-2017-16	12.00	28.77	2.40	outlier
	S005-2017-18	12.00	32.91	2.74	outlier
Cf-252; 45°	S005-2017-04	1.5	7.04	4.69	outlier
	S005-2017-10	1.5	3.54	2.36	outlier
Cf-252 (D_2O); 0°	S005-2017-28	1.2	4.00	3.33	outlier
	S005-2017-32	1.2	2.21	1.84	
	S005-2017-38	1.2	1.45	1.21	
	S005-2017-40	1.2	4.15	3.46	outlier
Cf-252 + shadow block; 0°	S005-2017-29	1	1.34	1.34	
	S005-2017-30	1	1.60	1.60	
Cf-252 + Cs-137; 0°	S005-2017-25	1.5	3.24	2.16	outlier
	S005-2017-33	1.5	3.96	2.64	outlier
	S005-2017-37	1.5	5.29	3.53	outlier
	S005-2017-39	1.5	3.28	2.19	outlier
Am-Be; 0°	S005-2017-07	1.50	11.33	7.55	outlier
	S005-2017-11	1.50	3.88	2.59	outlier
	S005-2017-15	1.50	7.34	4.89	outlier
	S005-2017-22	1.50	3.96	2.64	outlier

Radiation quality	Number of values	Median of R	Mean of R
Cf-252; 0°	12	3.79	6.40
Cf-252; 45°	2	3.53	3.53
Cf-252 (D_2O); 0°	4	2.59	2.46
Cf-252 + block; 0°	2	1.47	1.47
Cf-252 + Cs-137; 0°	4	2.41	2.63
Am-Be; 0°	4	3.77	4.42
All	28	2.64	4.46

Number of outliers:	24 of 28
Fraction of outliers:	86%

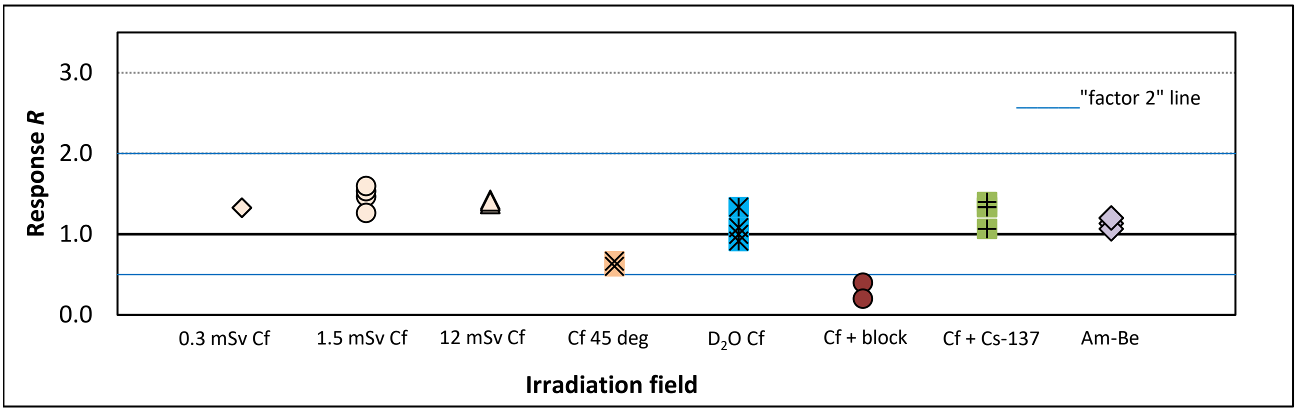


S006, dosemeter type: Track

Reference values reported by the irradiating laboratory			Results		
Radiation quality	Dosemeter code	$H_p(10)$ Reference value (mSv)	$H_p(10)$ Participant's value (mSv)	R Response (Participant/Reference)	OK / outlier
Cf-252; 0°	S006-2017-02	0.301	0.40	1.33	
	S006-2017-05	0.301	0.40	1.33	
	S006-2017-15	0.301	0.40	1.33	
	S006-2017-18	0.301	0.40	1.33	
	S006-2017-03	1.501	2.20	1.47	
	S006-2017-06	1.501	2.30	1.53	
	S006-2017-10	1.501	2.40	1.60	
	S006-2017-14	1.501	1.90	1.27	
	S006-2017-04	12.00	17.10	1.43	
	S006-2017-09	12.00	16.50	1.38	
	S006-2017-13	12.00	16.50	1.38	
	S006-2017-16	12.00	16.90	1.41	
Cf-252; 45°	S006-2017-07	1.499	0.90	0.60	
	S006-2017-11	1.499	1.00	0.67	
Cf-252 (D_2O); 0°	S006-2017-25	1.2	1.60	1.33	
	S006-2017-26	1.2	1.20	1.00	
	S006-2017-27	1.2	1.30	1.08	
	S006-2017-32	1.2	1.10	0.92	
Cf-252 + shadow block; 0°	S006-2017-30	1	0.40	0.40	outlier
	S006-2017-40	1	0.20	0.20	outlier
Cf-252 + Cs-137; 0°	S006-2017-29	1.5	2.00	1.33	
	S006-2017-31	1.5	2.10	1.40	
	S006-2017-37	1.5	2.00	1.33	
	S006-2017-38	1.5	1.60	1.07	
Am-Be; 0°	S006-2017-01	1.50	1.80	1.20	
	S006-2017-08	1.50	1.70	1.13	
	S006-2017-12	1.50	1.60	1.07	
	S006-2017-20	1.50	1.80	1.20	

Radiation quality	Number of values	Median of R	Mean of R
Cf-252; 0°	12	1.38	1.40
Cf-252; 45°	2	0.63	0.63
Cf-252 (D_2O); 0°	4	1.04	1.08
Cf-252 + block; 0°	2	0.30	0.30
Cf-252 + Cs-137; 0°	4	1.33	1.28
Am-Be; 0°	4	1.17	1.15
All	28	1.33	1.17

Number of outliers:	2 of 28
Fraction of outliers:	7%

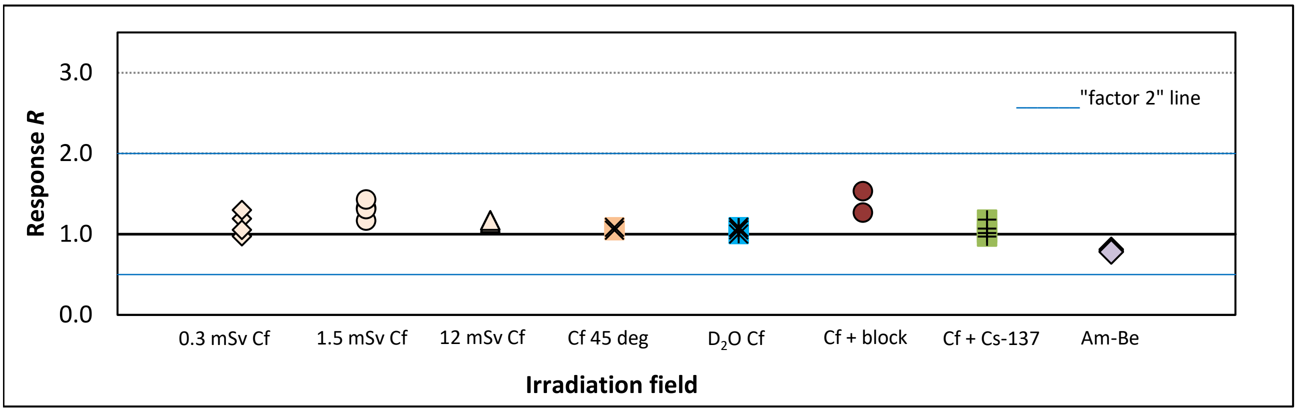


S008, dosemeter type: Albedo

Reference values reported by the irradiating laboratory			Results		
Radiation quality	Dosemeter code	$H_p(10)$ Reference value (mSv)	$H_p(10)$ Participant's value (mSv)	R Response (Participant/Reference)	OK / outlier
Cf-252; 0°	S008-2017-02	0.334	0.40	1.19	
	S008-2017-08	0.334	0.33	0.97	
	S008-2017-12	0.334	0.35	1.05	
	S008-2017-16	0.334	0.43	1.30	
	S008-2017-06	1.501	1.99	1.33	
	S008-2017-09	1.501	1.76	1.17	
	S008-2017-13	1.501	1.97	1.31	
	S008-2017-18	1.501	2.15	1.43	
	S008-2017-03	12.00	14.01	1.17	
	S008-2017-05	12.00	14.07	1.17	
	S008-2017-10	12.00	13.69	1.14	
	S008-2017-17	12.00	14.04	1.17	
Cf-252; 45°	S008-2017-11	1.499	1.58	1.05	
	S008-2017-15	1.499	1.63	1.08	
Cf-252 (D_2O); 0°	S008-2017-29	1.2	1.30	1.09	
	S008-2017-33	1.2	1.30	1.09	
	S008-2017-36	1.2	1.26	1.05	
	S008-2017-40	1.2	1.20	1.00	
Cf-252 + shadow block; 0°	S008-2017-27	1	1.53	1.53	
	S008-2017-34	1	1.27	1.27	
Cf-252 + Cs-137; 0°	S008-2017-26	1.5	1.77	1.18	
	S008-2017-28	1.5	1.45	0.97	
	S008-2017-35	1.5	1.52	1.02	
	S008-2017-38	1.5	1.61	1.07	
Am-Be; 0°	S008-2017-01	1.50	1.22	0.81	
	S008-2017-04	1.50	1.18	0.78	
	S008-2017-07	1.50	1.19	0.79	
	S008-2017-14	1.50	1.17	0.78	

Radiation quality	Number of values	Median of R	Mean of R
Cf-252; 0°	12	1.17	1.20
Cf-252; 45°	2	1.07	1.07
Cf-252 (D_2O); 0°	4	1.07	1.06
Cf-252 + block; 0°	2	1.40	1.40
Cf-252 + Cs-137; 0°	4	1.04	1.06
Am-Be; 0°	4	0.79	0.79
All	28	1.09	1.11

Number of outliers:	0 of 28
Fraction of outliers:	0%

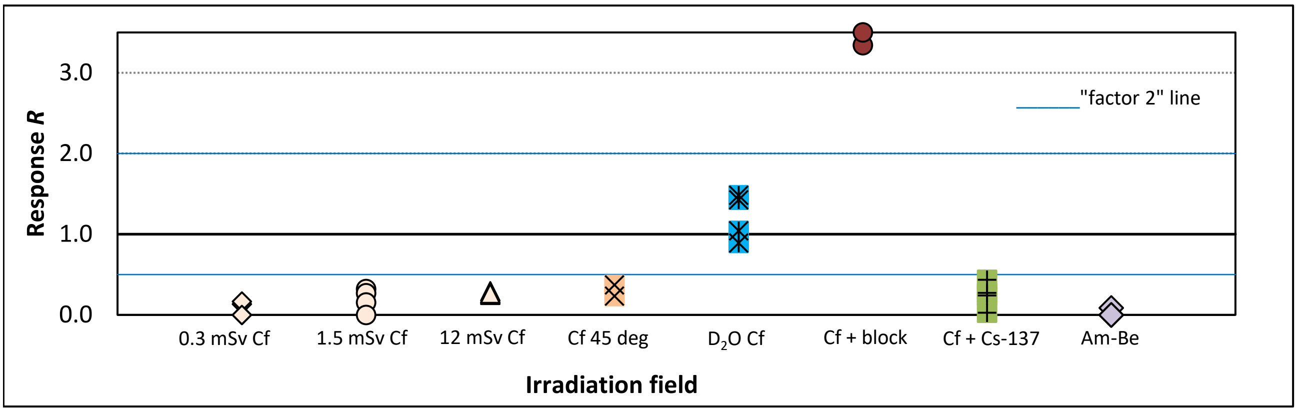


S009, dosemeter type: Albedo

Reference values reported by the irradiating laboratory			Results		
Radiation quality	Dosemeter code	$H_p(10)$ Reference value (mSv)	$H_p(10)$ Participant's value (mSv)	R Response (Participant/Reference)	OK / outlier
Cf-252; 0°	S009-2017-01	0.299	0.00	0.00	outlier
	S009-2017-07	0.299	0.04	0.13	outlier
	S009-2017-11	0.299	0.05	0.17	outlier
	S009-2017-18	0.299	0.00	0.00	outlier
	S009-2017-03	1.499	0.48	0.32	outlier
	S009-2017-06	1.499	0.40	0.27	outlier
	S009-2017-10	1.499	0.23	0.15	outlier
	S009-2017-13	1.499	0.00	0.00	outlier
	S009-2017-02	12.00	2.99	0.25	outlier
	S009-2017-05	12.00	3.22	0.27	outlier
	S009-2017-12	12.00	3.51	0.29	outlier
	S009-2017-17	12.00	3.19	0.27	outlier
Cf-252; 45°	S009-2017-08	1.5	0.35	0.23	outlier
	S009-2017-16	1.5	0.56	0.37	outlier
Cf-252 (D_2O); 0°	S009-2017-26	1.2	1.71	1.43	
	S009-2017-29	1.2	1.25	1.04	
	S009-2017-31	1.2	1.07	0.89	
	S009-2017-36	1.2	1.78	1.48	
Cf-252 + shadow block; 0°	S009-2017-35	1	3.34	3.34	outlier
	S009-2017-37	1	3.50	3.50	outlier
Cf-252 + Cs-137; 0°	S009-2017-27	1.5	0.41	0.27	outlier
	S009-2017-28	1.5	0.36	0.24	outlier
	S009-2017-33	1.5	0.65	0.43	outlier
	S009-2017-40	1.5	0.04	0.03	outlier
Am-Be; 0°	S009-2017-04	1.50	0.13	0.09	outlier
	S009-2017-14	1.50	0.00	0.00	outlier
	S009-2017-20	1.50	0.00	0.00	outlier
	S009-2017-22	1.50	0.00	0.00	outlier

Radiation quality	Number of values	Median of R	Mean of R
Cf-252; 0°	12	0.21	0.18
Cf-252; 45°	2	0.30	0.30
Cf-252 (D_2O); 0°	4	1.23	1.21
Cf-252 + block; 0°	2	3.42	3.42
Cf-252 + Cs-137; 0°	4	0.26	0.24
Am-Be; 0°	4	0.00	0.02
All	28	0.26	0.55

