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Content

Abstract

EURADOS, within the work performed by *Working Group 2 - Harmonization of Individual Monitoring in Europe*, has started a self-sustained programme of regular intercomparisons and has successfully executed three intercomparisons for whole body photon dosemeters (IC2008, IC2010, IC2012) and one intercomparison for extremity dosemeters for photon and beta fields (IC2009). In 2012, the EURADOS intercomparison IC2012n was launched for personal neutron dosemeters routinely used to measure personal dose equivalent, $H_p(10)$, in individual monitoring. No systems under development were allowed to participate.

IC2012n was carried out by a EURADOS nominated Organization Group (OG) consisting of: Marie-Anne Chevallier (IRSN, F), Rodolfo Cruz-Suarez (IAEA, UN-Vienna), Marlies Luszik-Bhadra (PTB, D), Sabine Mayer (PSI, CH), David J. Thomas (NPL, UK), Rick Tanner (PHE, UK), Filip Vanhavere (SCK-CEN, B) led by a Coordinator, Elena Fantuzzi (ENEA, I).

31 participants registered for the comparison, with 34 dosimetry systems. In total 816 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 the irradiation plan developed by the OG.

The overall results show that most, although not all, dosimetric systems perform acceptably well (within a factor of 2) for irradiations with a bare radionuclide source (^{252}Cf at 0°), whilst more than half of the systems underestimate the reference value for irradiations from non-normal angles of incidence irradiations (^{252}Cf at 45°) or for simulated workplace fields (^{252}Cf(D$_2$O) or ^{252}Cf source behind a shadow cone). The performance for 250 keV mono-energetic neutron irradiations varies mainly reflecting the detection principle on which the dosimetric systems are based. A few participants reported poor results for all irradiation fields, some reported poor results only for some fields.

A meeting was held during the 12th Neutron and Ion Dosimetry Symposium (NEUDOS-12, held in June 2013 in Aix-en-Provence, F) to allow the participants to discuss general aspects of this intercomparison and specific systems problems with the OG.

The intercomparison results can assist participants in showing compliance with their quality management systems. They allow comparisons of individual results with those of other participants and, if required, help in developing action plans for improving their systems.

IC2012n was the first EURADOS organized intercomparison exercise for neutron dosemeters. It is an important action because international neutron dosimetry intercomparisons have been performed only every 8-10 years.

1 Introduction

The European Radiation Dosimetry Group (EURADOS) has supported working groups investigating harmonisation of individual monitoring in Europe and these have shown [1,2,3] that intercomparison (IC) exercises are a fundamental prerequisite for harmonisation of individual monitoring services (IMSs). 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 intercomparisons 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 three intercomparisons for whole body photon dosemeters (IC2008, IC2010 and IC2012) and one intercomparison for extremity dosemeters for photon and beta fields (IC2009). Results have been published as EURADOS Report for IC2008 and IC2009 [6,7] whilst reports on IC2010 and 2012 are in progress.

In 2012, as a next step in the programme, EURADOS initiated two intercomparisons, IC2012ph for whole body photon dosemeters, and IC2012n for neutron personal dosemeters provided by IMSs to measure personal dose equivalent, $H_p(10)$ for exposed workers in neutron fields.

1.1 Gaps and challenges in neutron personal dosimetry

There are a number of factors that make it both harder and more expensive to conduct a neutron personal dosemeter intercomparison than one for photon dosemeters. These challenges need to be addressed to avoid skewing the intercomparison in favour of one type of dosemeter, whilst ensuring that it provides an adequate test and does not become prohibitively expensive.

Reference neutron fields are detailed in ISO 8529 parts 1 to 3 [8, 9, 10] and simulated workplace fields are described in ISO 12789 parts 1 and 2 [11, 12]. These are a mixture of radionuclide source and accelerator-generated fields. 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 difficult for neutrons than photons, because the accelerator facilities are more expensive, but also because thin targets are needed to generate monoenergetic neutrons and it is important that these are not damaged during an irradiation. This latter consideration limits the beam current and hence the fluence/dose rates that can be generated. This contrasts strongly with x-ray fields that can be used for photon intercomparisons. The problem for neutrons, however, is exacerbated when simulated workplace fields are generated, because the down-scattering in energy, which is part of the process of producing the field, lowers the dose rate and there is inevitable neutron capture that further lowers the fluence rate. Consequently, inclusion of accelerator based simulated workplace fields would require too much accelerator time for inclusion in an intercomparison on the scale of IC2012n and the cost would be prohibitive.

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 detector types. Some of these issues are expanded upon below.

The response of personal neutron dosemeters in a workplace field depends strongly on the neutron spectrum in the environment where it is used, and also on the orientation of the dosemeter to the directions of the incident neutrons. This is often information which is not available, and these dependencies make neutron personal dosimetry difficult and prone to large uncertainties. Although a small number of simulated workplace fields are available in calibration laboratories, and monoenergetic neutrons are available for determining dosemeter response characteristics, the majority of routine neutron calibrations are performed in the more readily available radionuclide neutron sources fields such as ^{241}Am-Be and ^{252}Cf. This is, however, not universally true. 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). These methods lack the rigour of reference field determination and strictly rely on determination of personal dose equivalent in the workplace, which is a difficult problem [13]. They also rely on the field remaining stable.

Lack of harmonisation due to variations in calibration procedures and the question of the suitability of dosemeters for use in neutron fields other than their calibration fields, were amongst the motivations behind the present exercise. It was hence important that the fields chosen should provide a test of these factors.

When high-energy accelerator facilities are excluded, terrestrial workplaces are exposed to 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 neutrons having 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.

Workers are rarely exposed to the bare source; instead the neutrons in the workplace fields have lost energy via several or many scatters, so they 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 1) 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 [14]. Ideally an intercomparison would test dosemeters across this range of energies, though the intermediate energy range is less dosimetrically important.

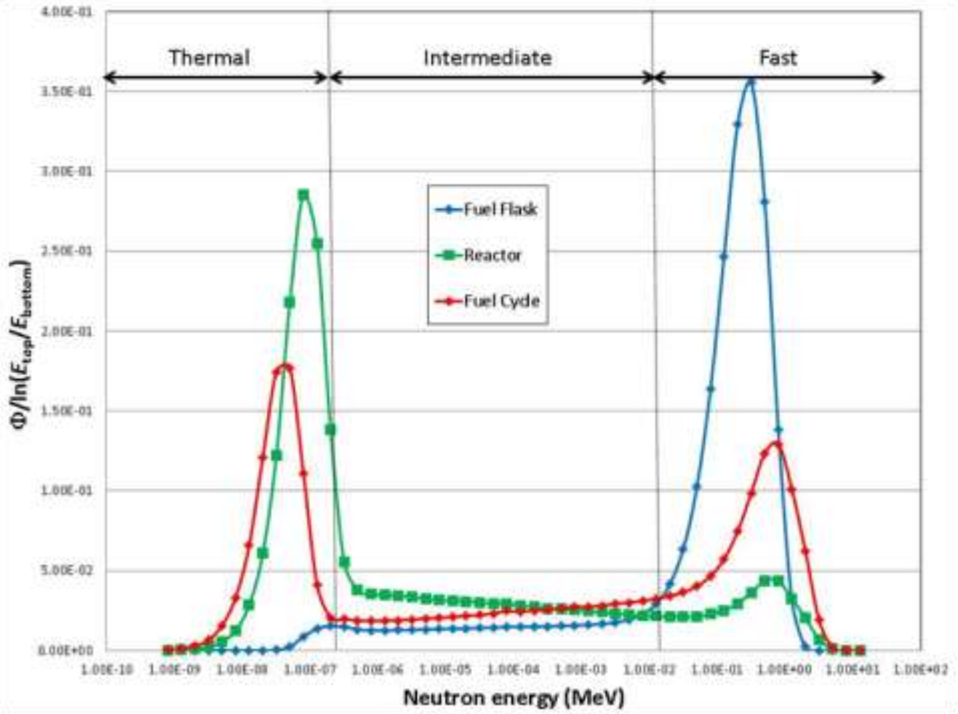

Figure 1: Workplace energy distributions measured at a research reactor, a fuel fabrication plant and near a fuel flask during the EVIDOS project [14]. The fluence is normalized to a total of 1 and then each bin is normalized to its logarithmic energy width.

The fluence to personal dose equivalent conversion coefficients vary strongly with neutron energy (Figure 2) because of the differences between the interactions that dominate for different energy regions: dose deposition by fast neutrons is mainly by elastic scattering whereas capture reactions dominate dose deposition for lower energies. Consequently, the conversion coefficients are relatively constant for lower energies, but they rise by a factor of about 60 between 10 keV and 20 MeV. Devising a dosemeter with a response that changes by this factor over this energy range is one of the main problems in neutron personal dosimetry and also a factor in the difficulty in designing a neutron intercomparison. The rapid increase in the conversion coefficient occurs because fast neutrons begin to deposit dose equivalent via elastic scattering on hydrogen, but the energy deposited is small and hence difficult to measure, which is a problem for all types of personal dosemeter. Additionally, in mixed fields the energy deposition by photons is similar in magnitude, albeit with lower $Q(L)$, so separation of the photon and neutron signals is problematic. It also follows from the conversion coefficients that much higher fluences will be required to test adequately the response below the fast threshold: low-energy dose rates can be very low. 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.