Number of outliers:	24 of 28
Fraction of outliers:	86%



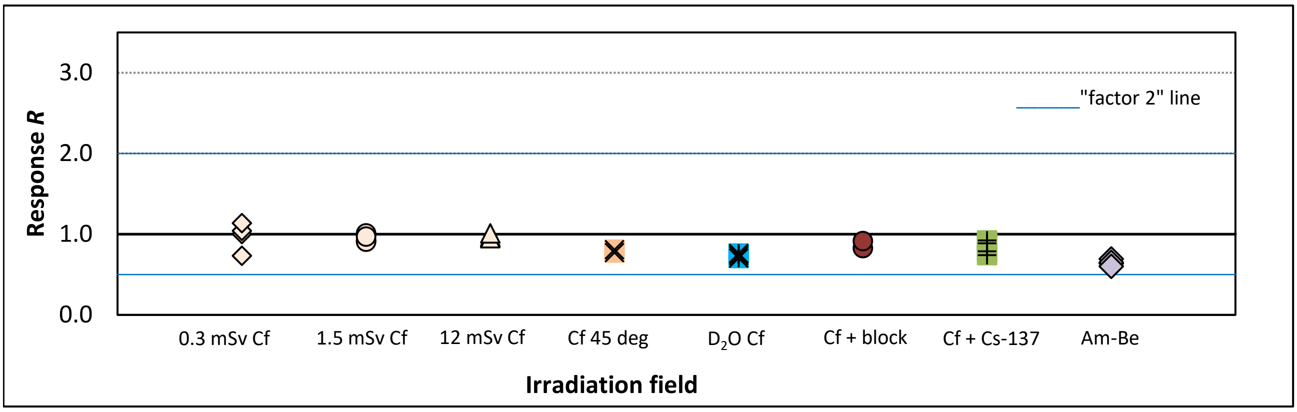
S010, dosemeter type: Albedo

Reference values reported by the irradiating laboratory			Results		
Radiation quality	Dosemeter code	$H_p(10)$ Reference value (mSv)	$H_p(10)$ Participant's value (mSv)	R Response (Participant/Reference)	OK / outlier
Cf-252; 0°	S010-2017-04	0.299	0.30	1.00	
	S010-2017-07	0.299	0.22	0.73	
	S010-2017-11	0.299	0.31	1.04	
	S010-2017-15	0.299	0.34	1.14	
	S010-2017-02	1.501	1.51	1.01	
	S010-2017-05	1.501	1.39	0.92	
	S010-2017-10	1.501	1.36	0.91	
	S010-2017-16	1.501	1.46	0.97	
	S010-2017-03	12.00	11.55	0.96	
	S010-2017-06	12.00	11.65	0.97	
	S010-2017-13	12.00	11.40	0.95	
	S010-2017-18	12.00	12.14	1.01	
Cf-252; 45°	S010-2017-09	1.499	1.16	0.77	
	S010-2017-12	1.499	1.21	0.81	
Cf-252 (D_2O); 0°	S010-2017-27	1.2	0.91	0.76	
	S010-2017-29	1.2	0.84	0.70	
	S010-2017-34	1.2	0.89	0.74	
	S010-2017-35	1.2	0.91	0.76	
Cf-252 + shadow block; 0°	S010-2017-25	1	0.83	0.83	
	S010-2017-33	1	0.91	0.91	
Cf-252 + Cs-137; 0°	S010-2017-28	1.5	1.19	0.79	
	S010-2017-31	1.5	1.11	0.74	
	S010-2017-32	1.5	1.33	0.89	
	S010-2017-36	1.5	1.38	0.92	
Am-Be; 0°	S010-2017-01	1.50	1.04	0.69	
	S010-2017-08	1.50	0.96	0.64	
	S010-2017-14	1.50	0.97	0.65	
	S010-2017-17	1.50	0.90	0.60	

Radiation quality	Number of values	Median of R	Mean of R
Cf-252; 0°	12	0.97	0.97
Cf-252; 45°	2	0.79	0.79
Cf-252 (D_2O); 0°	4	0.75	0.74
Cf-252 + block; 0°	2	0.87	0.87
Cf-252 + Cs-137; 0°	4	0.84	0.84
Am-Be; 0°	4	0.64	0.64
All	28	0.86	0.85

Number of outliers: 0 of 28

Fraction of outliers: 0%

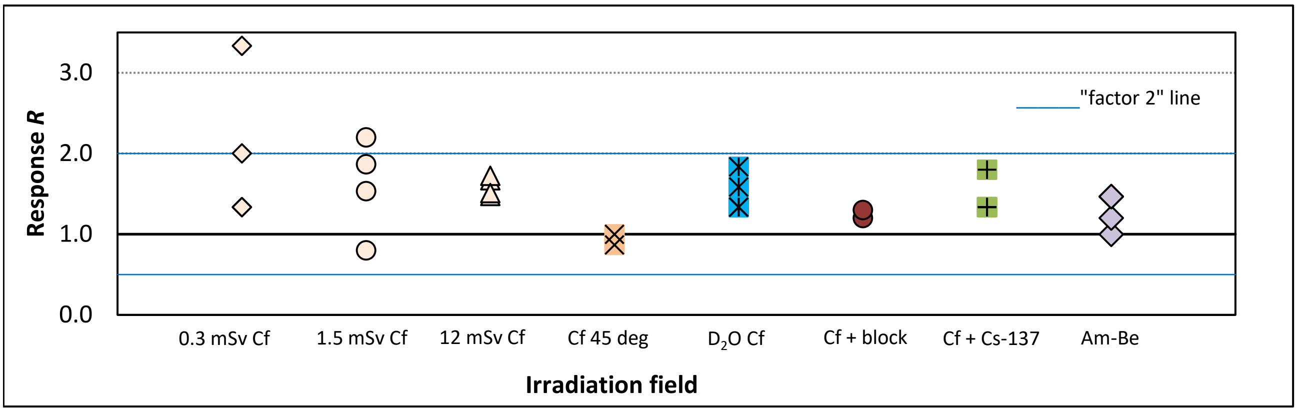


S011, dosemeter type: Track

Reference values reported by the irradiating laboratory			Results		
Radiation quality	Dosemeter code	$H_p(10)$ Reference value (mSv)	$H_p(10)$ Participant's value (mSv)	R Response (Participant/Reference)	OK / outlier
Cf-252; 0°	S011-2017-06	0.3	0.40	1.33	
	S011-2017-09	0.3	1.00	3.33	outlier
	S011-2017-11	0.3	0.60	2.00	
	S011-2017-14	0.3	0.40	1.33	
	S011-2017-02	1.5	3.30	2.20	outlier
	S011-2017-04	1.5	2.30	1.53	
	S011-2017-08	1.5	1.20	0.80	
	S011-2017-15	1.5	2.80	1.87	
	S011-2017-03	12.00	17.70	1.48	
	S011-2017-13	12.00	20.00	1.67	
	S011-2017-16	12.00	20.70	1.73	
	S011-2017-18	12.00	18.10	1.51	
Cf-252; 45°	S011-2017-01	1.501	1.30	0.87	
	S011-2017-12	1.501	1.50	1.00	
Cf-252 (D_2O); 0°	S011-2017-25	1.2	1.60	1.33	
	S011-2017-27	1.2	1.60	1.33	
	S011-2017-28	1.2	1.90	1.58	
	S011-2017-31	1.2	2.20	1.83	
Cf-252 + shadow block; 0°	S011-2017-26	1	1.20	1.20	
	S011-2017-34	1	1.30	1.30	
Cf-252 + Cs-137; 0°	S011-2017-29	1.5	2.00	1.33	
	S011-2017-30	1.5	2.00	1.33	
	S011-2017-33	1.5	2.70	1.80	
	S011-2017-35	1.5	2.00	1.33	
Am-Be; 0°	S011-2017-05	1.50	1.50	1.00	
	S011-2017-07	1.50	1.80	1.20	
	S011-2017-10	1.50	2.20	1.47	
	S011-2017-17	1.50	2.20	1.47	

Radiation quality	Number of values	Median of R	Mean of R
Cf-252; 0°	12	1.60	1.73
Cf-252; 45°	2	0.93	0.93
Cf-252 (D_2O); 0°	4	1.46	1.52
Cf-252 + block; 0°	2	1.25	1.25
Cf-252 + Cs-137; 0°	4	1.33	1.45
Am-Be; 0°	4	1.33	1.28
All	28	1.40	1.51

Number of outliers:	2 of 28
Fraction of outliers:	7%



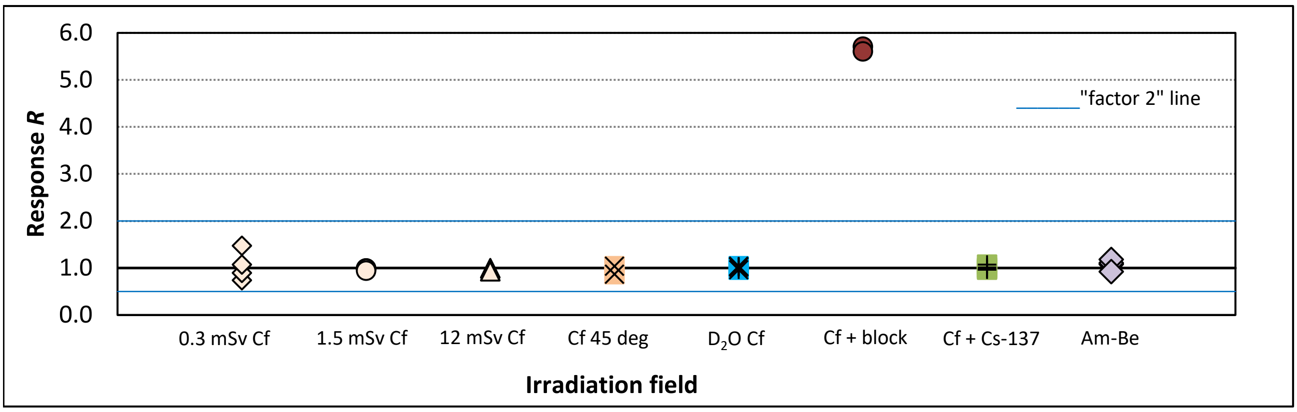
S014, dosemeter type: Track

Reference values reported by the irradiating laboratory			Results		
Radiation quality	Dosemeter code	$H_p(10)$ Reference value (mSv)	$H_p(10)$ Participant's value (mSv)	R Response (Participant/Reference)	OK / outlier
Cf-252; 0°	S014-2017-04	0.302	0.44	1.47	
	S014-2017-08	0.302	0.22	0.74	
	S014-2017-14	0.302	0.27	0.90	
	S014-2017-16	0.302	0.32	1.07	
	S014-2017-03	1.5	1.49	0.99	
	S014-2017-10	1.5	1.48	0.99	
	S014-2017-12	1.5	1.47	0.98	
	S014-2017-18	1.5	1.41	0.94	
	S014-2017-01	12.00	11.24	0.94	
	S014-2017-07	12.00	11.85	0.99	
	S014-2017-11	12.00	11.98	1.00	
	S014-2017-17	12.00	11.17	0.93	
Cf-252; 45°	S014-2017-05	1.5	1.56	1.04	
	S014-2017-15	1.5	1.31	0.87	
Cf-252 (D_2O); 0°	S014-2017-27	1.2	1.23	1.03	
	S014-2017-32	1.2	1.16	0.96	
	S014-2017-37	1.2	1.22	1.02	
	S014-2017-39	1.2	1.25	1.04	
Cf-252 + shadow block; 0°	S014-2017-28	1	5.71	5.71	outlier
	S014-2017-38	1	5.61	5.61	outlier
Cf-252 + Cs-137; 0°	S014-2017-29	1.5	1.52	1.01	
	S014-2017-31	1.5	1.44	0.96	
	S014-2017-34	1.5	1.47	0.98	
	S014-2017-40	1.5	1.61	1.07	
Am-Be; 0°	S014-2017-02	1.63	1.76	1.08	
	S014-2017-06	1.63	1.80	1.10	
	S014-2017-09	1.63	1.93	1.18	
	S014-2017-13	1.63	1.51	0.92	

Radiation quality	Number of values	Median of *R*	Mean of *R*
Cf-252; 0°	12	0.98	0.99
Cf-252; 45°	2	0.95	0.95
Cf-252 (D_2O); 0°	4	1.02	1.01
Cf-252 + block; 0°	2	5.66	5.66
Cf-252 + Cs-137; 0°	4	1.00	1.01
Am-Be; 0°	4	1.09	1.07
All	28	1.00	1.34

Number of outliers: 2 of 28

Fraction of outliers: 7%

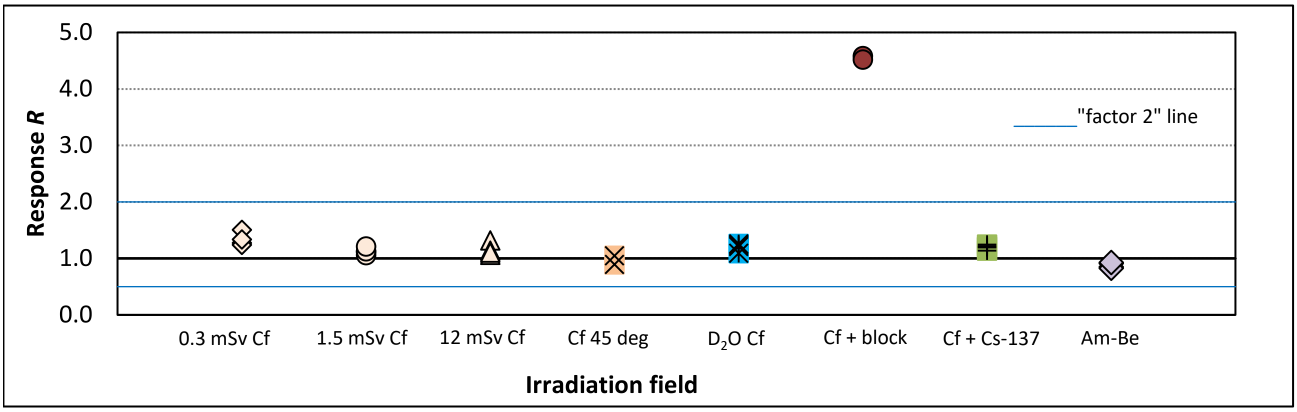


S015, dosemeter type: Albedo

Reference values reported by the irradiating laboratory			Results		
Radiation quality	Dosemeter code	$H_p(10)$ Reference value (mSv)	$H_p(10)$ Participant's value (mSv)	R Response (Participant/Reference)	OK / outlier
Cf-252; 0°	S015-2017-02	0.299	0.38	1.27	
	S015-2017-06	0.299	0.37	1.24	
	S015-2017-10	0.299	0.45	1.51	
	S015-2017-15	0.299	0.40	1.34	
	S015-2017-05	1.501	1.67	1.11	
	S015-2017-08	1.501	1.59	1.06	
	S015-2017-12	1.501	1.69	1.13	
	S015-2017-14	1.501	1.82	1.21	
	S015-2017-04	12.00	12.79	1.07	
	S015-2017-09	12.00	15.81	1.32	
	S015-2017-18	12.00	13.64	1.14	
	S015-2017-20	12.00	13.21	1.10	
Cf-252; 45°	S015-2017-13	1.5	1.34	0.89	
	S015-2017-17	1.5	1.57	1.05	
Cf-252 (D_2O); 0°	S015-2017-25	1.2	1.48	1.23	
	S015-2017-27	1.2	1.51	1.26	
	S015-2017-34	1.2	1.31	1.09	
	S015-2017-38	1.2	1.45	1.21	
Cf-252 + shadow block; 0°	S015-2017-30	1	4.58	4.58	outlier
	S015-2017-36	1	4.52	4.52	outlier
Cf-252 + Cs-137; 0°	S015-2017-26	1.5	1.71	1.14	
	S015-2017-31	1.5	1.87	1.25	
	S015-2017-32	1.5	1.79	1.19	
	S015-2017-39	1.5	1.82	1.21	
Am-Be; 0°	S015-2017-01	1.50	1.27	0.85	
	S015-2017-03	1.50	1.37	0.91	
	S015-2017-07	1.50	1.24	0.83	
	S015-2017-11	1.50	1.39	0.93	

Radiation quality	Number of values	Median of R	Mean of R
Cf-252; 0°	12	1.17	1.21
Cf-252; 45°	2	0.97	0.97
Cf-252 (D_2O); 0°	4	1.22	1.20
Cf-252 + block; 0°	2	4.55	4.55
Cf-252 + Cs-137; 0°	4	1.20	1.20
Am-Be; 0°	4	0.88	0.88
All	28	1.17	1.38

Number of outliers:	2 of 28
Fraction of outliers:	7%

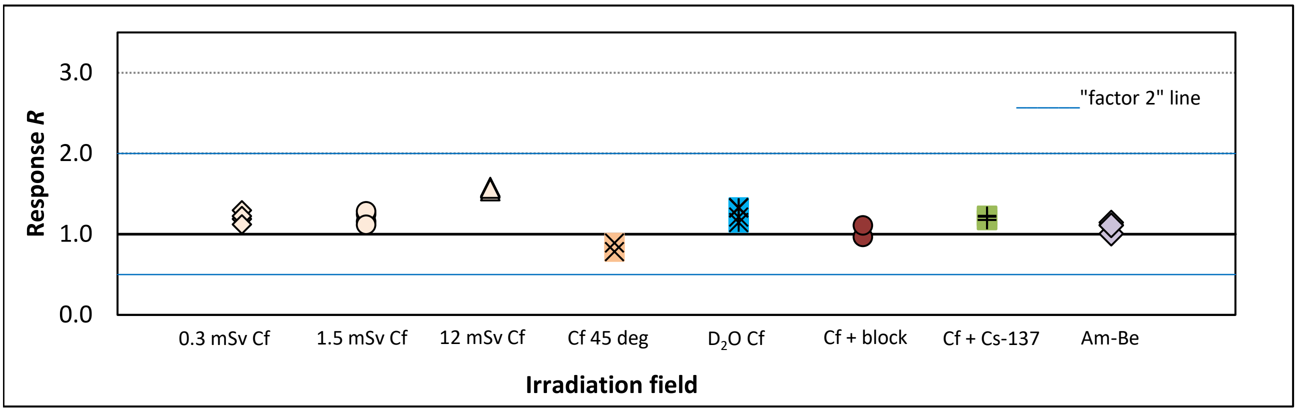


S016, dosemeter type: Track

Reference values reported by the irradiating laboratory			Results		
Radiation quality	Dosemeter code	$H_p(10)$ Reference value (mSv)	$H_p(10)$ Participant's value (mSv)	R Response (Participant/Reference)	OK / outlier
Cf-252; 0°	S016-2017-04	0.3	0.36	1.19	
	S016-2017-11	0.3	0.39	1.30	
	S016-2017-15	0.3	0.37	1.22	
	S016-2017-17	0.3	0.34	1.12	
	S016-2017-01	1.501	1.74	1.16	
	S016-2017-08	1.501	1.87	1.25	
	S016-2017-12	1.501	1.93	1.28	
	S016-2017-13	1.501	1.68	1.12	
	S016-2017-03	12.00	19.00	1.58	
	S016-2017-06	12.00	18.41	1.53	
	S016-2017-16	12.00	18.87	1.57	
	S016-2017-19	12.00	18.80	1.57	
Cf-252; 45°	S016-2017-07	1.5	1.18	0.79	
	S016-2017-14	1.5	1.34	0.89	
Cf-252 (D_2O); 0°	S016-2017-28	1.2	1.37	1.15	
	S016-2017-33	1.2	1.59	1.33	
	S016-2017-34	1.2	1.60	1.33	
	S016-2017-37	1.2	1.46	1.21	
Cf-252 + shadow block; 0°	S016-2017-27	1	0.97	0.97	
	S016-2017-36	1	1.11	1.11	
Cf-252 + Cs-137; 0°	S016-2017-25	1.5	1.83	1.22	
	S016-2017-32	1.5	1.84	1.23	
	S016-2017-39	1.5	1.77	1.18	
	S016-2017-40	1.5	1.77	1.18	
Am-Be; 0°	S016-2017-02	1.63	1.82	1.11	
	S016-2017-05	1.63	1.64	1.01	
	S016-2017-10	1.63	1.87	1.14	
	S016-2017-18	1.63	1.81	1.11	

Radiation quality	Number of values	Median of R	Mean of R
Cf-252; 0°	12	1.27	1.32
Cf-252; 45°	2	0.84	0.84
Cf-252 (D_2O); 0°	4	1.27	1.25
Cf-252 + block; 0°	2	1.04	1.04
Cf-252 + Cs-137; 0°	4	1.20	1.20
Am-Be; 0°	4	1.11	1.09
All	28	1.18	1.21

Number of outliers:	0 of 28
Fraction of outliers:	0%



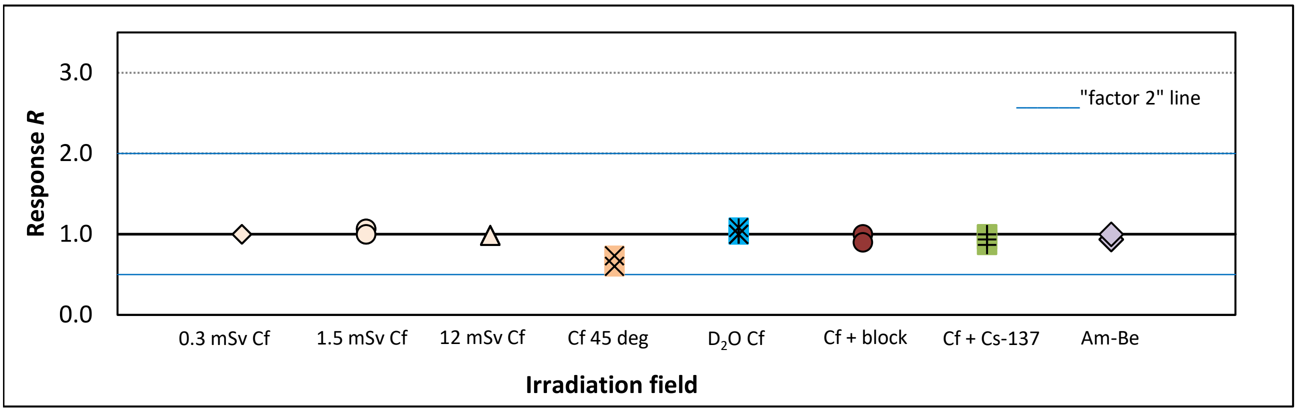
S017, dosemeter type: Track

Radiation quality	Dosemeter code	$H_p(10)$ Reference value (mSv)	$H_p(10)$ Participant's value (mSv)	R Response (Participant/Reference)	OK / outlier
Cf-252; 0°	S017-2017-04	0.3	0.30	1.00	
	S017-2017-08	0.3	0.30	1.00	
	S017-2017-11	0.3	0.30	1.00	
	S017-2017-15	0.3	0.30	1.00	
	S017-2017-02	1.5	1.60	1.07	
	S017-2017-05	1.5	1.50	1.00	
	S017-2017-13	1.5	1.60	1.07	
	S017-2017-17	1.5	1.50	1.00	
	S017-2017-01	12.00	11.80	0.98	
	S017-2017-06	12.00	11.80	0.98	
	S017-2017-10	12.00	11.90	0.99	
	S017-2017-18	12.00	11.80	0.98	
Cf-252; 45°	S017-2017-07	1.5	0.90	0.60	
	S017-2017-16	1.5	1.10	0.73	
Cf-252 (D_2O); 0°	S017-2017-25	1.2	1.20	1.00	
	S017-2017-27	1.2	1.20	1.00	
	S017-2017-36	1.2	1.20	1.00	
	S017-2017-39	1.2	1.30	1.08	
Cf-252 + shadow block; 0°	S017-2017-29	1	1.00	1.00	
	S017-2017-33	1	0.90	0.90	
Cf-252 + Cs-137; 0°	S017-2017-26	1.5	1.40	0.93	
	S017-2017-28	1.5	1.50	1.00	
	S017-2017-38	1.5	1.50	1.00	
	S017-2017-40	1.5	1.30	0.87	
Am-Be; 0°	S017-2017-09	1.50	1.40	0.93	
	S017-2017-12	1.50	1.40	0.93	
	S017-2017-14	1.50	1.40	0.93	
	S017-2017-21	1.50	1.50	1.00	

Reference values reported by the irradiating laboratory / Results

Radiation quality	Number of values	Median of R	Mean of R
Cf-252; 0°	12	1.00	1.01
Cf-252; 45°	2	0.67	0.67
Cf-252 (D_2O); 0°	4	1.00	1.02
Cf-252 + block; 0°	2	0.95	0.95
Cf-252 + Cs-137; 0°	4	0.97	0.95
Am-Be; 0°	4	0.93	0.95
All	28	1.00	0.96

Number of outliers:	0 of 28
Fraction of outliers:	0%



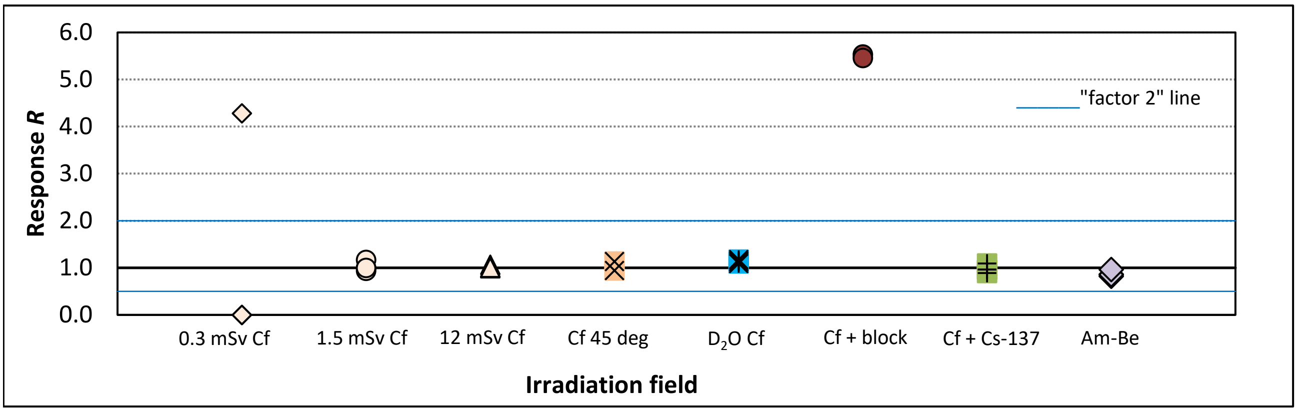
S018, dosemeter type: Albedo

Reference values reported by the irradiating laboratory			Results		
Radiation quality	Dosemeter code	$H_p(10)$ Reference value (mSv)	$H_p(10)$ Participant's value (mSv)	R Response (Participant/Reference)	OK / outlier
Cf-252; 0°	S018-2017-04	0.299	1.28	4.28	outlier
	S018-2017-06	0.299	0.00	0.00	outlier
	S018-2017-14	0.299	0.00	0.00	outlier
	S018-2017-17	0.299	0.00	0.00	outlier
	S018-2017-01	1.499	1.50	1.00	
	S018-2017-05	1.499	1.75	1.17	
	S018-2017-07	1.499	1.40	0.93	
	S018-2017-16	1.499	1.50	1.00	
	S018-2017-02	12.00	11.89	0.99	
	S018-2017-08	12.00	12.14	1.01	
	S018-2017-10	12.00	12.79	1.07	
	S018-2017-15	12.00	12.05	1.00	
Cf-252; 45°	S018-2017-12	1.5	1.41	0.94	
	S018-2017-18	1.5	1.70	1.13	
Cf-252 (D_2O); 0°	S018-2017-25	1.2	1.41	1.18	
	S018-2017-30	1.2	1.31	1.09	
	S018-2017-33	1.2	1.36	1.13	
	S018-2017-37	1.2	1.36	1.13	
Cf-252 + shadow block; 0°	S018-2017-34	1	5.53	5.53	outlier
	S018-2017-40	1	5.46	5.46	outlier
Cf-252 + Cs-137; 0°	S018-2017-29	1.5	1.45	0.97	
	S018-2017-32	1.5	1.64	1.09	
	S018-2017-38	1.5	1.33	0.89	
	S018-2017-39	1.5	1.45	0.97	
Am-Be; 0°	S018-2017-03	1.50	1.29	0.86	
	S018-2017-09	1.50	1.23	0.82	
	S018-2017-13	1.50	1.28	0.85	
	S018-2017-21	1.50	1.45	0.97	

Radiation quality	Number of values	Median of R	Mean of R
Cf-252; 0°	12	1.00	1.04
Cf-252; 45°	2	1.04	1.04
Cf-252 (D_2O); 0°	4	1.13	1.13
Cf-252 + block; 0°	2	5.50	5.50
Cf-252 + Cs-137; 0°	4	0.97	0.98
Am-Be; 0°	4	0.86	0.88
All	28	1.00	1.34