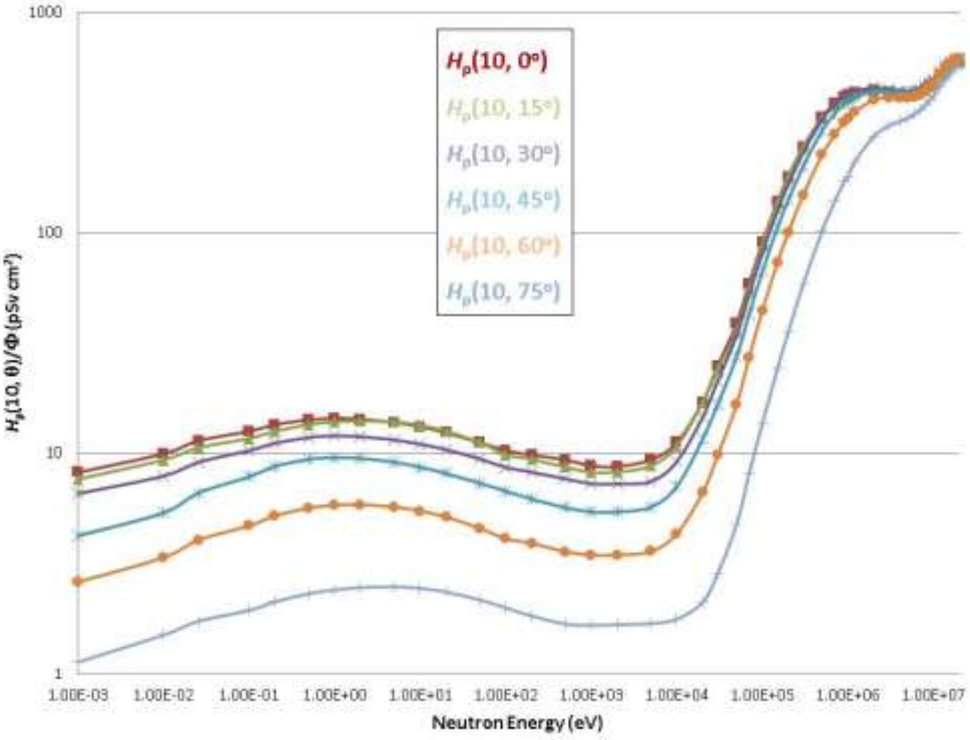

Figure 2: Fluence to personal dose equivalent conversion coefficients *vs* neutron energy and angle of incidence [ICRU57, ICRP74].

The main types of neutron personal dosemeter in use are etched track devices and luminescent albedo detectors (mainly TLD but also OSL). Whilst these passive designs were expected to form the bulk of the dosemeters submitted, the intercomparison was also open to active dosemeters.. These 3 different types of dosemeters have very different deficiencies in their response, which will make different fields tougher for them in the intercomparison:

- Etched track dosemeters do not have an intrinsic detection mechanism below their fast neutron threshold, which falls somewhere in the energy range from 50 keV to 1 MeV. Capture reactions from converters or dopants can extend the energy range down to thermal energies, but 10 mm of tissue equivalent moderator are required to achieve good response up to the fast threshold [15]. Above 50 keV the detector must rely on detection of elastically scattered hydrogen nuclei and have a rapidly increasing fluence response. Above a few MeV other recoils can also become important, because recoils of carbon and oxygen can have sufficient energy for detection. This proves difficult for most systems causing them to miss a crucial energy range in terms of dose in some fields. For these detectors, fields of 144 keV (an ISO recommended calibration energy) or lower would prove very difficult, depending on the precise processing and read methods employed. However, 250 keV neutrons can produce relatively large tracks so they ought to be above the energy range of greatest difficulty. The use of electrochemical etching or high magnification can make the tracks from lower energy neutrons readable.
- TLD and OSL albedo dosemeters detect below the fast neutron region with relatively flat dose equivalent response. In the fast energy range the fluence response drops slowly, but it needs to rise rapidly to give good fast neutron response. It cannot do this because elastic

scattering reactions do not deposit as much dose as capture reactions, so the dosemeters rely on algorithms or special calibrations to determine the component of personal dose equivalent due to fast neutrons. Consequently, fields with few neutrons with intermediate or thermal energy cause severe problems for albedo systems. Albedo dosemeters are not suitable for monoenergetic fields. These dosemeters would perform best in well characterized radiation fields.

- Electronic dosemeters may have a thermal/intermediate energy converter. If they do not then they will only respond above their fast neutron energy threshold, which is determined largely by the need for photon discrimination: in principle, electronic dosemeters can detect lower energy recoil protons similar to track detectors, but the pulses are not distinguishable from those of photons.
- One other, but rarely used, approach to neutron personal dosimetry was used by one service in the present exercise and this involved the use of fissile material and the detection of fission fragments in etched track material.

The photon component of reference neutron fields is not always known with high accuracy. This is 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.

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, since the recoil protons can not be detected above a critical angle, which depends on their energy and the etching procedure.

It was necessary to balance the cost against the rigour and fairness of the test. These considerations led to the fields selected (described in paragraph 2.4), which would provide tests of normal calibration conditions plus limited workplace type situations.

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 [16] and the European Basic Safety Standards [17] in accordance with the fundamental principles of justification of activities and optimization of protection, which shall be applied for all exposure situations [18]. 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) [19].

In general, 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 EN/ISO/IEC 17025 requirements [4] IMSs need to take part in intercomparison exercises on a regular basis. On the other hand EC's technical recommendations for individual monitoring [5] also recognize the importance to participate in intercomparison exercises. 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 dosimeters 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 [20]. The radiation fields were chosen to investigate the energy and angle dependence of different types of personal dosemeters 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 dosimeters from four different categories: albedo dosemeters, nuclear track detector (NTD)-based high-energy neutron dosemeters, multi-element dosemeters with one detector type (usually track etch or TLD) as well as multi-element dosemeters with at least two different detector types.

Irradiations were performed at the Institut de Radioprotection et de Sûreté Nucléaire (IRSN) in Cadarache, 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 by MCNP Monte Carlo computations. The dosemeters were mounted at the central area of the front face of an ISO water slab phantom (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, particular 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 was the large number of results underestimating 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 (for more details see reference 20). 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 personal neutron dosemeters to assess the capabilities of dosimetry services to measure the quantity personal dose equivalent, $H_p(10)$, in mixed neutron-gamma fields [21].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, 8 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 1 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), 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 for workplaces in 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 outliers 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.

In conclusion, it is clear that personal neutron dosimetry still has significant problems. Exercises such as IC2012n are important for informing the radiation protection community about the present state of the art, and for providing the dosimetry services with opportunities to demonstrate the capabilities of their dosemeters and any recent improvements they have made.

2 Outline of the EURADOS Intercomparison 2012n

The scope of the intercomparison is to provide Individual Monitoring Services (IMSs) for external dosimetry with the opportunity to test their performance, to compare their results with other IMSs and to show compliance with their own quality management system and at the same time to provide reference calibration traceable to Accredited Laboratories. Participation was on a voluntary basis. A participation fee was charged to cover the expenses for the 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 EURADOS Intercomparison 2012 for whole-body neutron dosemeters accepted both active and passive devices. A total of 31 individual monitoring services participated from within the EU, but also from Japan and the United States. Only routinely used dosemeters were accepted. The irradiation plan was defined by the Organization Group based on a combination of calibration and simulated workplace radiation fields at different levels of dose.

The results were provided to the participants in the Certificate of Participation with the certificates of the calibration given by the Irradiation Laboratories together with the signed copy of the results provided by the participants (prior to know the reference values) 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. Preliminary considerations of the results have been published in [22]. 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 [23]. The report provided extensive plans for a self-sustained programme of intercomparisons for Individual Monitoring Services with specific detailed proposals for the technical and organization procedures and financial aspects. The main features of the report are also presented in [24]. The proposed plan was put into practice starting with EURADOS IC2008 and was kept, essentially unaltered, for the following ICs, including IC2012n.

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 because the information is handled by a very limited number of persons.

For IC2012n the OG was formed by the authors of this report, with ENEA (Italy) acting as the coordinating institute. 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 between the participants and the irradiation laboratories were performed solely by the OG Coordinator.

2.2 Scope

IC2012n was set up for comparison of neutron dosemeters used to measure the personal dose equivalent, $H_p(10)$ as provided by Individual Monitoring Services (IMS) for exposed workers. Routine *passive* or *active dosemeters* were accepted, the latter were returned to the participants for readout. No systems under research and development were allowed. The irradiations have been restricted to neutrons, no additional photon irradiations were included over and above the photons associated with the neutron-production mechanism.

The radiation fields were standard calibration fields and simulated workplace fields with energy range from thermal to several MeV with different dose values and angles of incidence on the dosemeters.

The IC2012n allowed IMSs to test their performance and at the same time to provide reference calibration traceable to Accredited Laboratories.

2.3 Project set-up and phases

For all EURADOS IC, including IC2012n too, 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, a 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 the participants, the EURADOS Council approved the budget and gave formal approval to the OG to proceed with IC2012n.

During the *application phase* the IC exercise was formally announced on the EURADOS website and participants were able to send their application form to a dedicated email address in the EURADOS domain which was forwarded to the Coordinator. The Organization Group then met and 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 will be restricted to neutrons, no additional photon irradiations will be included over and above the photons associated with the neutron-production mechanism. The irradiations will be performed in European 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.*
>
> *Because pre-information on the neutron spectrum is often used to correct the bare results of neutron personal dosemeters, some basic simplified information on the spectrum of the irradiating field will be provided beforehand to the participants."*

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 were sent 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 (ENEA, Italy) following the guidelines before the set deadline.

The coordinator received and registered all dosemeters. The dosemeters were 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 2 background dosemeters and 4 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 including an Excel-sheet for digital transfer of the results.

Four of the participants using albedo dosemeters needed information on the radiation field in order to provide results according to their routine procedure. To allow for this, and to ensure the procedure was kept equal and fair to every IMS, an approach was adopted where the participants were asked to provide the results in 2 steps with different levels of information provided at each step. In this respect IC2012n differed from the ICs for photons. The information provided was:

- Step I: with very little information on the radiation fields provided by the OG
- Step II: with information on the radiation fields though it was up to the IMS to choose the proper calibration factor to be applied.

Participants were allowed to change their results between the first and the second step only according to their routine procedure, which had to be described and justified in their result file, and duly signed.

In the step I the following information on the radiation fields was provided to the participants

> *"Dosemeters were irradiated in groups with different neutron spectra: radionuclide source, mono-energetic fields or workplace fields. Some of the fields contained significant contributions from slow and intermediate energy neutrons. No additional gamma component was added to the field over and above that associated with the neutron production. No information on dose, radiation quality, or the angle of the incident radiation will be given at this stage"*

The information on radiation fields provided to the participants at step II is reported in Table 1.

Table1: Radiation field information provided to the participants in step II.

Irradiation conditions	Information provided
Bare ^{252}Cf source at 0°, 45°	Bare radionuclide source
250 keV mono-energetic neutrons at 0°	250 keV mono-energetic neutrons
^{252}Cf (D_2O moderated) at 0° and Bare ^{252}Cf behind a shadow cone	Radionuclide source with significant moderated neutron fluence component

Some of the participants remarked, for a few of their results, that the radiation field was not applicable or that they were aware that their dosimetric procedure was not appropriate for certain radiation fields.