Number of outliers: 6 of 28

Fraction of outliers: 21%

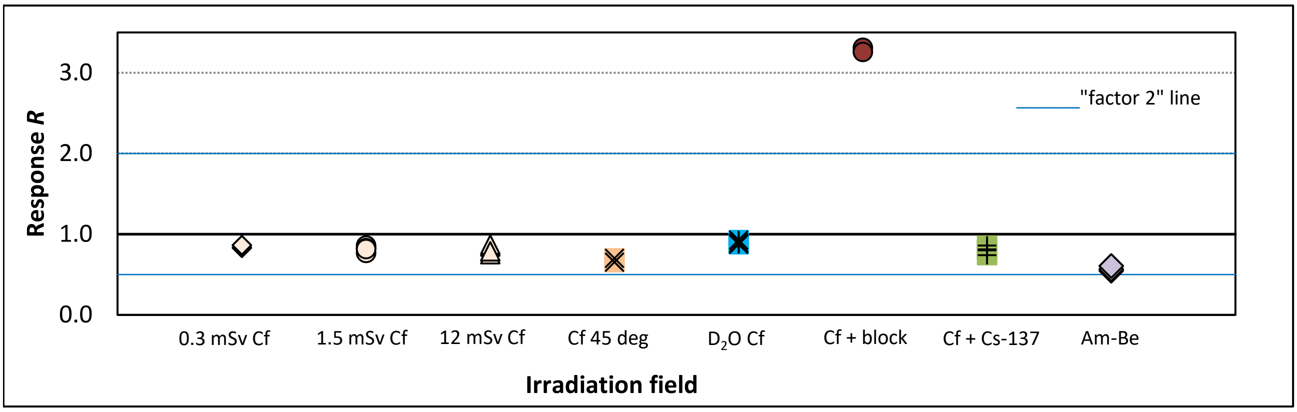


S019, dosemeter type: Albedo

Reference values reported by the irradiating laboratory			Results		
Radiation quality	Dosemeter code	$H_p(10)$ Reference value (mSv)	$H_p(10)$ Participant's value (mSv)	R Response (Participant/Reference)	OK / outlier
Cf-252; 0°	S019-2017-05	0.301	0.25	0.83	
	S019-2017-08	0.301	0.25	0.83	
	S019-2017-11	0.301	0.26	0.86	
	S019-2017-16	0.301	0.26	0.86	
	S019-2017-02	1.499	1.29	0.86	
	S019-2017-07	1.499	1.24	0.83	
	S019-2017-10	1.499	1.15	0.77	
	S019-2017-15	1.499	1.22	0.81	
	S019-2017-04	12.00	10.19	0.85	
	S019-2017-09	12.00	9.01	0.75	
	S019-2017-13	12.00	10.44	0.87	
	S019-2017-17	12.00	9.44	0.79	
Cf-252; 45°	S019-2017-01	1.499	1.05	0.70	
	S019-2017-06	1.499	0.98	0.65	
Cf-252 (D_2O); 0°	S019-2017-25	1.2	1.07	0.89	
	S019-2017-26	1.2	1.07	0.89	
	S019-2017-30	1.2	1.11	0.93	
	S019-2017-35	1.2	1.05	0.88	
Cf-252 + shadow block; 0°	S019-2017-32	1	3.31	3.31	outlier
	S019-2017-36	1	3.26	3.26	outlier
Cf-252 + Cs-137; 0°	S019-2017-28	1.5	1.20	0.80	
	S019-2017-31	1.5	1.22	0.81	
	S019-2017-34	1.5	1.11	0.74	
	S019-2017-40	1.5	1.29	0.86	
Am-Be; 0°	S019-2017-03	1.50	0.91	0.61	
	S019-2017-12	1.50	0.82	0.55	
	S019-2017-14	1.50	0.85	0.57	
	S019-2017-18	1.50	0.91	0.61	

Radiation quality	Number of values	Median of R	Mean of R
Cf-252; 0°	12	0.83	0.83
Cf-252; 45°	2	0.68	0.68
Cf-252 (D_2O); 0°	4	0.89	0.90
Cf-252 + block; 0°	2	3.29	3.29
Cf-252 + Cs-137; 0°	4	0.81	0.80
Am-Be; 0°	4	0.59	0.58
All	28	0.83	0.96

Number of outliers:	2 of 28
Fraction of outliers:	7%

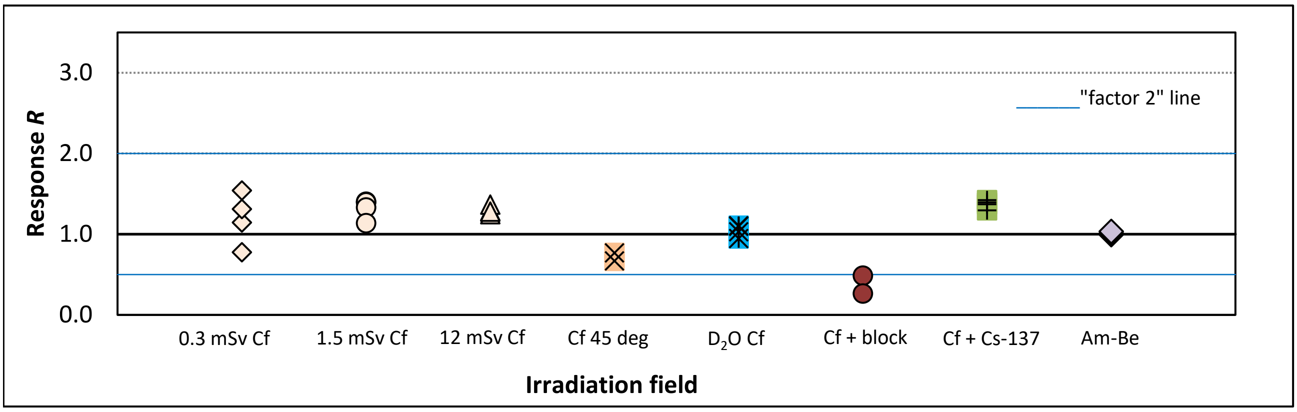


S020, dosemeter type: Track

Reference values reported by the irradiating laboratory			Results		
Radiation quality	Dosemeter code	$H_p(10)$ Reference value (mSv)	$H_p(10)$ Participant's value (mSv)	R Response (Participant/Reference)	OK / outlier
Cf-252; 0°	S020-2017-03	0.3	0.23	0.78	
	S020-2017-09	0.3	0.34	1.14	
	S020-2017-11	0.3	0.39	1.31	
	S020-2017-15	0.3	0.46	1.54	
	S020-2017-01	1.499	2.10	1.40	
	S020-2017-05	1.499	2.09	1.40	
	S020-2017-10	1.499	1.99	1.33	
	S020-2017-17	1.499	1.70	1.14	
	S020-2017-04	12.00	14.97	1.25	
	S020-2017-07	12.00	15.46	1.29	
	S020-2017-13	12.00	16.38	1.37	
	S020-2017-18	12.00	15.34	1.28	
Cf-252; 45°	S020-2017-02	1.562	1.04	0.67	
	S020-2017-14	1.562	1.20	0.77	
Cf-252 (D_2O); 0°	S020-2017-27	1.2	1.14	0.95	
	S020-2017-37	1.2	1.33	1.10	
	S020-2017-38	1.2	1.32	1.10	
	S020-2017-40	1.2	1.24	1.03	
Cf-252 + shadow block; 0°	S020-2017-26	1	0.49	0.49	outlier
	S020-2017-33	1	0.27	0.27	outlier
Cf-252 + Cs-137; 0°	S020-2017-28	1.5	2.10	1.40	
	S020-2017-29	1.5	1.95	1.30	
	S020-2017-30	1.5	2.14	1.42	
	S020-2017-39	1.5	2.06	1.37	
Am-Be; 0°	S020-2017-08	1.50	1.49	1.00	
	S020-2017-12	1.50	1.50	1.00	
	S020-2017-16	1.50	1.51	1.01	
	S020-2017-19	1.50	1.55	1.04	

Radiation quality	Number of values	Median of R	Mean of R
Cf-252; 0°	12	1.30	1.27
Cf-252; 45°	2	0.72	0.72
Cf-252 (D_2O); 0°	4	1.06	1.04
Cf-252 + block; 0°	2	0.38	0.38
Cf-252 + Cs-137; 0°	4	1.38	1.37
Am-Be; 0°	4	1.01	1.01
All	28	1.14	1.11

Number of outliers:	2 of 28
Fraction of outliers:	7%



S021, dosemeter type: Track

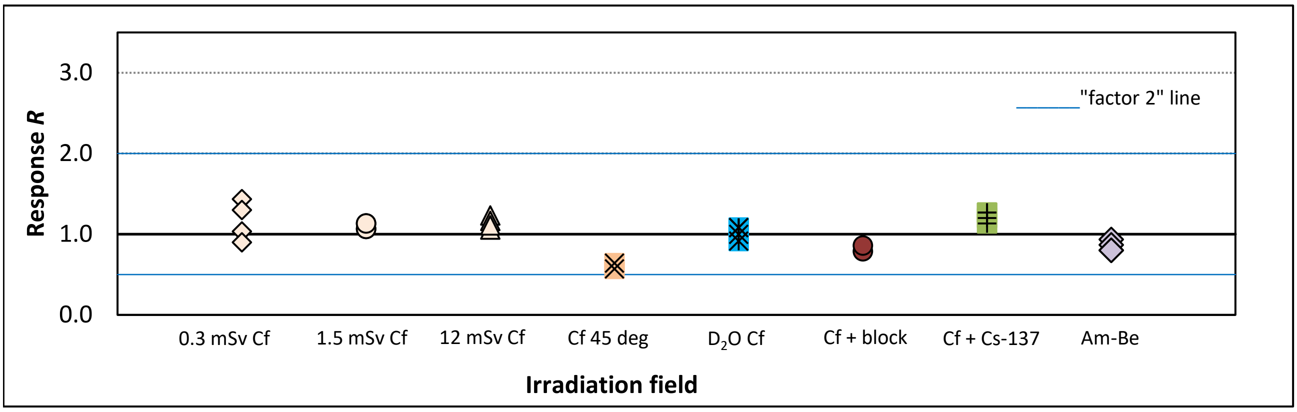
Radiation quality	Dosemeter code	$H_p(10)$ Reference value (mSv)	$H_p(10)$ Participant's value (mSv)	R Response (Participant/Reference)	OK / outlier
Cf-252; 0°	S021-2017-04	0.3	0.31	1.03	
	S021-2017-06	0.3	0.43	1.43	
	S021-2017-13	0.3	0.27	0.90	
	S021-2017-17	0.3	0.39	1.30	
	S021-2017-08	1.5	1.70	1.13	
	S021-2017-10	1.5	1.60	1.07	
	S021-2017-12	1.5	1.60	1.07	
	S021-2017-16	1.5	1.70	1.13	
	S021-2017-03	12.00	12.70	1.06	
	S021-2017-07	12.00	14.80	1.23	
	S021-2017-14	12.00	14.00	1.17	
	S021-2017-20	12.00	13.30	1.11	
Cf-252; 45°	S021-2017-02	1.562	0.89	0.57	
	S021-2017-05	1.562	1.00	0.64	
Cf-252 (D_2O); 0°	S021-2017-29	1.2	1.30	1.08	
	S021-2017-31	1.2	1.10	0.92	
	S021-2017-34	1.2	1.20	1.00	
	S021-2017-38	1.2	1.30	1.08	
Cf-252 + shadow block; 0°	S021-2017-37	1	0.79	0.79	
	S021-2017-39	1	0.86	0.86	
Cf-252 + Cs-137; 0°	S021-2017-26	1.5	1.70	1.13	
	S021-2017-30	1.5	1.90	1.27	
	S021-2017-32	1.5	1.80	1.20	
	S021-2017-33	1.5	1.90	1.27	
Am-Be; 0°	S021-2017-01	1.50	1.40	0.93	
	S021-2017-09	1.50	1.30	0.87	
	S021-2017-11	1.50	1.20	0.80	
	S021-2017-22	1.50	1.20	0.80	

The header group "Reference values reported by the irradiating laboratory" covers Radiation quality, Dosemeter code and Reference value; "Results" covers Participant's value, Response and OK / outlier.

Radiation quality	Number of values	Median of R	Mean of R
Cf-252; 0°	12	1.12	1.14
Cf-252; 45°	2	0.60	0.60
Cf-252 (D_2O); 0°	4	1.04	1.02
Cf-252 + block; 0°	2	0.83	0.83
Cf-252 + Cs-137; 0°	4	1.23	1.22
Am-Be; 0°	4	0.83	0.85
All	28	1.07	1.03

Number of outliers: 0 of 28

Fraction of outliers: 0%

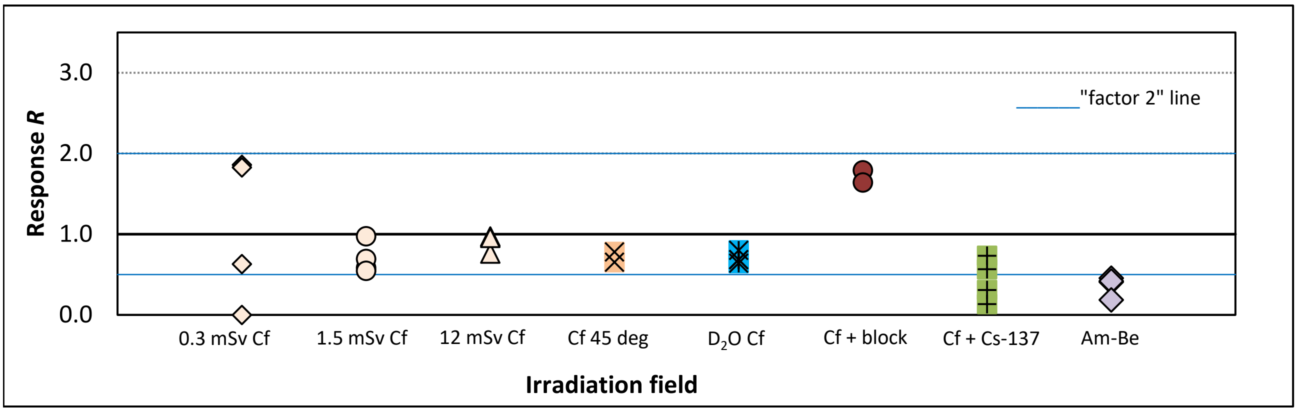


S022, dosemeter type: Track

Reference values reported by the irradiating laboratory			Results		
Radiation quality	Dosemeter code	$H_p(10)$ Reference value (mSv)	$H_p(10)$ Participant's value (mSv)	R Response (Participant/Reference)	OK / outlier
Cf-252; 0°	S022-2017-04	0.301	0.00	0.00	outlier
	S022-2017-07	0.301	0.19	0.63	
	S022-2017-14	0.301	0.56	1.86	
	S022-2017-17	0.301	0.55	1.83	
	S022-2017-03	1.499	1.46	0.97	
	S022-2017-09	1.499	0.87	0.58	
	S022-2017-12	1.499	1.04	0.69	
	S022-2017-15	1.499	0.82	0.55	
	S022-2017-05	12.00	11.63	0.97	
	S022-2017-08	12.00	9.13	0.76	
	S022-2017-11	12.00	11.63	0.97	
	S022-2017-18	12.00	11.47	0.96	
Cf-252; 45°	S022-2017-01	1.499	1.17	0.78	
	S022-2017-10	1.499	0.98	0.65	
Cf-252 (D_2O); 0°	S022-2017-29	1.2	0.77	0.64	
	S022-2017-30	1.2	0.96	0.80	
	S022-2017-37	1.2	0.82	0.68	
	S022-2017-40	1.2	0.82	0.68	
Cf-252 + shadow block; 0°	S022-2017-25	1	1.79	1.79	
	S022-2017-34	1	1.64	1.64	
Cf-252 + Cs-137; 0°	S022-2017-26	1.5	0.20	0.13	outlier
	S022-2017-31	1.5	0.46	0.31	outlier
	S022-2017-32	1.5	0.85	0.57	
	S022-2017-33	1.5	1.10	0.73	
Am-Be; 0°	S022-2017-02	1.50	0.68	0.45	outlier
	S022-2017-06	1.50	0.61	0.41	outlier
	S022-2017-13	1.50	0.63	0.42	outlier
	S022-2017-16	1.50	0.28	0.19	outlier

Radiation quality	Number of values	Median of R	Mean of R
Cf-252; 0°	12	0.86	0.90
Cf-252; 45°	2	0.72	0.72
Cf-252 (D_2O); 0°	4	0.68	0.70
Cf-252 + block; 0°	2	1.72	1.72
Cf-252 + Cs-137; 0°	4	0.44	0.44
Am-Be; 0°	4	0.41	0.37
All	28	0.68	0.77

Number of outliers:	7 of 28
Fraction of outliers:	25%

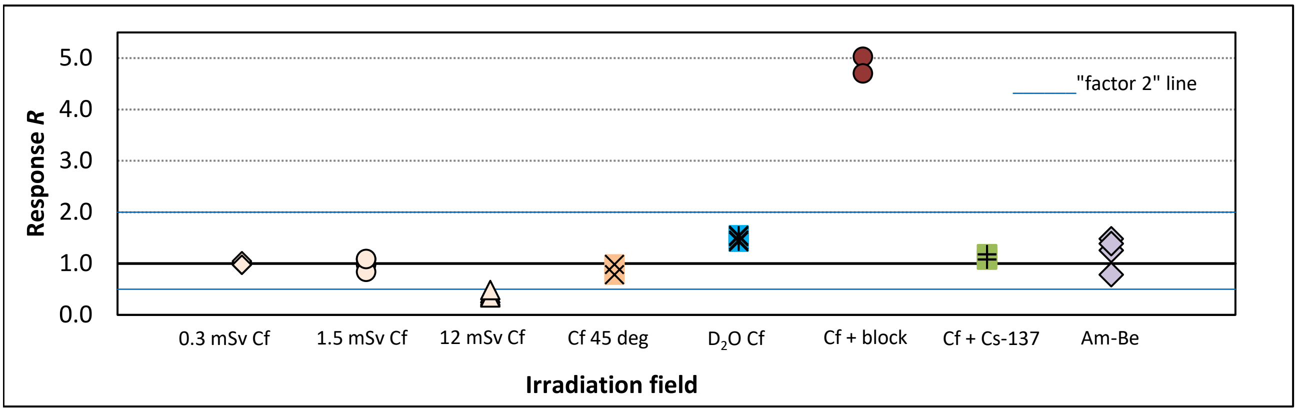


S023, dosemeter type: Track

Reference values reported by the irradiating laboratory			Results		
Radiation quality	Dosemeter code	$H_p(10)$ Reference value (mSv)	$H_p(10)$ Participant's value (mSv)	R Response (Participant/Reference)	OK / outlier
Cf-252; 0°	S023-2017-01	0.296	0.29	0.98	
	S023-2017-04	0.296	0.30	1.01	
	S023-2017-11	0.296	0.31	1.05	
	S023-2017-16	0.296	0.29	0.98	
	S023-2017-03	1.5	1.47	0.98	
	S023-2017-10	1.5	1.62	1.08	
	S023-2017-13	1.5	1.26	0.84	
	S023-2017-15	1.5	1.63	1.09	
	S023-2017-05	12.00	4.44	0.37	outlier
	S023-2017-07	12.00	5.06	0.42	outlier
	S023-2017-14	12.00	4.11	0.34	outlier
	S023-2017-17	12.00	5.78	0.48	outlier
Cf-252; 45°	S023-2017-08	1.5	1.18	0.79	
	S023-2017-09	1.5	1.47	0.98	
Cf-252 (D_2O); 0°	S023-2017-28	1.2	1.86	1.55	
	S023-2017-32	1.2	1.83	1.53	
	S023-2017-36	1.2	1.71	1.43	
	S023-2017-38	1.2	1.75	1.46	
Cf-252 + shadow block; 0°	S023-2017-26	1	5.03	5.03	outlier
	S023-2017-37	1	4.70	4.70	outlier
Cf-252 + Cs-137; 0°	S023-2017-25	1.5	1.76	1.17	
	S023-2017-27	1.5	1.77	1.18	
	S023-2017-30	1.5	1.62	1.08	
	S023-2017-34	1.5	1.61	1.07	
Am-Be; 0°	S023-2017-02	1.51	1.90	1.26	
	S023-2017-06	1.51	2.24	1.48	
	S023-2017-12	1.51	1.18	0.78	
	S023-2017-18	1.51	2.10	1.39	

Radiation quality	Number of values	Median of R	Mean of R
Cf-252; 0°	12	0.98	0.80
Cf-252; 45°	2	0.88	0.88
Cf-252 (D_2O); 0°	4	1.49	1.49
Cf-252 + block; 0°	2	4.87	4.87
Cf-252 + Cs-137; 0°	4	1.13	1.13
Am-Be; 0°	4	1.32	1.23
All	28	1.08	1.30

Number of outliers:	6 of 28
Fraction of outliers:	21%

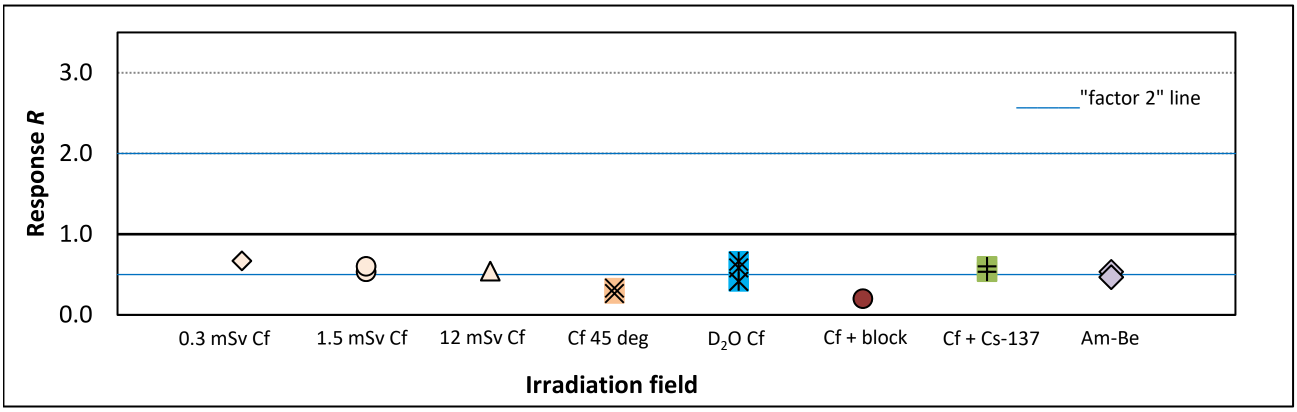


S024, dosemeter type: Track

Reference values reported by the irradiating laboratory			Results		
Radiation quality	Dosemeter code	$H_p(10)$ Reference value (mSv)	$H_p(10)$ Participant's value (mSv)	R Response (Participant/Reference)	OK / outlier
Cf-252; 0°	S024-2017-02	0.299	0.20	0.67	
	S024-2017-04	0.299	0.20	0.67	
	S024-2017-07	0.299	0.20	0.67	
	S024-2017-12	0.299	0.20	0.67	
	S024-2017-05	1.499	0.80	0.53	
	S024-2017-09	1.499	0.90	0.60	
	S024-2017-13	1.499	0.80	0.53	
	S024-2017-18	1.499	0.90	0.60	
	S024-2017-01	12.00	6.50	0.54	
	S024-2017-06	12.00	6.50	0.54	
	S024-2017-11	12.00	6.50	0.54	
	S024-2017-16	12.00	6.50	0.54	
Cf-252; 45°	S024-2017-15	1.5	0.50	0.33	outlier
	S024-2017-23	1.5	0.40	0.27	outlier
Cf-252 (D_2O); 0°	S024-2017-25	1.2	0.70	0.58	
	S024-2017-29	1.2	0.80	0.67	
	S024-2017-30	1.2	0.50	0.42	outlier
	S024-2017-34	1.2	0.50	0.42	outlier
Cf-252 + shadow block; 0°	S024-2017-26	1	0.20	0.20	outlier
	S024-2017-33	1	0.20	0.20	outlier
Cf-252 + Cs-137; 0°	S024-2017-27	1.5	0.90	0.60	
	S024-2017-31	1.5	0.80	0.53	
	S024-2017-32	1.5	0.90	0.60	
	S024-2017-35	1.5	0.80	0.53	
Am-Be; 0°	S024-2017-03	1.50	0.80	0.53	
	S024-2017-08	1.50	0.70	0.47	outlier
	S024-2017-10	1.50	0.70	0.47	outlier
	S024-2017-14	1.50	0.70	0.47	outlier

Radiation quality	Number of values	Median of R	Mean of R
Cf-252; 0°	12	0.57	0.59
Cf-252; 45°	2	0.30	0.30
Cf-252 (D_2O); 0°	4	0.50	0.52
Cf-252 + block; 0°	2	0.20	0.20
Cf-252 + Cs-137; 0°	4	0.57	0.57
Am-Be; 0°	4	0.47	0.48
All	28	0.54	0.51

Number of outliers:	9 of 28
Fraction of outliers:	32%

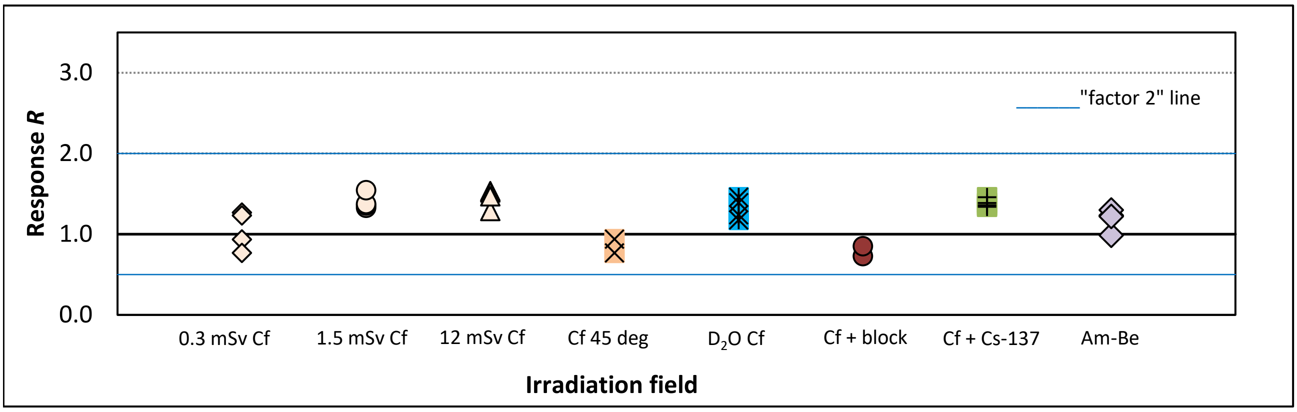


S025, dosemeter type: Track

Reference values reported by the irradiating laboratory			Results		
Radiation quality	Dosemeter code	$H_p(10)$ Reference value (mSv)	$H_p(10)$ Participant's value (mSv)	R Response (Participant/Reference)	OK / outlier
Cf-252; 0°	S025-2017-02	0.3	0.28	0.93	
	S025-2017-08	0.3	0.23	0.77	
	S025-2017-15	0.3	0.38	1.27	
	S025-2017-17	0.3	0.37	1.23	
	S025-2017-03	1.5	1.99	1.33	
	S025-2017-05	1.5	2.03	1.35	
	S025-2017-09	1.5	2.06	1.37	
	S025-2017-18	1.5	2.32	1.55	
	S025-2017-01	12.00	18.42	1.54	
	S025-2017-12	12.00	15.44	1.29	
	S025-2017-16	12.00	18.21	1.52	
	S025-2017-20	12.00	17.66	1.47	
Cf-252; 45°	S025-2017-04	1.5	1.41	0.94	
	S025-2017-07	1.5	1.15	0.77	
Cf-252 (D_2O); 0°	S025-2017-26	1.2	1.75	1.46	
	S025-2017-31	1.2	1.41	1.18	
	S025-2017-34	1.2	1.49	1.24	
	S025-2017-36	1.2	1.67	1.39	
Cf-252 + shadow block; 0°	S025-2017-37	1	0.73	0.73	
	S025-2017-39	1	0.85	0.85	
Cf-252 + Cs-137; 0°	S025-2017-27	1.5	2.01	1.34	
	S025-2017-32	1.5	2.19	1.46	
	S025-2017-35	1.5	2.08	1.39	
	S025-2017-38	1.5	2.04	1.36	
Am-Be; 0°	S025-2017-06	1.50	1.48	0.99	
	S025-2017-10	1.50	1.85	1.23	
	S025-2017-13	1.50	1.95	1.30	
	S025-2017-21	1.50	1.83	1.22	

Radiation quality	Number of values	Median of R	Mean of R
Cf-252; 0°	12	1.34	1.30
Cf-252; 45°	2	0.85	0.85
Cf-252 (D_2O); 0°	4	1.32	1.32
Cf-252 + block; 0°	2	0.79	0.79
Cf-252 + Cs-137; 0°	4	1.37	1.39
Am-Be; 0°	4	1.23	1.19
All	28	1.29	1.23