After the dose evaluation was provided by the IMSs, the reported dose values, H_m, were compared with the 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 final results were considered to be the ones provided in the 2nd step, nevertheless both series of values were provided in the certificates for the sake of clarity and integrity of the data.

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 the participants' meeting was organized to present and discuss the results among the Organization Group and the participants. The meeting was scheduled to coincide with the Neutron and Ion Dosimetry Symposium NEUDOS12, held in June 2013 in Aix-en-Provence, France. 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 (http://www.eurados.org/en/Events/presentations/IC2012n).The participants present at the meeting received their Certificate of Participation which included the irradiation certificates provided by the irradiation laboratories. The participants who did not attend the meeting received their Certificates of Participation by post. Finally, the results of the intercomparison are published and fully discussed 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 the IC2012n was performed is reported in Appendix A: Time Schedule. The IC application and execution phases were completed within 15 months from April 2012 until June 2013 and throughout the work performed by the OG was undertaken under a strict confidentiality agreement (Appendix B).

2.4 Irradiation plan

Neutron irradiation qualities as described by the standard ISO 8529, parts 1 to 3 [8-10], were selected as well as a simulated workplace field, produced according to the standard ISO 12789, part 1 and part 2 [11, 12].

The irradiations were restricted to neutrons, no additional photon irradiations were included over and above the photons associated with the neutron-production mechanism.

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 the range of different workplaces in which neutron personal detectors are used is wide, 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. These were:

- how well the dosemeters performed when irradiated in a routinely used radionuclide source calibration field, their linearity in this field, and the angle dependence of response at one angle other than normal incidence, again in the source field.
- To provide some information on the energy dependence. A single monoenergetic field was chosen and two fields which, although they do not simulate a particular workplace environment, do include the wide range of energies which cause uncertainties in neutron personal dosimetry.

The chosen fields and the number of dosemeters irradiated in each one are outlined in Table 2.

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). Table 2 summarizes the irradiation plan executed in a random order for each dosimetry system.

For the IC2012n, each participant was asked to provide 36 dosemeters: 24 to be irradiated, 8 spare dosemeters and 4 background dosemeters.

Table 2: Irradiation plan for the EURADOS IC2012n intercomparison for whole body neutron dosemeters

Quality at irradiation laboratory	**Dosemeters at $H_p(10)$ values**	**Dosemeters at $H_p(10)$ values**	**Dosemeters at $H_p(10)$ values**	**Total number of dosemeters**
Bare sources at 0° (^{252}Cf) (NPL)	**4 at 0.3 mSv**	**4 at 3 mSv**	**4 at 15 mSv**	**4 + 4 + 4**
Monoenergetic neutrons (250 keV) (PTB)		**4 at 1 mSv**		**4**
Bare sources at 45°(^{252}Cf) (NPL)		**2 at 2 mSv**		**2**
Workplace field: ^{252}Cf(D_2O) (NPL)		**4 at 3 mSv**		**4**
Other workplace field: bare ^{252}Cf + shadow cone (PTB)		**2 at 2 mSv**		**2**
			Total	**24**
Un-irradiated dosemeters				**8 spares + 4 background**
			Total	**36**

2.5 Participants and dosemeter types

A total of 31 IMSs participated with 34 dosimetry systems: 28 of the IMSs were from 16 European countries, 2 from Japan and 1 from the US.

An overview of the dosemeters samples of the 34 systems taking part to the IC2012n is shown in Figure 3.

Results were received from 30 participants for 32 dosimetry systems (30 passive and 2 active). In fact one participant withdrew one system after receiving the irradiated dosemeters but before the reference value were available, whilst another participant was unable to provide the results due to problems with their reading system.

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

Figure 3: Dosemeters samples of the systems taking part at IC2012n

According to the information provided by the participants most of the dosimetry systems were albedo dosemeters based on thermoluminescence or etched track detectors - i.e. proton recoil dosemeters, based on polyallyldiglycol carbonate (PADC) - or a combination of the above mentioned detectors. In addition 2 systems were based on optically stimulated luminescence (OSL), 1 was a fission track dosemeter and 2 were electronic devices based on silicon diodes.

Table 3: Number of Individual Monitoring Services (IMSs) per country.

Country	Number of participants per country
France	4
Germany, Italy, United Kingdom	3
Austria, Czech Republic, Japan, Switzerland	2
Belgium, Finland, Greece, Israel, Poland, Romania, Slovenia, Sweden, The Netherlands, USA	1

Results are reported according to the following classification: etched track, albedo and other. However, each of the categories could be further sub-divided, as shown below.

Etched track: 18 systems

- 5 with track detectors for fast neutrons and TLD for thermal neutrons,
- 9 with track detectors for fast neutrons combined with converters for thermal neutrons,
- 4 with track detectors for fast neutrons only, i.e. no evidence of a thermal sensor

Albedo: 13 systems

- 3 based on TLD + cadmium shield,
- 6 based on TLD + boron loaded shield,
- 4 based on TLD or OSL (no information on shielding of direct thermal neutrons)

Other: 3 systems

- 1 based on fission track detection,
- 2 electronic, based on silicon diodes.

Only four of the *etched track* dosemeters were based on the detection of charged recoils only, while all others contained an additional thermal sensor. Recoil protons can usually be detected, depending on the evaluation procedure, with energies above 100 keV to 500 keV. 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). Alternatively, TLDs, containing ^{6}Li or ^{10}B, are used and their thermal neutron reading is evaluated by a TLD reader.

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 case of albedo dosemeters, fast neutrons are detected via neutrons thermalized and backscattered by the body. The personal dose equivalent reading of these dosemeters increases strongly for lower-energy neutrons, i.e., for intermediate-energy neutrons and – if no 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 factor. Four out of the 13 systems use the field-specific calibration factor according to 4 application areas as defined by the standard DIN-6802-4 [25]. These dosemeters are hereafter called “DIN- albedo systems”.

The dosemeter category ‘other’ contained a fission track detector and electronic devices. The electronic dosemeters are based on silicon diodes with converters on front which produce recoil protons and also (n,α) reactions. Since the diodes are sensitive to photons, a threshold is usually set at about 1 MeV for the detection of recoil protons and there is a need to detect lower-energy neutrons by the albedo principle. The fission track detectors use a heavy isotope, such as ^{237}Np, that has a fission cross section for fast and thermal neutrons. This enables it to detect the full energy range in a thin layer of polycarbonate, which registers one of the fission fragments as an etchable track.

2.6 Execution of the irradiations

A total of 816 dosemeters were exposed according to the irradiation plan at the two irradiation laboratories contracted for the IC by EURADOS: NPL-UK and PTB-D.

Each irradiation laboratory provided irradiation certificates with all data to the Coordinator and an individual certificate for each participant. Each participant received the irradiation certificates (see example in appendix D) as an annex of the Certificate of Participation.

All irradiations were performed according to the recommendations of ISO 8529 and ISO 29661 [26] on the appropriate phantom. The dose equivalent reported was the operational quantity, personal dose equivalent, $H_p(10)$, derived from fluence measurements using conversion coefficients recommended by a joint ICRP/ICRU committee [27, 28]. For all the irradiation conditions except one an ISO water phantom was employed. This 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 attached, which is 2.5 mm thick. In the case of the simulated workplace field, using ^{252}Cf behind a shadow object, a solid phantom, 30 cm × 30 cm × 15 cm, made of PMMA, was used. Dosemeters were attached to the front face of the phantom using thin adhesive tape (see Appendix E).

Usually 4 dosemeters were irradiated simultaneously for irradiations at 0° and 2 dosemeters, mounted on the rotation axis, for irradiations at 45°. As described in ISO 29661, the dosemeters were mounted with their rear side (including a clip) onto 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.

As stated in ISO 29661, the reference point was in the centre of the phantom front surface, irrespective of the arrangement of the dosemeters on the surface Different distances of the dosemeters from the radiation source were considered. At NPL corrections were made for the slightly increased distance for the dosemeters not exactly at the centre of the phantom front face, whilst PTB gave the reference value in the centre of the phantom surface with no corrections.

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 the D_2O moderated ^{252}Cf source and ^{252}Cf behind a shadow cone. These low-energy neutrons make almost no contribution to personal dose equivalent (see Figure 5), but can contribute considerably to the readings of dosemeters with increasing dose equivalent response at lower energies, e.g. albedo dosemeters. Spectra for the fields involving a bare or heavy-water moderated ^{252}Cf source can be found in ISO 8529-1 and that for a ^{252}Cf source shielded by a shadow cone in a room which provides a significant scatter component can be found in reference [29]. Numerical data are provided in Annex F.

The corresponding mean fluence-to-personal dose equivalent coefficients are an indication of the field hardness and are listed in Table 4.

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

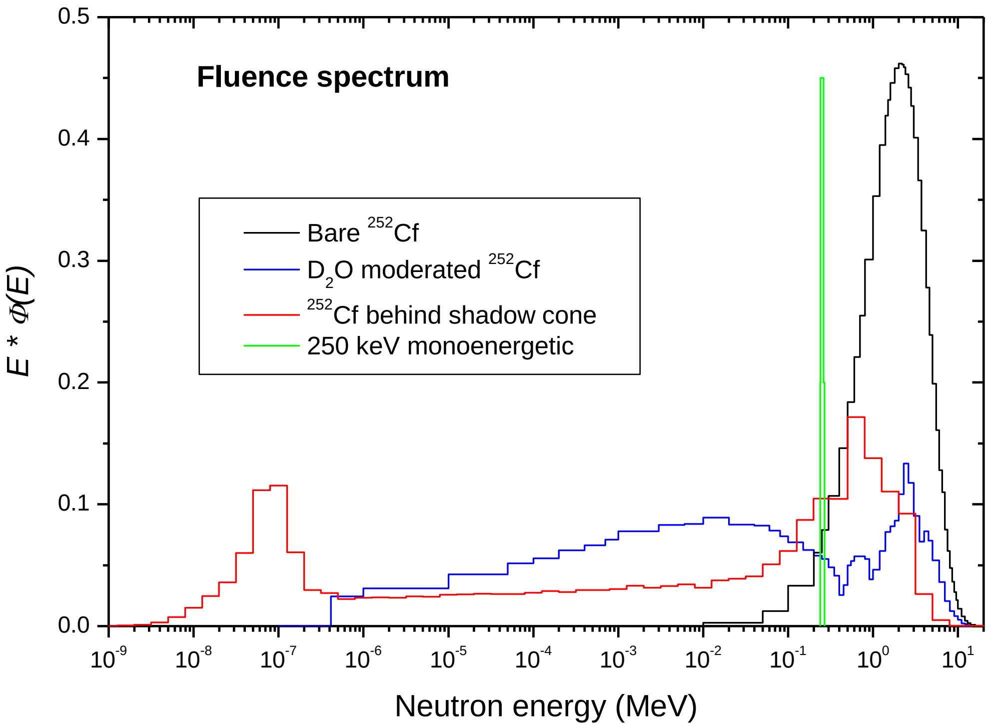

Figure 4: Fluence spectra of the radiation fields. The ^{252}Cf based spectra have all been normalised to unit fluence. The 250 keV spectrum simply provides an indication of the position of this monoenergetic peak relative to the neutrons in the radionuclide source spectra.