Number of outliers:	0 of 28
Fraction of outliers:	0%

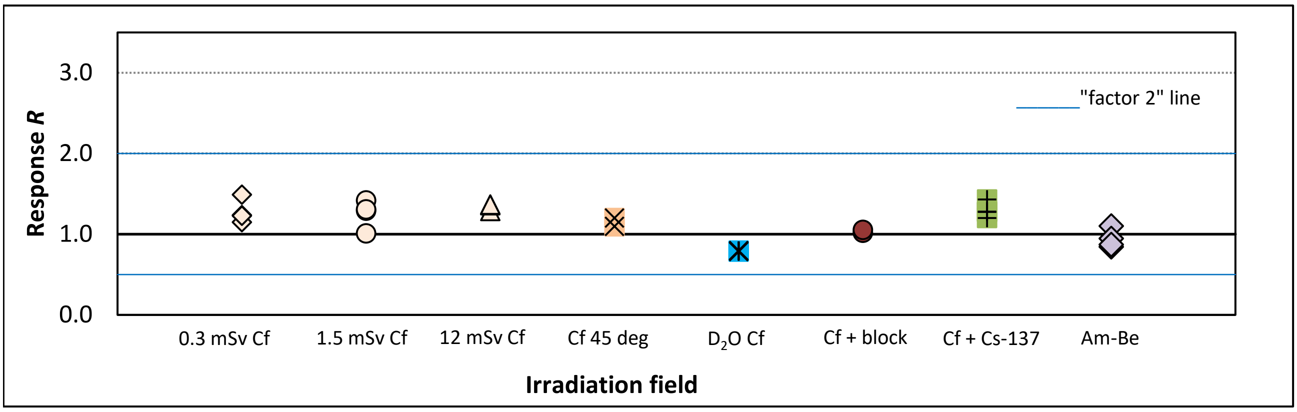


S026, dosemeter type: Albedo

Radiation quality	Dosemeter code	$H_p(10)$ Reference value (mSv)	$H_p(10)$ Participant's value (mSv)	R Response (Participant/Reference)	OK / outlier
Reference values reported by the irradiating laboratory			Results		
Cf-252; 0°	S026-2017-02	0.3	0.45	1.49	
	S026-2017-09	0.3	0.35	1.15	
	S026-2017-15	0.3	0.37	1.24	
	S026-2017-18	0.3	0.37	1.23	
	S026-2017-04	1.5	2.13	1.42	
	S026-2017-08	1.5	1.51	1.01	
	S026-2017-13	1.5	1.94	1.29	
	S026-2017-16	1.5	1.96	1.31	
	S026-2017-01	12.00	15.44	1.29	
	S026-2017-05	12.00	16.32	1.36	
	S026-2017-11	12.00	16.42	1.37	
	S026-2017-22	12.00	16.42	1.37	
Cf-252; 45°	S026-2017-06	1.499	1.80	1.20	
	S026-2017-17	1.499	1.64	1.10	
Cf-252 (D_2O); 0°	S026-2017-25	1.2	0.94	0.79	
	S026-2017-26	1.2	0.96	0.80	
	S026-2017-38	1.2	0.95	0.79	
	S026-2017-39	1.2	0.95	0.80	
Cf-252 + shadow block; 0°	S026-2017-29	1	1.02	1.02	
	S026-2017-35	1	1.05	1.05	
Cf-252 + Cs-137; 0°	S026-2017-27	1.5	1.92	1.28	
	S026-2017-28	1.5	1.80	1.20	
	S026-2017-36	1.5	1.92	1.28	
	S026-2017-37	1.5	2.15	1.43	
Am-Be; 0°	S026-2017-07	1.55	1.31	0.84	
	S026-2017-10	1.55	1.71	1.10	
	S026-2017-14	1.55	1.47	0.95	
	S026-2017-20	1.55	1.35	0.87	

Radiation quality	Number of values	Median of R	Mean of R
Cf-252; 0°	12	1.30	1.29
Cf-252; 45°	2	1.15	1.15
Cf-252 (D_2O); 0°	4	0.79	0.79
Cf-252 + block; 0°	2	1.04	1.04
Cf-252 + Cs-137; 0°	4	1.28	1.30
Am-Be; 0°	4	0.91	0.94
All	28	1.20	1.14

Number of outliers:	0 of 28
Fraction of outliers:	0%



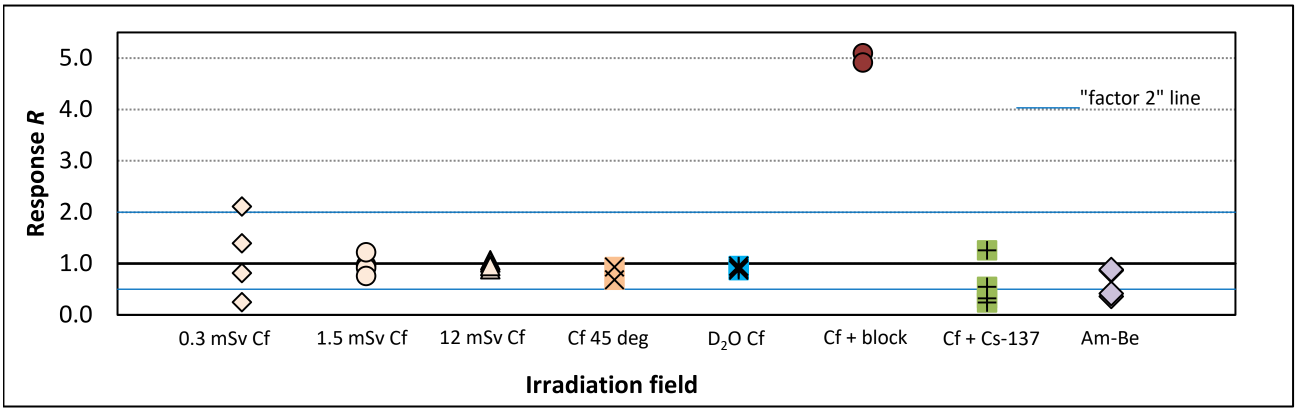
S027, dosemeter type: Albedo

Radiation quality	Dosemeter code	$H_p(10)$ Reference value (mSv)	$H_p(10)$ Participant's value (mSv)	R Response (Participant/Reference)	OK / outlier
Cf-252; 0°	S0272017-01	0.3	0.24	0.81	
	S0272017-05	0.3	0.08	0.25	outlier
	S0272017-08	0.3	0.63	2.11	outlier
	S0272017-18	0.3	0.42	1.39	
	S0272017-04	1.5	1.46	0.97	
	S0272017-09	1.5	1.37	0.91	
	S0272017-13	1.5	1.83	1.22	
	S0272017-15	1.5	1.14	0.76	
	S0272017-02	12.00	12.75	1.06	
	S0272017-06	12.00	12.21	1.02	
	S0272017-12	12.00	10.64	0.89	
	S0272017-14	12.00	11.43	0.95	
Cf-252; 45°	S0272017-07	1.5	1.02	0.68	
	S0272017-10	1.5	1.40	0.93	
Cf-252 (D_2O); 0°	S027-2017-28	1.2	1.04	0.87	
	S027-2017-29	1.2	1.14	0.95	
	S027-2017-34	1.2	1.13	0.94	
	S027-2017-35	1.2	1.09	0.91	
Cf-252 + shadow block; 0°	S027-2017-26	1	5.10	5.10	outlier
	S027-2017-27	1	4.92	4.92	outlier
Cf-252 + Cs-137; 0°	S027-2017-25	1.5	0.82	0.55	
	S027-2017-30	1.5	0.48	0.32	outlier
	S027-2017-31	1.5	1.89	1.26	
	S027-2017-32	1.5	0.36	0.24	outlier
Am-Be; 0°	S0272017-03	1.55	0.56	0.36	outlier
	S0272017-11	1.55	0.65	0.42	outlier
	S0272017-16	1.55	1.34	0.86	
	S0272017-17	1.55	1.37	0.88	

Radiation quality	Number of values	Median of R	Mean of R
Cf-252; 0°	12	0.96	1.03
Cf-252; 45°	2	0.81	0.81
Cf-252 (D_2O); 0°	4	0.92	0.92
Cf-252 + block; 0°	2	5.01	5.01
Cf-252 + Cs-137; 0°	4	0.43	0.59
Am-Be; 0°	4	0.64	0.63
All	28	0.91	1.16

Number of outliers: 8 of 28

Fraction of outliers: 29%

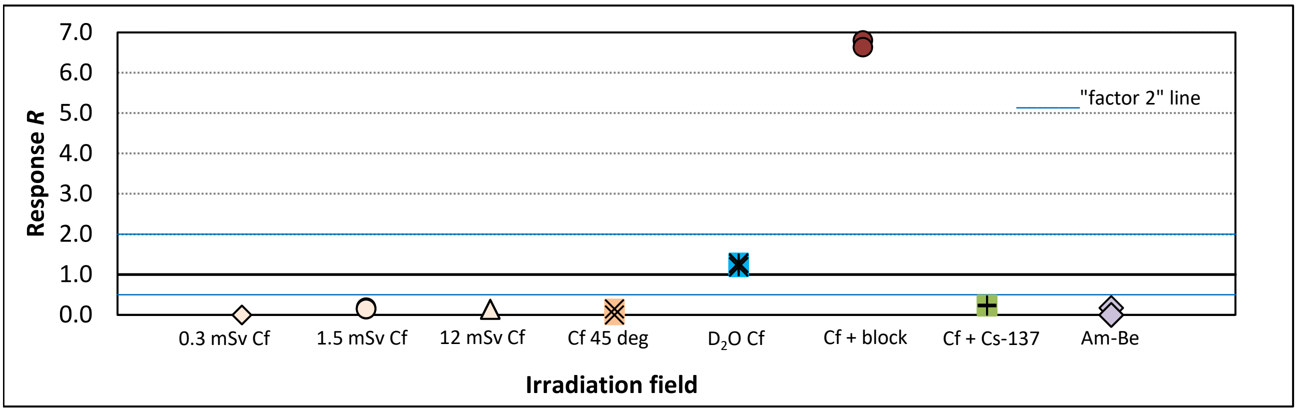


S028, dosemeter type: Albedo

Reference values reported by the irradiating laboratory			Results		
Radiation quality	Dosemeter code	$H_p(10)$ Reference value (mSv)	$H_p(10)$ Participant's value (mSv)	R Response (Participant/Reference)	OK / outlier
Cf-252; 0°	S028-2017-06	0.3	0.00	0.00	outlier
	S028-2017-09	0.3	0.00	0.00	outlier
	S028-2017-16	0.3	0.00	0.00	outlier
	S028-2017-18	0.3	0.00	0.00	outlier
	S028-2017-01	1.5	0.27	0.18	outlier
	S028-2017-05	1.5	0.21	0.14	outlier
	S028-2017-10	1.5	0.23	0.15	outlier
	S028-2017-15	1.5	0.23	0.15	outlier
	S028-2017-03	12.00	1.63	0.14	outlier
	S028-2017-13	12.00	1.76	0.15	outlier
	S028-2017-17	12.00	1.68	0.14	outlier
	S028-2017-20	12.00	1.59	0.13	outlier
Cf-252; 45°	S028-2017-04	1.499	0.22	0.15	outlier
	S028-2017-07	1.499	0.00	0.00	outlier
Cf-252 (D_2O); 0°	S028-2017-27	1.2	1.42	1.19	
	S028-2017-29	1.2	1.55	1.29	
	S028-2017-32	1.2	1.52	1.27	
	S028-2017-33	1.2	1.43	1.20	
Cf-252 + shadow block; 0°	S028-2017-31	1	6.80	6.80	outlier
	S028-2017-35	1	6.64	6.64	outlier
Cf-252 + Cs-137; 0°	S028-2017-25	1.5	0.32	0.21	outlier
	S028-2017-28	1.5	0.37	0.25	outlier
	S028-2017-34	1.5	0.38	0.25	outlier
	S028-2017-36	1.5	0.35	0.23	outlier
Am-Be; 0°	S028-2017-02	1.50	0.26	0.18	outlier
	S028-2017-12	1.50	0.00	0.00	outlier
	S028-2017-14	1.50	0.00	0.00	outlier
	S028-2017-19	1.50	0.00	0.00	outlier

Radiation quality	Number of values	Median of R	Mean of R
Cf-252; 0°	12	0.14	0.10
Cf-252; 45°	2	0.07	0.07
Cf-252 (D_2O); 0°	4	1.23	1.23
Cf-252 + block; 0°	2	6.72	6.72
Cf-252 + Cs-137; 0°	4	0.24	0.24
Am-Be; 0°	4	0.00	0.04
All	28	0.15	0.74

Number of outliers:	24 of 28
Fraction of outliers:	86%

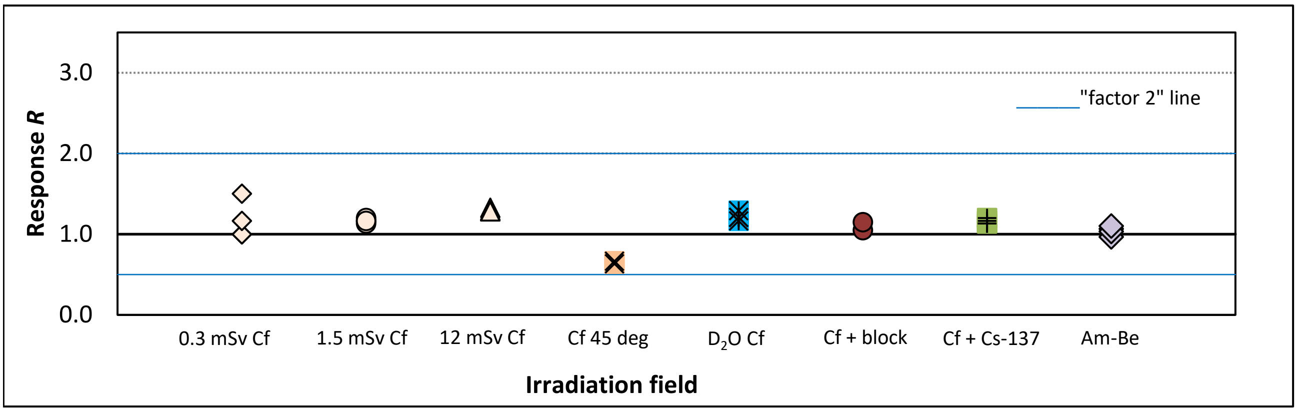


S029, dosemeter type: Track

Reference values reported by the irradiating laboratory			Results		
Radiation quality	Dosemeter code	$H_p(10)$ Reference value (mSv)	$H_p(10)$ Participant's value (mSv)	R Response (Participant/Reference)	OK / outlier
Cf-252; 0°	S029-2017-01	0.3	0.30	1.00	
	S029-2017-09	0.3	0.45	1.50	
	S029-2017-14	0.3	0.30	1.00	
	S029-2017-17	0.3	0.35	1.17	
	S029-2017-02	1.5	1.75	1.17	
	S029-2017-06	1.5	1.80	1.20	
	S029-2017-08	1.5	1.70	1.13	
	S029-2017-11	1.5	1.75	1.17	
	S029-2017-04	12.00	15.55	1.30	
	S029-2017-07	12.00	15.95	1.33	
	S029-2017-12	12.00	15.40	1.28	
	S029-2017-15	12.00	15.40	1.28	
Cf-252; 45°	S029-2017-10	1.5	0.95	0.63	
	S029-2017-16	1.5	1.00	0.67	
Cf-252 (D_2O); 0°	S029-2017-30	1.2	1.45	1.21	
	S029-2017-35	1.2	1.40	1.17	
	S029-2017-37	1.2	1.55	1.29	
	S029-2017-40	1.2	1.45	1.21	
Cf-252 + shadow block; 0°	S029-2017-28	1	1.05	1.05	
	S029-2017-33	1	1.15	1.15	
Cf-252 + Cs-137; 0°	S029-2017-25	1.5	1.70	1.13	
	S029-2017-31	1.5	1.80	1.20	
	S029-2017-32	1.5	1.70	1.13	
	S029-2017-38	1.5	1.75	1.17	
Am-Be; 0°	S029-2017-03	1.50	1.60	1.07	
	S029-2017-05	1.50	1.45	0.97	
	S029-2017-18	1.50	1.55	1.03	
	S029-2017-21	1.50	1.65	1.10	