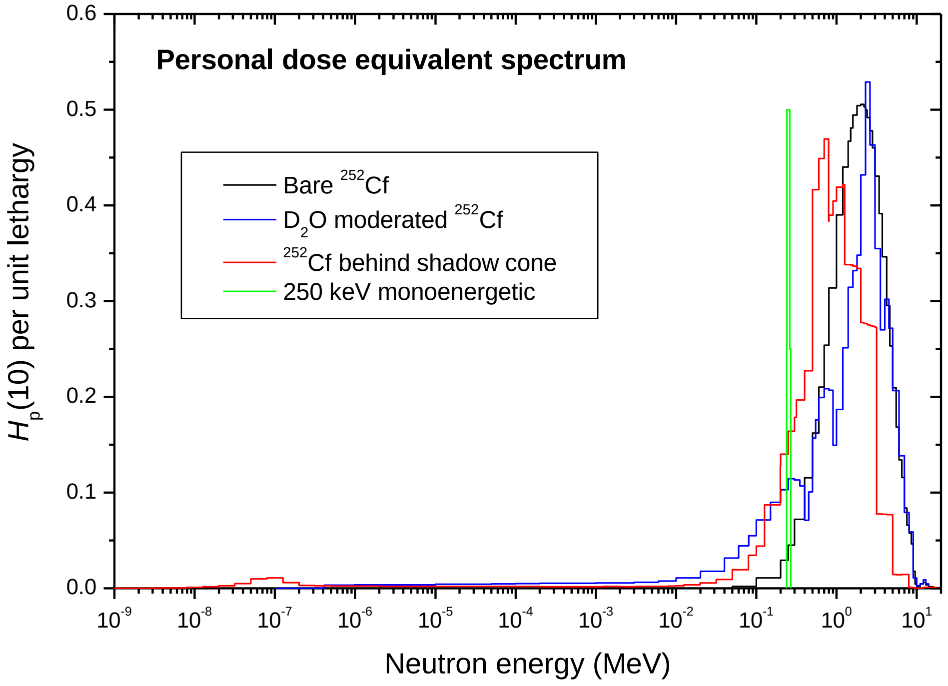

Figure 5: $H_p(10)$ spectra of the radiation fields. The ^{252}Cf based spectra are normalised to unit $H_p(10)$.

Table 4. Fluence to personal dose equivalent conversion coefficients

Neutron radiation field	$h_{p\Phi}(10)$ (pSv cm^2)
Bare ^{252}Cf, 0°	400
Bare ^{252}Cf, 45°	389
250 keV monoenergetic, 0°	209
D_2O moderated ^{252}Cf, 0°	110
^{252}Cf behind shadow cone, isotropic	50

2.6.1 The radiation fields at NPL – ^{252}Cf(bare) and ^{252}Cf(D_2O)

Irradiations at NPL were performed using physically small cylindrical ^{252}Cf sources (less than 2 cm high and 1 cm diameter). The dosemeters were attached to the front face of an ISO water filled slab phantom the mid-point of which was positioned at 75 cm from the centre of the source. All irradiations but one were performed with a source having an emission rate of 2.9×10^8 s^{-1}. The 0.3 mSv irradiation was performed with a lower output source of 3.4×10^7 s^{-1} to avoid timing problems. Irradiation times varied from 20 minutes (2 mSv ^{252}Cf 45°) to 2 hours 27 minutes (15 mSv ^{252}Cf). Each irradiation time was assumed to have a standard timing uncertainty of ± 4 seconds.

Source emission rates had been measured in the NPL manganese bath and the emission anisotropy using a long counter. Fluence values at NPL were derived from a measurement of the source total emission rate into 4π steradians plus a measurement 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 [30]. Emission from the source is not, however, isotropic, and needs to be measured. This is done at NPL using a long counter [31]. The ^{252}Cf sources used at NPL have a cylindrical encapsulation and are physically small. Anisotropy factors, defined as the fluence in a plane at 90° to the capsule axis and passing through the centre of the capsule are close to one. The uncertainties in the reference quantities are outlined in Table 5.

Irradiations were performed in the low-scatter area which has dimensions of 24m × 18m × 18m. 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 [32]. Fluence to dose equivalent conversion coefficients were taken from ISO 8529-3 .

Table 5: Percentage standard uncertainties associated with the determination of the personal dose equivalent values from bare and D_2O moderated ^{252}Cf sources

Uncertainty component	**Relative uncertainty for radiation quality**				
	^{252}Cf **$\theta = 0^\circ$** **0.3 mSv**	**^{252}Cf,** **$\theta = 0^\circ$** **3 mSv**	**^{252}Cf** **$\theta = 0^\circ$** **15 mSv**	**^{252}Cf(D_2O)** **$\theta = 0^\circ$** **3 mSv**	**^{252}Cf** **$\theta = 45^\circ$** **2 mSv**
Type B (non-random)					
Reference irradiation distance*	± 0.53%	± 0.53%	± 0.53%	± 0.53%	± 0.53%
Source emission rate ($MnSO_4$ bath) including component for half-life	± 0.60%	± 0.40%	± 0.40%	± 0.40%	± 0.40%
Source anisotropy correction	± 0.50%	± 0.50%	± 0.50%	± 0.0%	± 0.50%
Timing	± 0.26%	± 0.22%	± 0.04%	± 0.05%	± 0.33%
Scatter	± 1.0%	± 1.0%	± 1.0%	± 1.0%	± 1.0%
$H_p(10,\theta)$ conversion coefficient†	± 1.0%	± 1.0%	± 1.0%	± 4.0%	± 1.0%
Total standard uncertainty Components added in quadrature	**± 1.7%**	**± 1.7%**	**± 1.6%**	**± 4.2%**	**± 1.7%**
Expanded uncertainty ✠	**± 3.4%**	**± 3.4%**	**± 3.2%**	**± 8.4%**	**± 3.4%**

* 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 25 and 26 are by convention taken to be exact. The uncertainties quoted derive from ISO 8529-2 and 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 field at PTB - 250 keV monoenergetic neutrons

Monoenergetic neutrons with energy (248 ± 10) keV were produced in the low-scatter measurement hall (24 m × 30 m ×14 m) of the PTB accelerator facility [33]. Four dosemeters were irradiated with normally incident neutrons on an ISO water filled slab phantom (phantom to target distance: 75 cm). Each irradiation ($H_p(10)$ = 1 mSv) took roughly 1.5 h. The use of freshly prepared metallic lithium targets helped to save time.

The following procedure was used to determine the reference $H_p(10)$ values:

- The total neutron fluence Φ is the sum of the fluence Φ_{dir} of the direct neutrons and of the fluence Φ_{sc} of neutrons scattered in the solid-state target assembly. The fluence of un-scattered neutrons Φ_{dir} at the reference position was measured using a recoil proton proportional counter. Details of the measurement and analysis procedures are described in references [34] and [35].
- The fluence of neutrons scattered in the solid-state Li target assemblies was calculated using the Monte Carlo code TARGET [36]. The fluence ratio Φ_{sc}/Φ_{dir} is listed in Table 6.
- The dose equivalent $H_p(10)$ is the sum of the dose equivalent $H_{p,dir}(10)$ of the direct neutrons and the dose equivalent $H_{p,sc}(10)$ of the neutrons scattered in the target assembly. $H_{p,dir}(10)$ and $H_{p,sc}(10)$ are calculated from Φ_{dir} and Φ_{sc} using the conversion coefficients $h_{p,\Phi,dir}(10)$ and $h_{p,\Phi,sc}(10)$. The values for $h_{p,\Phi,dir}(10)$, taken from reference ISO-8529-3 are identical to those in ICRP-publication no. 74. The values for $h_{p,\Phi,sc}(10)$ are the spectral averages of the energy dependent conversion factors specified in ICRP publication no. 74, weighted with the spectral neutron fluence $\Phi_{E,sc}$. The conversion factors used to calculate the dose-equivalent quantities are listed in Table 6.

The mean neutron energy of the field produced using a metallic Li target and the ^{7}Li(p,n)^{7}Be reaction was measured using a ^{3}He proportional counter. The data are listed in Table 6.

The mean energy E_n and the width ΔE_n (FWHM) of the un-scattered neutron distributions are nominal values calculated using the target data. All uncertainties assigned are extended measurement uncertainties (k = 2). (Φ_{sc}/Φ_{dir}) is the ratio of the fluences of scattered neutrons Φ_{sc} and unscattered neutrons Φ_{dir}. The uncertainty of the conversion coefficient, $h_{p,\Phi,dir}(10)$ for the direct neutrons and $h_{p,\Phi,sc}(10)$ for the scattered neutrons, includes the averaging over the spectral distribution Φ_E.

The uncertainties of the $H_p(10)$ values were 7%, and are the expanded measurement uncertainties which are obtained by multiplying the standard uncertainty by the coverage factor k = 2. They were determined in accordance with the "Guide to the Expression of Uncertainty in Measurement (GUM)" [37]. The value of the measurand then normally lies, with a probability of 95%, within the attributed coverage interval.

Table 6: Data for the monoenergetic neutron field produced using a solid-state Li metal target (100 µg/cm^2).

Reaction	**Target**	E_n **(MeV)**	ΔE_n **(MeV)**	(Φ_{sc} / Φ_{dir})	$h_{p,\Phi,dir}(10)$ **(pSv cm^2)**	$h_{p,\Phi,sc}(10)$ **(pSv cm^2)**
^{7}Li(p,n)^{7}Be	Li	0.248 ± 0.010	0.017	0.0259 ± 0.0026	212.9 ± 3.2	81.1 ± 1.8

2.6.3 The radiation field at PTB - ^{252}Cf source behind a shadow cone

The neutron source facility of the PTB was used for the irradiation with the field of a bare ^{252}Cf source behind a shadow cone. The size of the concrete-shielded irradiation room is 7 m x 7 m x 6.5 m, with the source in the centre. The neutron field behind a shadow cone is an isotropic field of wall-scattered neutrons.

All irradiations were performed on a PMMA phantom (size: 30 cm x 30 cm x 15 cm). The distance between the centre of the neutron source and the centre of the phantom) was 170 cm. For the irradiations, the phantom 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 were irradiated together. Each irradiation ($H_\mathrm{p}(10)$ = 2 mSv) took roughly three days.

The measurement quantity, the neutron personal dose equivalent $H_\mathrm{p}(10)$, was calculated from the fluence of the in-scattered neutrons with the fluence to personal dose equivalent conversion coefficients $h_{\mathrm{p},\Phi,\mathrm{ins}}$ (10; isotropic). The values $h_{\mathrm{p},\Phi,\mathrm{ins}}$ (10; isotropic) = (50 ± 7) pSv cm^2 have been determined from the spectral distribution of the scattered neutrons measured with the PTB Bonner-sphere spectrometer [38, 39] using the energy dependent fluence to personal dose equivalent conversion coefficients for isotropic incidence on the phantom according to references [10] and [27].

The uncertainties of the $H_\mathrm{p}(10)$ values were 15%, and are the expanded measurement uncertainties which are obtained by multiplying the standard uncertainty by the coverage factor $k = 2$.

2.6.4 Quality control of irradiation fields

Validity of dose information is proven by key international comparisons. 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.

Figure 6: The neutron irradiation geometry for ^{252}Cf irradiations behind shadow cone

2.7 Relevance of existing standards to the IC2012n Intercomparison

The standard ISO14146 [40] followed for the EURADOS photon intercomparisons is not applicable to neutrons and no other international standard provides guidance on how to perform an intercomparison among neutron dosimetry systems or on the criteria to be applied to the results.

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 Standardisation) 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), HSE (Health and Safety Executive, UK) and ANSI (American National Standard Institute) 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.

However, in practice there is not an internationally agreed document answering precisely to the question: "which procedure and criterion should be applied for overall dosimetric performances and comparison between different kind of personal neutron dosemeters?".

2.7.1 Overview of the existing standards and guidelines related to personal neutron dosimetry

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 performances of personal dosemeters.

The ISO29661 [25] standard recently published provides the definitions and fundamental concepts, underlying the methods of production and characterization for the reference radiation fields and procedure to calibrate dosemeters for radiation protection. It applies to photon, beta and neutron reference radiation fields.

For neutrons, there are two international standards dedicated to reference fields. The first one, *"ISO 8529: Reference neutron radiations"*, describing the reference neutron sources and the general concepts and methodology of calibration to be used, has three parts [8, 9, 10]. The neutron fields defined in this standard are:

- Neutrons sources: bare ^{252}Cf, D_2O moderated ^{252}Cf, ^{241}Am-B(α,n) and ^{241}Am-Be(α,n), which are the most readily available around the world,
- Mono-energetic neutron fields at these different energies: 2 keV, 24 keV, 144 keV, 250 keV, 565 keV, 1.2 MeV, 2.5 MeV, 2.8 MeV, 5 MeV, 14.8 MeV, 19 MeV. These are very important for the energy response characterisation of dosemeters, but more complex to setup and less available,
- Thermal spectra, important in the rare situations in which thermal neutrons give a significant contribution to the dose received, and for characterizing dosemeters which can be particularly sensitive to a thermal neutron field.

The second standard dedicated to reference neutron fields is *"ISO 12789: Reference radiation fields - Simulated workplace neutron fields"* [11, 12]. This series describes the characteristics and methods for producing simulated workplaces fields. Facilities following this standard to simulate workplace neutron field are not widely available and the corresponding situations of exposure are not largely taken into account while determining the performances of the neutron dosemeters.

The standard ISO 21909 [41] is the international document establishing the type tests and the requirements for passive neutron personal dosemeters. This standard has been under revision since 2011 with the objective of rectifying the weaknesses of the present document. Indeed, this present version defines tests and criteria which differ for the different techniques (nuclear tracks emulsions dosemeters, solid state nuclear track dosemeters, thermoluminescence albedo dosemeters, superheated emulsion dosemeters, ion chamber dosemeters with direct ion storage). Moreover it is not constraining enough to ensure that personal dosimetry will be reliable in most of the usual work situations i.e. low dose levels and neutron energy ranges representative of the encountered workplaces. The new version may have less constraining criteria at low doses to assure the quality of the dosimetry without being unachievable.

The standard IEC 61526 [42] is the international document establishing the type tests and requirements for all active personal dosemeters for gamma, neutron and beta radiations.

Other standards exist at a national level. American standards ANSI/HPS N13.11-2009 [43] treats the general criteria and testing requirements for establishing personal dosimetry performance and ANSI/HPS N13.52-1999 [44] give specific requirements and recommendations for neutron dosemeters. However, only tests with un-moderated ^{252}Cf and D_2O moderated ^{252}Cf neutron source are considered in these standards. The German standard for neutron dosimetry, DIN 6802 [45,46, 47, and 24] is specific for dosimetry systems using albedo technique and does not provide criteria for the performance of personal dosemeters which are instead provided in the guidelines by the German authority SSK [48].

International guidelines such as ICRU report n°66 [49], for the determination of operational dose equivalent quantities for neutrons, or ICRP Publication n°75 [50], which gives the recommendations for radiation protection of workers, apply also to personal neutron dosimetry.

2.7.2 Criteria for an intercomparison of the performance of personal neutron monitoring

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 dosimetric system and to quantify the difference between systems, criteria are needed to appreciate what can be considered in terms of an acceptable under-response or an acceptable over-response.

Among all the documents related to personal neutron dosimetry, only three give such criteria, applied to the response:

ICRP 75, at §251 says:

- *"The commission has noted that . . . in the workplace, where the energy spectrum and orientation of the radiation field are generally not well known, . . . the overall uncertainty at the 95% confidence level in the estimation of the effective dose around the relevant dose limit may well be a* ***factor of 1.5*** *in either direction for photons* ***and may be substantially greater for neutrons of uncertain energy*** *and for electrons."*
- ***"Greater uncertainties are also inevitable at low levels of effective dose for all qualities of radiation."***

IEC 61526 gives different criteria for a combined energy and angle dependence of response for three neutron energy ranges and angles of incidence from 0° to ± 60° (H_m being the measured dose and H_{ref} the reference dose) and states a number of monoenergetic and broad radiation fields for testing the response:

$$0.65 \le \frac{H_m}{H_{ref}} \le 4.0 \qquad for \qquad E_{min} \le E_n \le 100\ keV$$

$$0.65 \le \frac{H_m}{H_{ref}} \le 2.22 \qquad for \qquad 100\ keV \le E_n \le 10\ MeV$$

$$0.65 \le \frac{H_m}{H_{ref}} \le 4.0 \qquad for \qquad 10\ MeV \le E_n \le E_{max}$$

ISO 21909, which is under revision, provides a series of test and performance requirements for specific issues (e.g. linearity, detection threshold, energy and angle dependence of response, etc.). The requirements are different for different types of dosemeters, e.g. for the energy dependence of response it says:

- "not applicable" for thermoluminescence albedo dosemeters,
- "The response at normal incidence in the stated energy range for the dosimetry system shall not vary by more than ± 50 % for a personal doseequivalent of a least 1 mSv" for etched track detectors to be tested at normal incidence for four neutron energy fields chosen from the reference standards fields as stated in ISO 8529-1 in the stated energy range for the dosimetry system.

It appears that the criteria which could be considered to be applicable for an intercomparison depend on the dosimetric techniques and the standards. Moreover as it is suggested in ICRP Publication 75 and in the discussions for the new version of ISO Standard 21909, the criteria would need to be less constraining for the low dose levels.

However, it is clear that an intercomparison cannot perform all tests needed for a full type test.

Considering this lack of international consensus for criteria for the results of neutron intercomparisons, criteria used at previous international intercomparisons (see paragraph 1.2.1) need also to be pointed out. The *EURADOS Performance Test 1999* fixed the following criterion

$$\frac{1}{1.5}\cdot\left(1-\frac{2\cdot H_0}{H_0+H_{ref}}\right)\le\frac{H_m}{H_{ref}}\le 1.5\cdot\left(1+\frac{H_0}{2\cdot H_0+H_{ref}}\right)\qquad with\quad H_0=0.085mSv$$

whilst the IAEA intercomparison 2003/04 the following one:

$$\frac{1}{2}\cdot\left(1-\frac{2\cdot H_0}{H_0+H_{ref}}\right)\le\frac{H_m}{H_{ref}}\le 2\qquad with\quad H_0=0.1mSv$$

where, for both of the above criteria, H_0 is the detection limit of the system.

Considering the variety of approaches and criteria and the results of previous intercomparison, the Organization Group decided to use a factor of 2 as a general criterion for the response, *R,* for all dose values.

Therefore the following criterion for an "acceptably good" response was eventually used for the 2012 EURADOS neutron intercomparison:

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

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

Figure 7 shows a synthesis of the different criteria which were discussed.

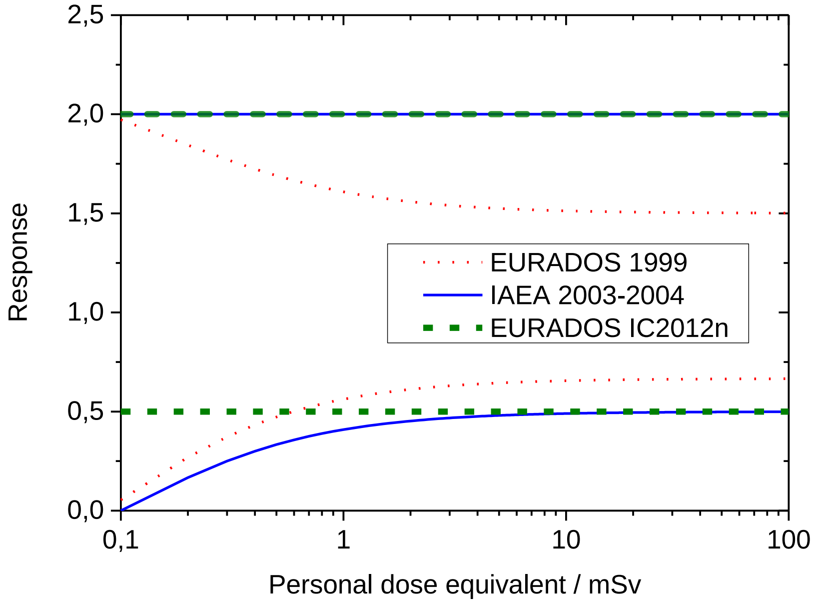

Figure 7: Synthesis of criteria considered to quantify neutron personal dosimetry performance

2.8 Background and transit dose control

For each dosimetry system 4 dosemeters were reserved as "background and transit dose control" dosemeters to allow for background and transfer dose corrections. In addition, 8 dosemeters were assigned as "spare" dosemeters to be used by the irradiation laboratory in case of damage or errors with the irradiations. No spare dosemeters had to be used for this purpose. The dosemeters were sent in one shipment to each of the irradiation laboratory.