Radiation quality	Number of values	Median of R	Mean of R
Cf-252; 0°	12	1.18	1.21
Cf-252; 45°	2	0.65	0.65
Cf-252 (D_2O); 0°	4	1.21	1.22
Cf-252 + block; 0°	2	1.10	1.10
Cf-252 + Cs-137; 0°	4	1.15	1.16
Am-Be; 0°	4	1.05	1.04
All	28	1.17	1.13

Number of outliers:	0 of 28
Fraction of outliers:	0%

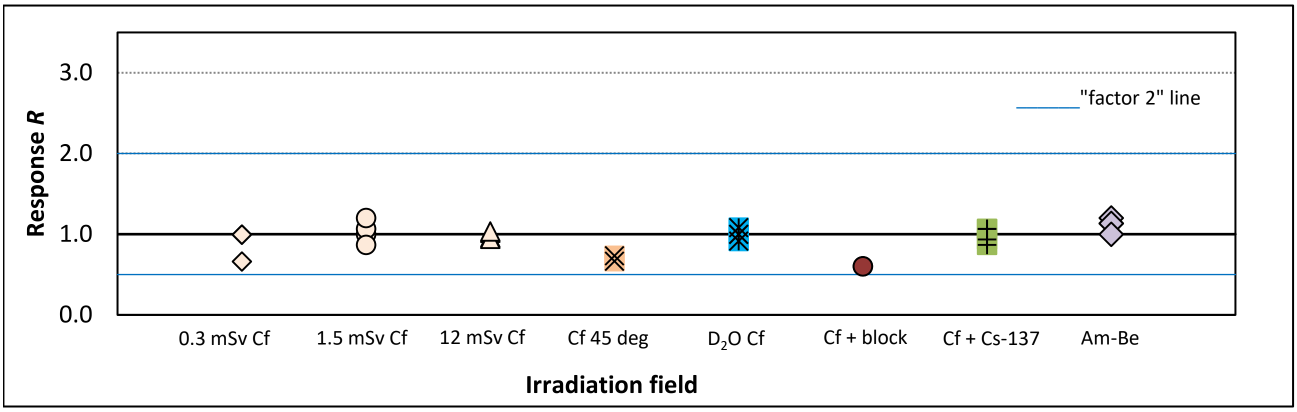


S030, dosemeter type: Track

Reference values reported by the irradiating laboratory			Results		
Radiation quality	Dosemeter code	$H_p(10)$ Reference value (mSv)	$H_p(10)$ Participant's value (mSv)	R Response (Participant/Reference)	OK / outlier
Cf-252; 0°	S030-2017-04	0.302	0.20	0.66	
	S030-2017-09	0.302	0.30	0.99	
	S030-2017-13	0.302	0.30	0.99	
	S030-2017-16	0.302	0.30	0.99	
	S030-2017-01	1.5	1.50	1.00	
	S030-2017-07	1.5	1.60	1.07	
	S030-2017-10	1.5	1.80	1.20	
	S030-2017-18	1.5	1.30	0.87	
	S030-2017-03	12.00	11.50	0.96	
	S030-2017-08	12.00	12.20	1.02	
	S030-2017-11	12.00	11.30	0.94	
	S030-2017-17	12.00	12.40	1.03	
Cf-252; 45°	S030-2017-02	1.5	1.10	0.73	
	S030-2017-06	1.5	1.00	0.67	
Cf-252 (D_2O); 0°	S030-2017-36	1.2	1.30	1.08	
	S030-2017-37	1.2	1.10	0.92	
	S030-2017-38	1.2	1.20	1.00	
	S030-2017-39	1.2	1.20	1.00	
Cf-252 + shadow block; 0°	S030-2017-27	1	0.60	0.60	
	S030-2017-32	1	0.60	0.60	
Cf-252 + Cs-137; 0°	S030-2017-25	1.5	1.40	0.93	
	S030-2017-28	1.5	1.60	1.07	
	S030-2017-33	1.5	1.30	0.87	
	S030-2017-40	1.5	1.60	1.07	
Am-Be; 0°	S030-2017-05	1.50	1.70	1.13	
	S030-2017-12	1.50	1.80	1.20	
	S030-2017-15	1.50	1.70	1.13	
	S030-2017-21	1.50	1.50	1.00	

Radiation quality	Number of values	Median of R	Mean of R
Cf-252; 0°	12	0.99	0.98
Cf-252; 45°	2	0.70	0.70
Cf-252 (D_2O); 0°	4	1.00	1.00
Cf-252 + block; 0°	2	0.60	0.60
Cf-252 + Cs-137; 0°	4	1.00	0.98
Am-Be; 0°	4	1.13	1.12
All	28	1.00	0.95

Number of outliers:	0 of 28
Fraction of outliers:	0%

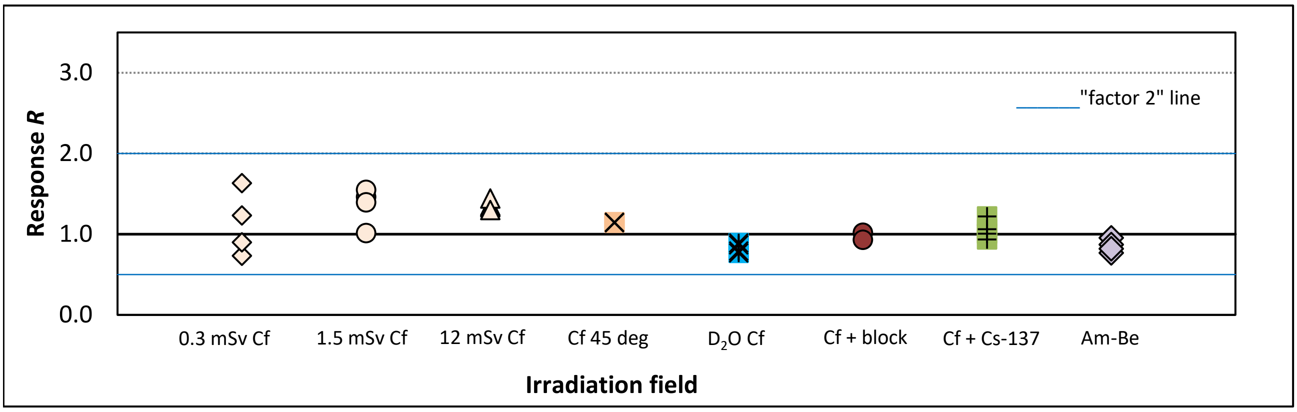


S031, dosemeter type: Albedo

Reference values reported by the irradiating laboratory			Results		
Radiation quality	Dosemeter code	$H_p(10)$ Reference value (mSv)	$H_p(10)$ Participant's value (mSv)	R Response (Participant/Reference)	OK / outlier
Cf-252; 0°	S031-2017-02	0.3	0.49	1.63	
	S031-2017-07	0.3	0.22	0.73	
	S031-2017-10	0.3	0.37	1.23	
	S031-2017-14	0.3	0.27	0.90	
	S031-2017-01	1.499	2.19	1.46	
	S031-2017-05	1.499	2.32	1.55	
	S031-2017-09	1.499	2.09	1.39	
	S031-2017-18	1.499	1.52	1.01	
	S031-2017-04	12.00	16.20	1.35	
	S031-2017-08	12.00	16.00	1.33	
	S031-2017-11	12.00	17.30	1.44	
	S031-2017-15	12.00	15.60	1.30	
Cf-252; 45°	S031-2017-06	1.499	1.72	1.15	
	S031-2017-17	1.499	1.71	1.14	
Cf-252 (D_2O); 0°	S031-2017-32	1.2	1.07	0.89	
	S031-2017-34	1.2	1.04	0.87	
	S031-2017-37	1.2	0.92	0.77	
	S031-2017-38	1.2	0.95	0.79	
Cf-252 + shadow block; 0°	S031-2017-31	1	1.02	1.02	
	S031-2017-39	1	0.93	0.93	
Cf-252 + Cs-137; 0°	S031-2017-28	1.5	1.83	1.22	
	S031-2017-29	1.5	1.59	1.06	
	S031-2017-30	1.5	1.40	0.93	
	S031-2017-33	1.5	1.51	1.01	
Am-Be; 0°	S031-2017-03	1.50	1.43	0.95	
	S031-2017-12	1.50	1.31	0.87	
	S031-2017-16	1.50	1.15	0.77	
	S031-2017-22	1.50	1.23	0.82	

Radiation quality	Number of values	Median of R	Mean of R
Cf-252; 0°	12	1.34	1.28
Cf-252; 45°	2	1.14	1.14
Cf-252 (D_2O); 0°	4	0.83	0.83
Cf-252 + block; 0°	2	0.98	0.98
Cf-252 + Cs-137; 0°	4	1.03	1.06
Am-Be; 0°	4	0.85	0.85
All	28	1.02	1.09

Number of outliers:	0 of 28
Fraction of outliers:	0%



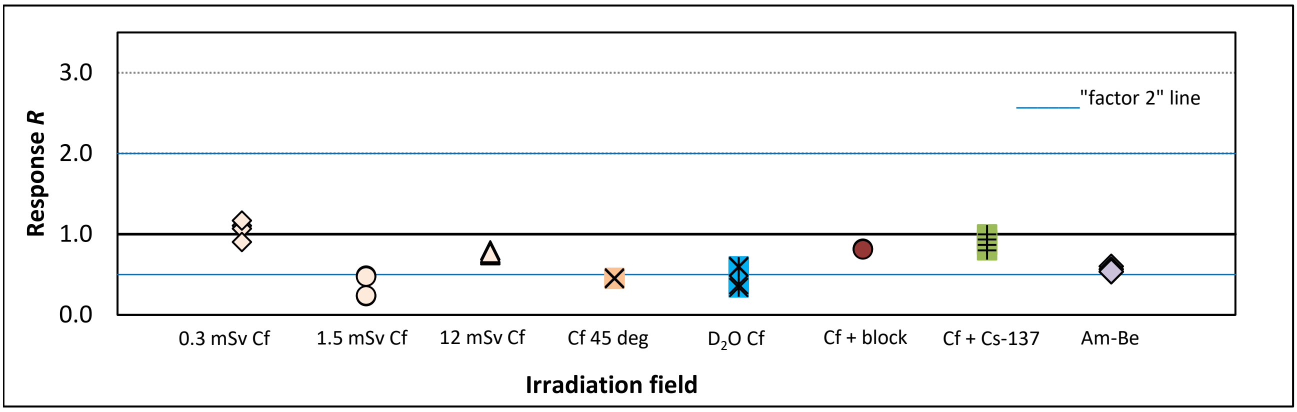
S032, dosemeter type: Track

Reference values reported by the irradiating laboratory			Results		
Radiation quality	Dosemeter code	$H_p(10)$ Reference value (mSv)	$H_p(10)$ Participant's value (mSv)	R Response (Participant/Reference)	OK / outlier
Cf-252; 0°	S032-2017-02	0.299	0.33	1.10	
	S032-2017-07	0.299	0.32	1.07	
	S032-2017-15	0.299	0.35	1.17	
	S032-2017-18	0.299	0.27	0.90	
	S032-2017-01	1.5	0.35	0.23	outlier
	S032-2017-04	1.5	0.36	0.24	outlier
	S032-2017-08	1.5	0.73	0.49	outlier
	S032-2017-11	1.5	0.71	0.47	outlier
	S032-2017-05	12.00	9.60	0.80	
	S032-2017-10	12.00	8.90	0.74	
	S032-2017-12	12.00	9.10	0.76	
	S032-2017-17	12.00	9.20	0.77	
Cf-252; 45°	S032-2017-03	1.5	0.67	0.45	outlier
	S032-2017-09	1.5	0.69	0.46	outlier
Cf-252 (D_2O); 0°	S032-2017-26	1.2	0.71	0.59	
	S032-2017-28	1.2	0.45	0.38	outlier
	S032-2017-32	1.2	0.41	0.34	outlier
	S032-2017-35	1.2	0.72	0.60	
Cf-252 + shadow block; 0°	S032-2017-31	1	0.82	0.82	
	S032-2017-33	1	0.81	0.81	
Cf-252 + Cs-137; 0°	S032-2017-27	1.5	1.20	0.80	
	S032-2017-29	1.5	1.50	1.00	
	S032-2017-30	1.5	1.40	0.93	
	S032-2017-37	1.5	1.30	0.87	
Am-Be; 0°	S032-2017-06	1.50	0.90	0.60	
	S032-2017-13	1.50	0.85	0.57	
	S032-2017-16	1.50	0.80	0.53	
	S032-2017-21	1.50	0.81	0.54	

Radiation quality	Number of values	Median of R	Mean of R
Cf-252; 0°	12	0.76	0.73
Cf-252; 45°	2	0.45	0.45
Cf-252 (D_2O); 0°	4	0.48	0.48
Cf-252 + block; 0°	2	0.82	0.82
Cf-252 + Cs-137; 0°	4	0.90	0.90
Am-Be; 0°	4	0.55	0.56
All	28	0.67	0.68

Number of outliers: 8 of 28

Fraction of outliers: 29%

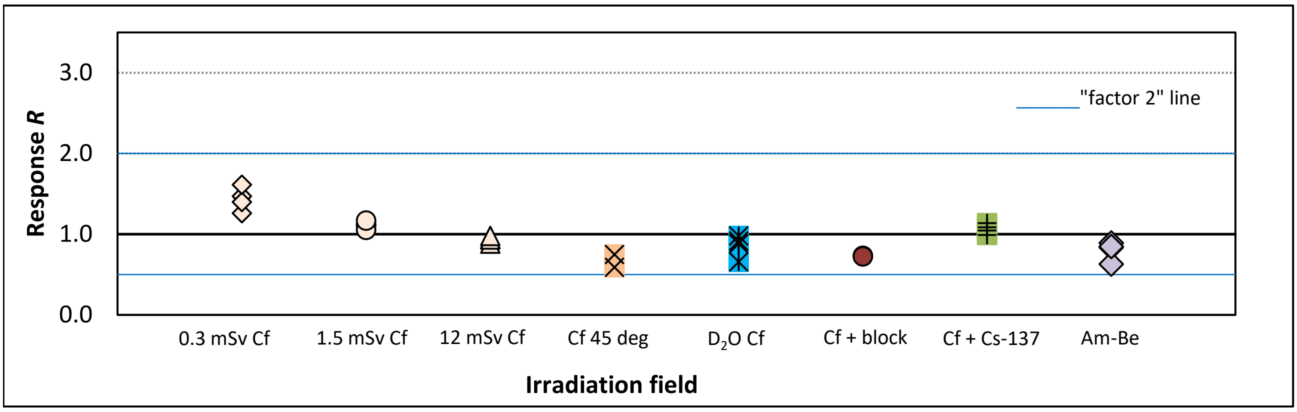


S034, dosemeter type: Track

Reference values reported by the irradiating laboratory			Results		
Radiation quality	Dosemeter code	$H_p(10)$ Reference value (mSv)	$H_p(10)$ Participant's value (mSv)	R Response (Participant/Reference)	OK / outlier
Cf-252; 0°	S034-2017-03	0.3	0.38	1.26	
	S034-2017-08	0.3	0.44	1.47	
	S034-2017-10	0.3	0.42	1.40	
	S034-2017-14	0.3	0.48	1.61	
	S034-2017-02	1.5	1.66	1.11	
	S034-2017-07	1.5	1.68	1.12	
	S034-2017-11	1.5	1.58	1.06	
	S034-2017-16	1.5	1.75	1.17	
	S034-2017-05	12.00	11.29	0.94	
	S034-2017-09	12.00	10.59	0.88	
	S034-2017-13	12.00	11.20	0.93	
	S034-2017-17	12.00	11.72	0.98	
Cf-252; 45°	S034-2017-04	1.499	1.12	0.75	
	S034-2017-12	1.499	0.88	0.59	
Cf-252 (D_2O); 0°	S034-2017-25	1.2	1.06	0.88	
	S034-2017-30	1.2	1.10	0.92	
	S034-2017-31	1.2	0.79	0.66	
	S034-2017-35	1.2	1.17	0.98	
Cf-252 + shadow block; 0°	S034-2017-32	1	0.73	0.73	
	S034-2017-37	1	0.73	0.73	
Cf-252 + Cs-137; 0°	S034-2017-26	1.5	1.71	1.14	
	S034-2017-27	1.5	1.57	1.04	
	S034-2017-33	1.5	1.63	1.09	
	S034-2017-36	1.5	1.49	0.99	
Am-Be; 0°	S034-2017-01	1.50	1.26	0.84	
	S034-2017-06	1.50	1.34	0.89	
	S034-2017-15	1.50	0.95	0.63	
	S034-2017-18	1.50	1.27	0.85	

Radiation quality	Number of values	Median of R	Mean of R
Cf-252; 0°	12	1.11	1.16
Cf-252; 45°	2	0.67	0.67
Cf-252 (D_2O); 0°	4	0.90	0.86
Cf-252 + block; 0°	2	0.73	0.73
Cf-252 + Cs-137; 0°	4	1.07	1.07
Am-Be; 0°	4	0.84	0.80
All	28	0.96	0.99

Number of outliers:	0 of 28
Fraction of outliers:	0%

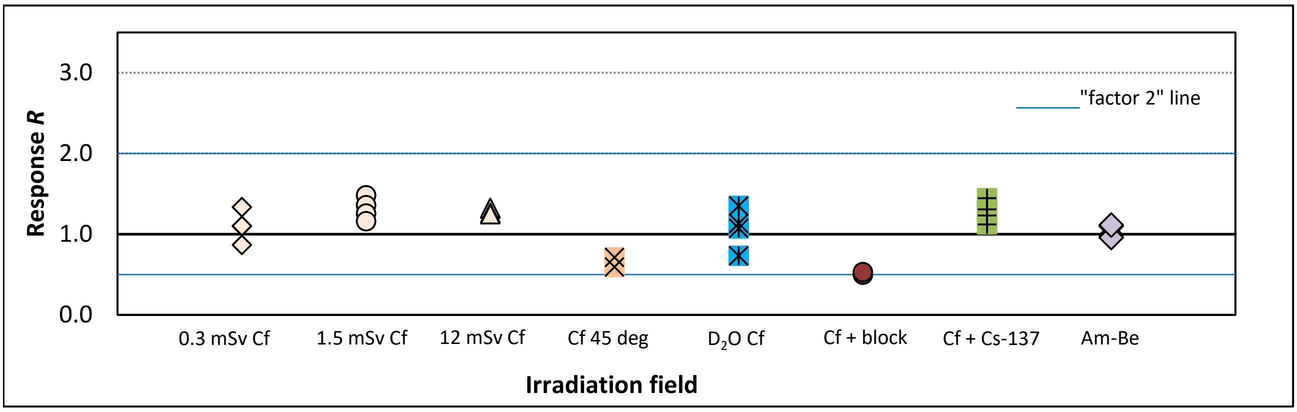


S036, dosemeter type: Track

Reference values reported by the irradiating laboratory			Results		
Radiation quality	Dosemeter code	$H_p(10)$ Reference value (mSv)	$H_p(10)$ Participant's value (mSv)	R Response (Participant/Reference)	OK / outlier
Cf-252; 0°	S036-2017-01	0.3	0.26	0.87	
	S036-2017-06	0.3	0.33	1.10	
	S036-2017-10	0.3	0.40	1.33	
	S036-2017-15	0.3	0.33	1.10	
	S036-2017-02	1.499	2.22	1.48	
	S036-2017-07	1.499	2.04	1.36	
	S036-2017-12	1.499	1.88	1.25	
	S036-2017-16	1.499	1.74	1.16	
	S036-2017-08	12.00	15.80	1.32	
	S036-2017-13	12.00	15.91	1.33	
	S036-2017-18	12.00	15.19	1.27	
	S036-2017-22	12.00	15.00	1.25	
Cf-252; 45°	S036-2017-04	1.5	0.89	0.59	
	S036-2017-09	1.5	1.07	0.71	
Cf-252 (D_2O); 0°	S036-2017-26	1.2	1.29	1.08	
	S036-2017-28	1.2	1.36	1.13	
	S036-2017-33	1.2	0.88	0.73	
	S036-2017-38	1.2	1.62	1.35	
Cf-252 + shadow block; 0°	S036-2017-29	1	0.50	0.50	
	S036-2017-34	1	0.53	0.53	
Cf-252 + Cs-137; 0°	S036-2017-27	1.5	2.17	1.45	
	S036-2017-31	1.5	1.85	1.23	
	S036-2017-32	1.5	1.68	1.12	
	S036-2017-39	1.5	1.96	1.31	
Am-Be; 0°	S036-2017-03	1.50	1.48	0.99	
	S036-2017-11	1.50	1.65	1.10	
	S036-2017-14	1.50	1.44	0.96	
	S036-2017-17	1.50	1.67	1.11	

Radiation quality	Number of values	Median of R	Mean of R
Cf-252; 0°	12	1.26	1.23
Cf-252; 45°	2	0.65	0.65
Cf-252 (D_2O); 0°	4	1.10	1.07
Cf-252 + block; 0°	2	0.52	0.52
Cf-252 + Cs-137; 0°	4	1.27	1.28
Am-Be; 0°	4	1.04	1.04
All	28	1.13	1.10

Number of outliers:	0 of 28
Fraction of outliers:	0%

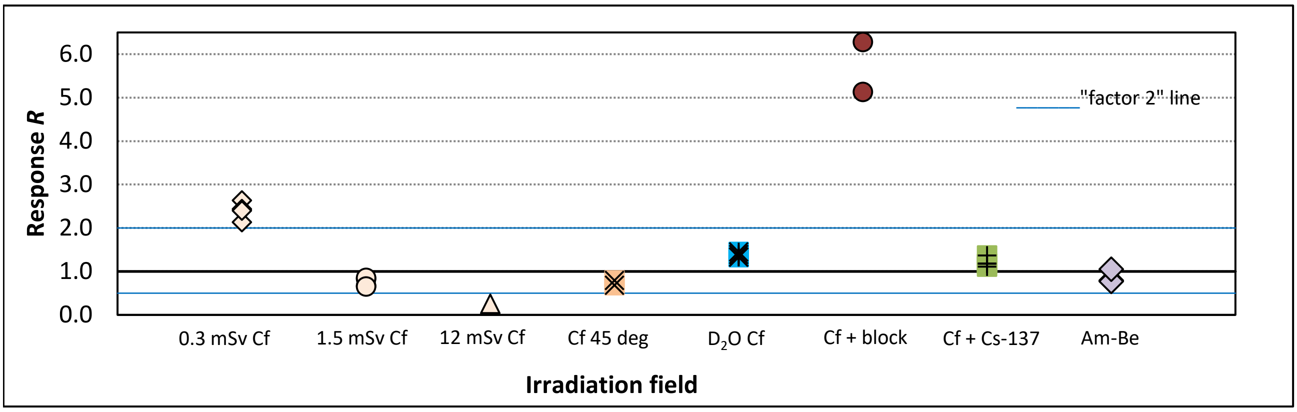


S038, dosemeter type: Albedo

Reference values reported by the irradiating laboratory			Results		
Radiation quality	Dosemeter code	$H_p(10)$ Reference value (mSv)	$H_p(10)$ Participant's value (mSv)	R Response (Participant/Reference)	OK / outlier
Cf-252; 0°	S038-2017-04	0.3	0.79	2.63	outlier
	S038-2017-08	0.3	0.64	2.13	outlier
	S038-2017-12	0.3	0.73	2.43	outlier
	S038-2017-16	0.3	0.72	2.40	outlier
	S038-2017-02	1.499	1.24	0.83	
	S038-2017-07	1.499	1.00	0.67	
	S038-2017-13	1.499	1.28	0.85	
	S038-2017-17	1.499	0.98	0.65	
	S038-2017-03	12.00	2.63	0.22	outlier
	S038-2017-06	12.00	2.62	0.22	outlier
	S038-2017-09	12.00	2.71	0.23	outlier
	S038-2017-15	12.00	3.09	0.26	outlier
Cf-252; 45°	S038-2017-01	1.501	1.02	0.68	
	S038-2017-10	1.501	1.19	0.79	
Cf-252 (D_2O); 0°	S038-2017-27	1.2	1.60	1.33	
	S038-2017-31	1.2	1.67	1.39	
	S038-2017-34	1.2	1.60	1.33	
	S038-2017-40	1.2	1.74	1.45	
Cf-252 + shadow block; 0°	S038-2017-25	1	5.13	5.13	outlier
	S038-2017-33	1	6.28	6.28	outlier
Cf-252 + Cs-137; 0°	S038-2017-26	1.5	1.67	1.11	
	S038-2017-28	1.5	1.78	1.19	
	S038-2017-35	1.5	1.77	1.18	
	S038-2017-37	1.5	2.05	1.37	
Am-Be; 0°	S038-2017-05	1.50	1.19	0.79	
	S038-2017-11	1.50	1.17	0.78	
	S038-2017-14	1.50	1.16	0.77	
	S038-2017-21	1.50	1.58	1.05	

Radiation quality	Number of values	Median of R	Mean of R
Cf-252; 0°	12	0.75	1.13
Cf-252; 45°	2	0.74	0.74
Cf-252 (D_2O); 0°	4	1.36	1.38
Cf-252 + block; 0°	2	5.71	5.71
Cf-252 + Cs-137; 0°	4	1.18	1.21
Am-Be; 0°	4	0.79	0.85
All	28	1.08	1.43

Number of outliers:	10 of 28
Fraction of outliers:	36%



S040, dosemeter type: Albedo

Radiation quality	Dosemeter code	$H_p(10)$ Reference value (mSv)	$H_p(10)$ Participant's value (mSv)	R Response (Participant/Reference)	OK / outlier
Cf-252; 0°	S040-2017-45	0.3	0.28	0.92	
	S040-2017-50	0.3	0.18	0.61	
	S040-2017-57	0.3	0.26	0.88	
	S040-2017-63	0.3	0.20	0.65	
	S040-2017-51	1.501	1.59	1.06	
	S040-2017-55	1.501	1.54	1.02	
	S040-2017-61	1.501	0.87	0.58	
	S040-2017-64	1.501	1.67	1.11	
	S040-2017-41	12.00	11.19	0.93	
	S040-2017-48	12.00	10.08	0.84	
	S040-2017-53	12.00	9.18	0.76	
	S040-2017-56	12.00	9.94	0.83	
Cf-252; 45°	S040-2017-44	1.5	1.30	0.87	
	S040-2017-62	1.5	1.06	0.71	
Cf-252 (D_2O); 0°	S040-2017-29	1.2	0.84	0.70	
	S040-2017-32	1.2	0.79	0.66	
	S040-2017-34	1.2	0.85	0.71	
	S040-2017-40	1.2	0.83	0.69	
Cf-252 + shadow block; 0°	S040-2017-25	1	4.51	4.51	outlier
	S040-2017-26	1	4.32	4.32	outlier
Cf-252 + Cs-137; 0°	S040-2017-27	1.5	1.82	1.21	
	S040-2017-28	1.5	2.18	1.45	
	S040-2017-33	1.5	0.48	0.32	outlier
	S040-2017-35	1.5	0.53	0.35	outlier
Am-Be; 0°	S040-2017-43	1.50	1.34	0.89	
	S040-2017-46	1.50	1.03	0.68	
	S040-2017-54	1.50	0.42	0.28	outlier
	S040-2017-58	1.50	0.53	0.36	outlier

Radiation quality	Number of values	Median of R	Mean of R
Cf-252; 0°	12	0.86	0.85
Cf-252; 45°	2	0.79	0.79
Cf-252 (D_2O); 0°	4	0.70	0.69
Cf-252 + block; 0°	2	4.42	4.42
Cf-252 + Cs-137; 0°	4	0.78	0.84
Am-Be; 0°	4	0.52	0.55
All	28	0.80	1.03

Number of outliers:	6 of 28
Fraction of outliers:	21%