The organizer provided the participants with the identification codes of the 4"background" and 8 "spare" dosemeters (4 used for each irradiation location). Since no spares were used for irradiations there were in effect 6 background controls per irradiation laboratory.

The participants were not instructed on how to deal with these dosemeters. However, they were told which ones were kept as background and spare dosemeters and they were asked to proceed according to their routine procedure.

IMSs should apply a correction for the increase in the background signal that accompanies extended issue periods, which in the case of this intercomparison exceeded 3 months. This should account for all factors that may cause an increase in the background signal, including environmental radiation.

The issue of background radiation is significant for photon dosemeters, which are sufficiently sensitive for them to have low minimal recording levels. These can cause difficulties when dosemeters are issued in areas of higher than average natural background, so the dosemeters for the EURADOS photon intercomparisons were accompanied by active dosemeters to estimate transit dose.

Correction of dosemeters readings for background signal is much less significant for neutron personal dosemeters than it is for photon dosemeters. In the UK, where most of the irradiations were performed, the neutron background from cosmic rays is about 90 µSv per year [51], whereas the gamma-ray background is approximately 350 µSv per year, a factor of almost 4 higher. Additionally, the neutron background is relatively high in energy, being from cosmic rays. The efficiency of personal dosemeters is generally low in this energy region, so the impact on the readings will be reduced.

The issue of background differs for the different dosemeter types, but all types should apply a routine background correction to account for background accrual from neutrons and other sources of increasing reading at sea level:

- Active dosemeters were switched on prior to irradiation and switched off after. They hence had almost no transit dose and a very small background exposure to the background dosemeters which were switched on only during the irradiation time. It is hence not anticipated that any background signal could come from neutrons, though source photons or other effects could be an issue: electromagnetic fields or microphonic effects for example.
- TLD or OSL based systems rely on subtraction of the photon signal from the neutron signal via the non-neutron sensitive elements. When “issued” for 3-4 months the background accrual could be significant for the lower doses, which affects the precision, especially for low neutron doses.
- Track detectors are prone to background outliers; i.e. false positives. This, rather than detection of cosmic ray background, might account for some dosemeters registering small implied doses.

The correction that IMSs may not be able to take into account is for transit dose during flight. This comes from cosmic ray neutrons and is characterized by its main dose equivalent peak around 100 MeV. Albedo dosemeters have a negligible response at such high energies, but track dosemeters are used for cosmic radiation measurements, though with special calibration factors to account for their relatively low response for such high energies neutrons. In IC2012n the short haul European flights should have given negligible doses. Values reported in Table 7 have been calculated through EPCARD (European Program Package for the Calculation of Aviation Route Doses) [52]. On the other hand, only the long haul destinations should have resulted in doses that might perturb the results: 150 µSv for California and 162 µSv for Japan. The IMSs had the data for their unexposed dosemeters available to them, and could have subtracted their background readings if they chose to do so. There were no major solar particle events during this period that could be classified as ground level events, so it may be assumed that no abnormal solar activity would have resulted in measurably increased transit doses for the period at aviation altitude.

If the transit doses were to have an impact on any of the results, then the lowest irradiation dose would most likely be affected. This was 300 µSv of ^{252}Cf for which the transit doses could have caused a bias of up to +50% for the long haul destinations.

Table 7: EPCARD doses for 2012 for return doses to London, with an assumed flight profile

Destination from London	Return route neutron dose (μSv)
Belgium	4
France	6
Austria, Germany, Italy, Switzerland	14
Sweden	20
Romania	26
Israel	40
California	150
Japan	162

The IMSs had information on which dosemeters were unexposed, and could have subtracted their background readings if they chose to do so.

Some participants reported the results for unexposed dosemeters, whilst others did not. Some may have subtracted a mean signal from their reported results for the exposed dosemeters. The reported backgrounds, where available, tend to range from 0.01 to 0.117 mSv.

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.

The present intercomparison was prepared and carried out by a EURADOS nominated Organization Group (OG, the authors of this paper) led by a Coordinator (ENEA - Italy). Each member of the Organization Group has signed a confidentiality clause (see appendix B) prior to her/his participation at 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 would 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 in a random order 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 parallel data streams. All official results were reported on signed papers. In parallel data were exchanged in electronic formats for efficient processing and to prevent typographic errors. In case of any ambiguity the data on the signed papers was taken as "correct".

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: for each dosemeter numbered by the participant, irradiation quality, value of $H_p(10)$ as reported by participant, value of $H_p(10)$ as reported by the irradiation laboratory, and the ratio of these two values for both step I and step II. In the certificates, no performance limits were indicated.

The OG organized a participants meeting, held during the Neutron and Ion Dosimetry Symposium NEUDOS12, held in June 2013 in Aix-en-Provence, France to show and discuss the results among the OG and the participants. At this meeting the participants received their Certificate of Participation including information on the irradiation qualities, doses imparted, response values and overall uncertainties. For those participants not attending the meeting, the certificate of participation was sent by mail.

3 Results and Discussion

3.1 Review of the comments received from participants

During and after the intercomparison several comments were received by the participants. The comments were received by e-mail by the coordinator.

After sending the reference data to the participants, comments were received from a few participants. These comments included:

- A small number of the participants remarked that, for few of their results, the radiation field was not applicable or that they were aware that their dosimetric procedure was not appropriate for certain radiation fields;
- some of the participants remarked that the information provided for the radiation field was not sufficient to apply their routine procedure which requests that the user should define the "application area" factor to be applied to the results;
- a few requests for changing or leaving out results for specific radiation qualities.

The OG did not allow participation only to part of the irradiation exercise. The OG asked the participants not to changes the results. They had only the option to confirm entirely or only partially the results in the II Step, that is the final step.

Some of the participants decided to provide only a limited number of final results whilst other participants did not withdraw those results, which they can clearly claim to be outside their routine procedure (e.g. zero values). In particular to those participants who claimed that the information received did not allow them to apply their routine procedure as requested, the OG replied that they are aware of the issue raised by the participants and that it would be specifically addressed at the Participants' meeting and in the EURADOS report on the IC2012n (see paragraph 3.2). However, the EURADOS IC has been designed to allow participation of services from any country with various different dosimetric systems. Providing the information to the participant, assigning the application area for each radiation field, field-specific calibration factor according to the classification area as they expect from their users would give them an advantage over the other participants (see further comments in paragraph 3.5.2).

For the above reasons and for sake of completeness the OG decided to provide in the certificate of Participation the results for both the I step and the II-Final Step. The data would help the participants to show how their system could have worked with a more specific description of the radiation field.

In only one particular case the participant showed that the results provided for two neighbouring dosemeters in the printed list had been transposed in the reporting file and that was not a mistake in the evaluation procedures. Examining the proofs provided by the participant the OG allowed the participant to report again the 2 results in the proper order.

3.2 Basic statistical results

A total of 31 IMSs sent application forms for 34 systems. However, one participant withdrew one of the two systems they had submitted after receiving the irradiated dosemeters but before the reference values were available. Another participant was unable to provide meaningful dose values due to problems with their reading system which meant that only the thermal component from a two-sensor dosemeter was available.

Therefore, results were received from 30 participants for 32 dosimetry systems (30 passive and 2 active). In the analysis of the data no results are presented for two withdrawn systems of the 34. The breakdown of the analyzed systems was *Albedo* 12, *Track* 17, *Other* 3.

One participant provided final results only for 6 dosemeters saying that the radiation fields used for the other 18 were 'not applicable' for their system. Another participant provided results for all fields, but said that their calibration was specific to their measurement locations; the majority of their evaluated doses were zero.

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

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

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

where:

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

H_{ref} is the reference value as determined by the irradiating laboratory.

Table 8 shows the total number of values reported in the II step (final results) for $H_p(10)$, together with estimates for the central value of the distribution of response values (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 section were derived using all the reported values for the dosemeters from all services who provided results.

Values for $H_p(10)$ were reported for more than 92% of the irradiated dosemeters. The estimates of the central values for the arithmetic mean and median for the responses were 1.06 and 1.00 respectively. The spread (standard deviation) in the values for R was 0.80. From the percentiles the 95% coverage intervals of the responses for all results of all participants together can be derived: this was 0.00 – 2.55.

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

In each case 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 the mean, and the minimum and maximum values are represented by up and down triangles respectively.

Table 8: Total number of values reported for Hp(10) and some statistical quantities indicating the central values and spread of the results for R

	$H_p(10)$
Number of irradiated dosemeters	816
Number of reported values[a]	750
	R
Arithmetic mean	1.06
Median	1.00
Standard deviation	0.80
2.5th-percentile	0.00
97.5th-percentile	2.55

[a] Two services (S18 and S22) provided either a very limited number of results or results which were predominantly zero. These two services only had location specific calibrations for their dosemeters so results in any other fields were highly suspect. The effect of removal of these results on the statistical information is a slight increase in the mean and median values and a slight reduction in the standard deviation and range values, but the effect is not large because the numbers are small compared to the total number of dosemeters, and zero or very low *R* values also occurred throughout the results from other services.

For all the ^{252}Cf source based irradiations the 50% range boxes are similar in size, although there is some evidence of a decrease in the spread as the dose increases for the bare 0° irradiations. The 250 keV monoenergetic results have the widest spread. For the bare and D_2O moderated ^{252}Cf irradiations the 90% range line (5% to 95% of response) is somewhat one-sided extending further towards the low values than the high ones. This is due to the low, or even zero, responses registered by several dosemeters. For the other two radiation qualities the 90% range extends more towards high values than low values. In most cases the 90% range extends almost from the minimum to maximum values. The exceptions are the values for the D_2O moderated ^{252}Cf field and the field behind a shadow cone for which there were two spuriously high sets of responses.

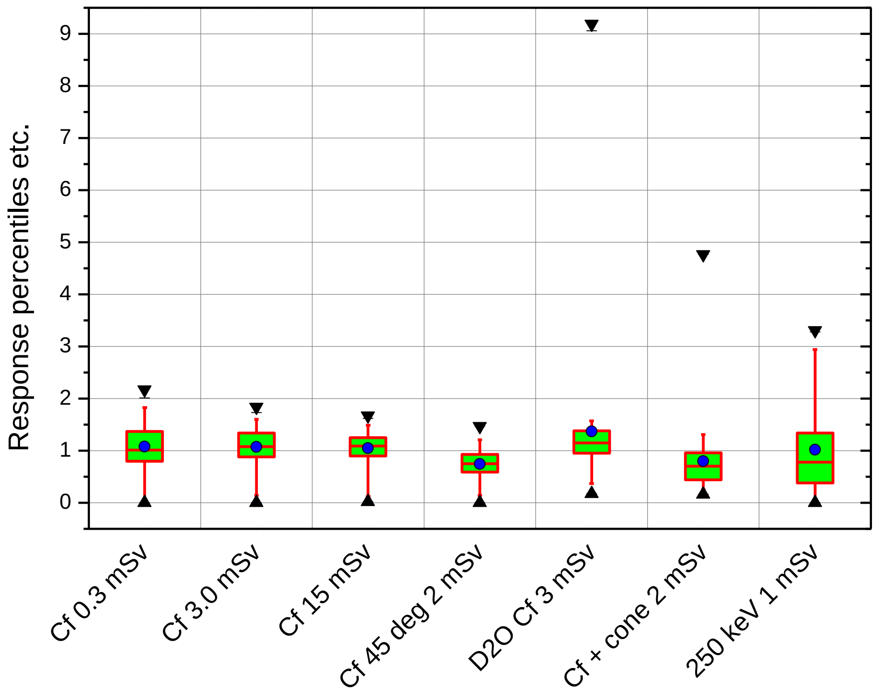

Figure 8: Distribution of response values *R* for irradiations with different radiation qualities. Circle = mean value, box = 50% range, vertical red line = 90% range, horizontal red line inside the box = median, up and down triangles = minimum and maximum values

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 zero for the 2.5th-percentile for several of the fields reflect the fact that there were a number of zero values for the responses in these fields.

To present information on how the statistical data vary for the different dosemeter types the mean and standard deviation values are listed in Table 10 for the various irradiation fields. The mean values for the three dosemeter types tend to be roughly similar for a particular irradiation field. For example in the case of the ^{252}Cf field at 45° all dosemeter types have a low mean value although there is a decrease in going from *Albedo* to *Track* to *Other*.

Table 9: Statistical data for the individual radiation qualities

Statistical values	0.3 mSv ^{252}Cf 0°	3 mSv ^{252}Cf 0°	15 mSv ^{252}Cf 0°	2 mSv ^{2152}Cf at 45°	3 mSv D_2O ^{252}Cf	^{252}Cf + Shadow cone	250 keV
No. of reported values	124	124	124	62	128	64	124
Mean	1.08	1.07	1.05	0.74	1.37	0.80	1.02
Median	1.03	1.08	1.09	0.75	1.16	0.71	0.78
Standard deviation	0.50	0.40	0.34	0.29	1.40	0.75	0.90
2.5th.-percentile	0.00	0.00	0.02	0.00	0.18	0.16	0.00
97.5th.-percentile	1.99	1.73	1.57	1.44	8.80	4.56	3.11

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		Other	
	Mean	*s*	Mean	*s*	Mean	*s*	Mean	*s*
^{252}Cf 0.3 mSv	1.08	0.49	1.05	0.63	1.11	0.40	0.99	0.33
^{252}Cf 3.0 mSv	1.07	0.39	0.94	0.47	1.22	0.27	0.73	0.08
^{252}Cf 15 mSv	1.05	0.34	0.94	0.47	1.16	0.20	0.85	0.17
^{252}Cf all 0° data	1.07	0.41	0.98	0.54	1.16	0.30	0.86	0.24
^{252}Cf at 45°	0.74	0.29	0.85	0.43	0.70	0.17	0.57	0.07
D_2O mod ^{252}Cf	1.37	1.40	1.65	2.26	1.16	0.21	1.41	0.12
^{252}Cf + cone	0.80	0.75	0.96	1.16	0.63	0.24	1.11	0.18
250 keV	1.02	0.90	1.22	1.12	0.97	0.76	0.51	0.22

3.3 Distribution of response values with radiation quality

Figure 9 shows the mean responses at step II for all radiation fields, for all systems for which results were reported. They are ordered with *Albedo* on the left, *Other* on the right, and *Track* in the middle. To simplify the plot mean responses are plotted for each radiation field for each individual service. The error bars are one standard error of the mean and are included simply to give an indication of the spread of results rather than the absolute accuracy.

This plot essentially encapsulates all the information from step II of the intercomparison, and allows all results to be compared and individual mean results for any system to be picked out. Some general trends can clearly be seen e.g. the fact that there are more results below 0.5 than above 2.0. Results which are very high are rare. The tendency for the *Track* results for the ^{252}Cf + cone field to be low is also evident.

As shown in Figure 9 and the results given in Appendix G, about half of the systems (14 out of 32 who delivered results) show response values within a factor of roughly 2; 7 of them were *Track* detector systems which needed no additional field information, i.e., no change from step I to step II results.

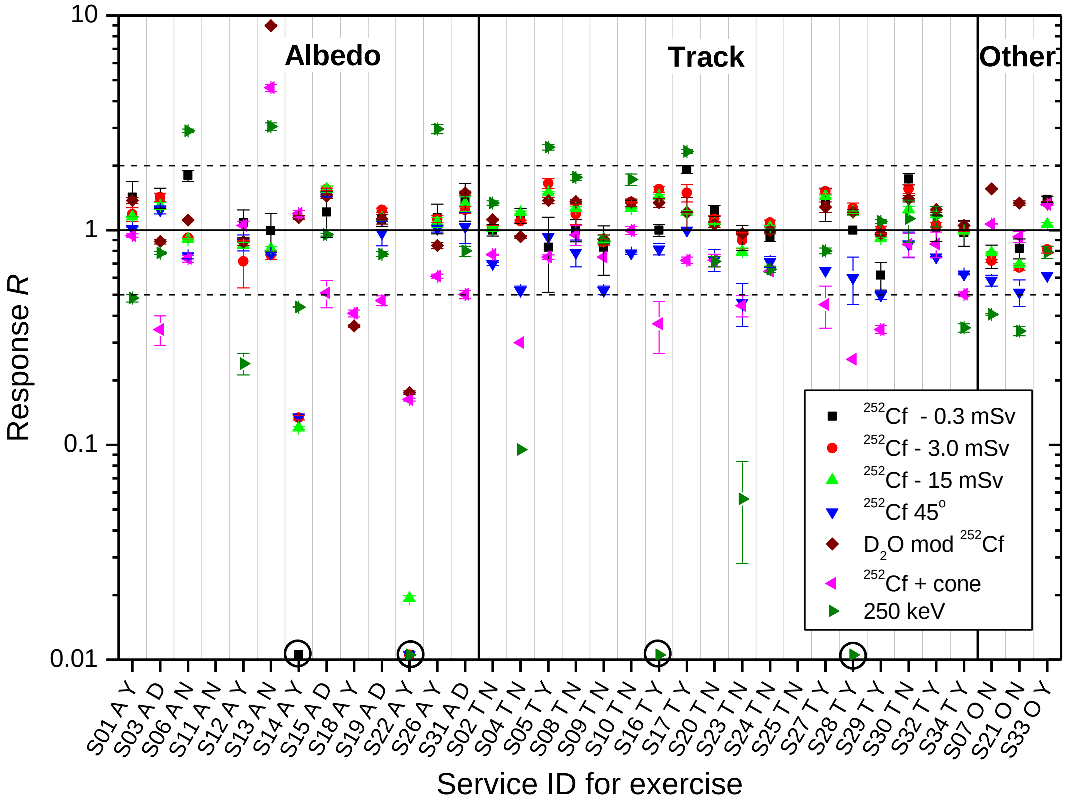

Figure 9: Summary of all reported response values. To simplify the plot mean responses are plotted for each radiation field for each individual service. The error bars are one standard error of the mean and are included simply to give an indication of the spread of results rather than the absolute accuracy. In the X-axis captions: A stands for Albedo, T for Track, O for Other, Y for a change from step I to step II, N for no change, and D for the dosemeters that use the DIN-albedo systems approach to deriving the response. Points at R=0.01 with rings around them were actually reported as zero.

To investigate the results for individual radiation fields the relevant responses are plotted in Figures 10 to 14. Figure 10 shows the results for all the bare ^{252}Cf irradiations at 0°. Again the error bars are the standard errors of the means and are used simply as an indication of the spread of the results. Except for the two *Albedo* systems with low results all the values lie between 0.5 and 2.0. The spread of the responses was generally higher for the 0.3 mSv irradiation than the two higher doses. This is not surprising as 0.3 mSv is close to the lower detection limit for some systems and this dose had been chosen when planning the exercise to test low dose measurement capability. The responses are on average slightly greater than one with a mean of 1.07 and a median of 1.08.

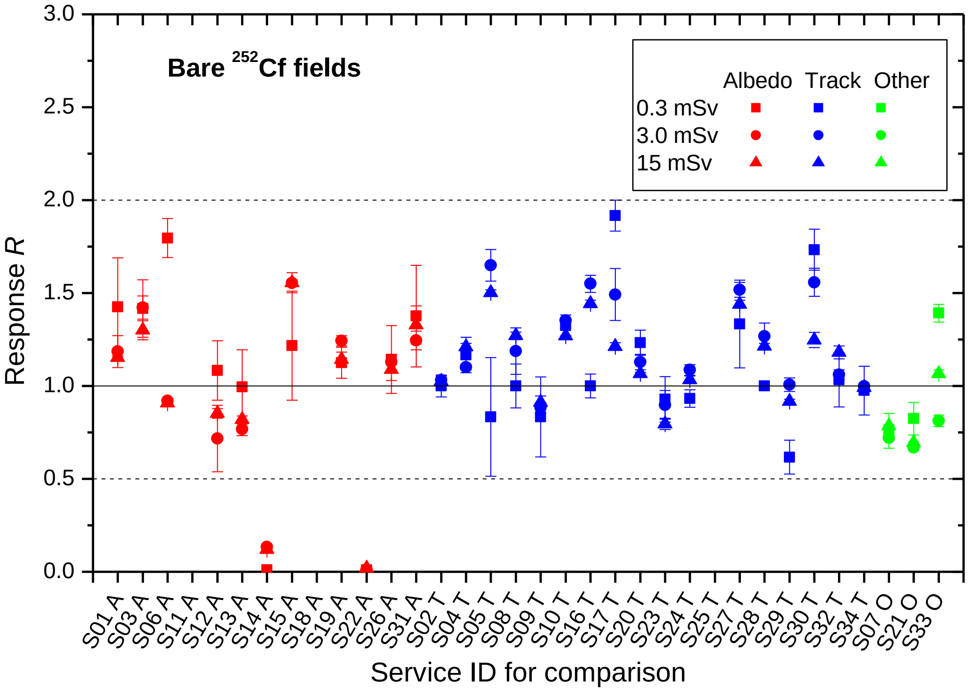

Figure 10: Summary of responses for irradiations in bare ^{252}Cf fields with 0° incidence. Data points represent mean values for a field and the error bars standard errors of the mean. The different fields are indicated by the different symbols.

Figure 11 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 2 mSv and a comparison with Figure 10 indicates that the generally low mean values in Figure 11 are not the result of the radiation source or the dose delivered but of the angle of incidence on the dosemeter. Except for a couple of outliers the *Albedo* dosemeters appear to have a better angle dependence of response than the other two types.

Results for the responses to D_2O moderated ^{252}Cf are shown in Figure 12. The average response is greater than unity for all three dosemeter types. Those for *Track* and *Other* dosemeters are quite tightly grouped and range from 0.83 to 1.63. The majority of the *Albedo* results are also good although there are three with results outside the 0.5 to 2.0 range, two with low results and one with high results. The personal dose equivalent delivered was 3 mSv so the results can be compared directly with irradiation to the same personal dose equivalent with bare ^{252}Cf neutrons.

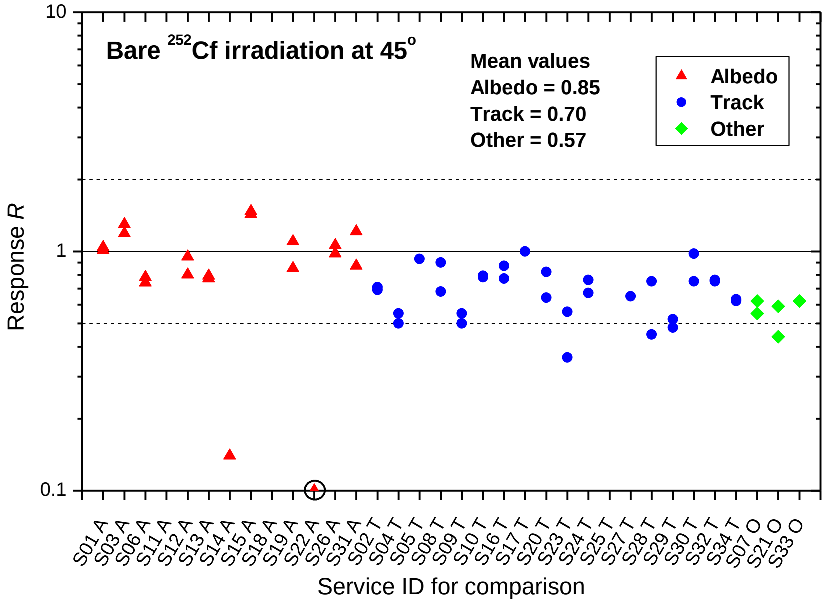

Figure 11: Responses for all dosemeters irradiated with ^{252}Cf neutrons at 45°. Only two dosemeters were irradiated for each system. The circled result was actually a zero value and not 0.1

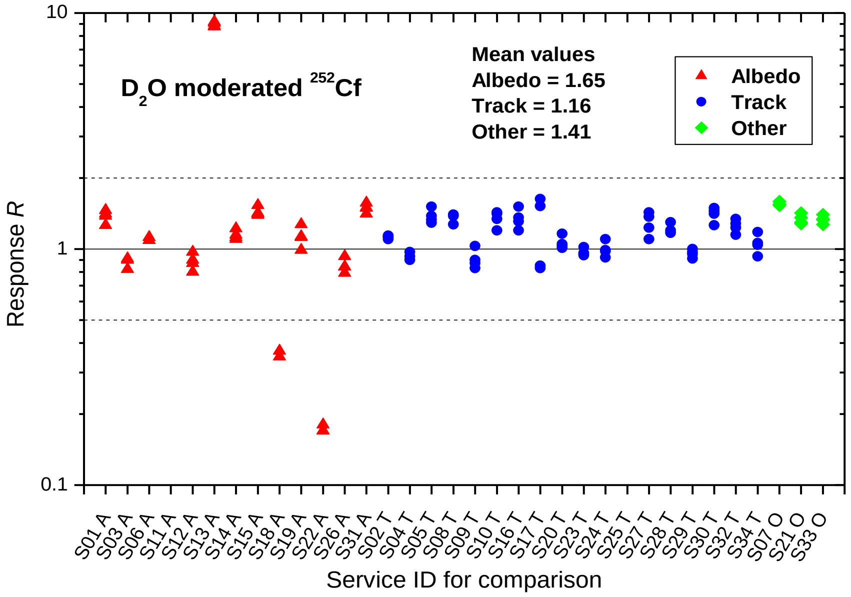

Figure 12: Responses for all dosemeters irradiated with D$_2$O moderated ^{252}Cf neutrons. Four dosemeters were irradiated for each system.

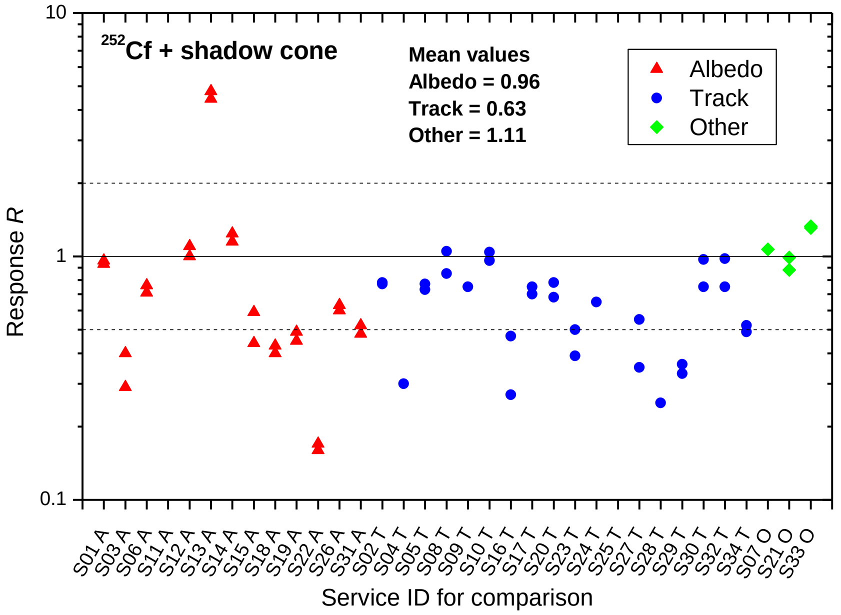

Figure 13: Responses for all dosemeters irradiated in a field produced by a ^{252}Cf source shielded by a shadow cone but in a room which provided scattered neutrons. Two dosemeters were irradiated for each system.

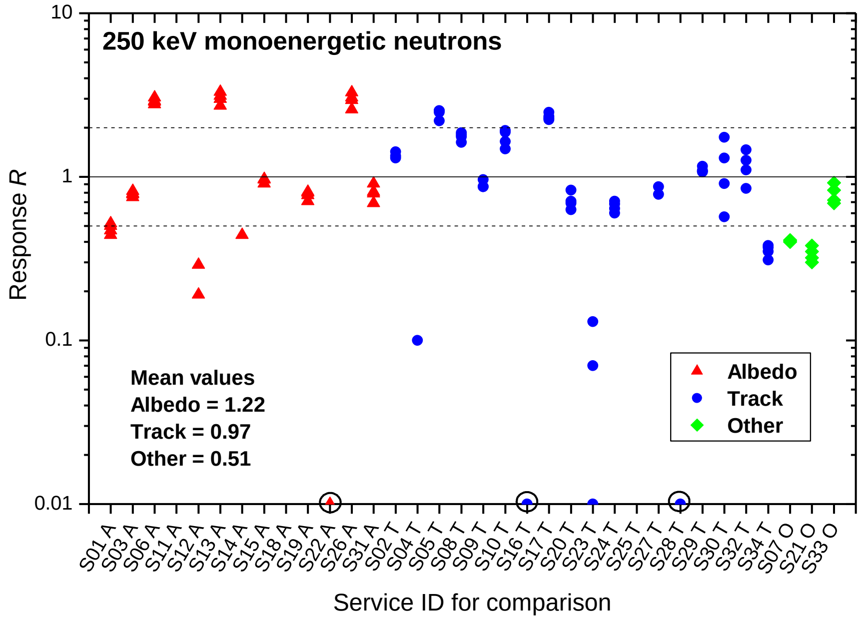

Figure 14: Responses for all dosemeters irradiated with monoenergetic 250 keV neutrons. Four dosemeters were irradiated for each system.

Figure 13 presents the results for irradiation of the dosemeters with a ^{252}Cf source behind a shadow cone. The responses for dosemeters of type *Other* are all close to unity and those for *Albedo* and *Track* are on average low. For the *Albedo* sets there is one pair of high results and if these two values are removed the overall average drops to 0.63, which is the same as for *Track* devices. At first sight it is perhaps surprising that the *Albedo* devices do not do significantly better than the *Track* dosemeters in a field which has been deliberately developed to include lower energy neutrons. However, an inspection of the dose equivalent distribution as plotted in Figure 5 shows that most of this occurs in the reasonably high energy region around 1 MeV, although it does extend to the region around 100 keV where both types of dosemeters have response functions which are not ideal.

Finally, Figure 14 shows the results for irradiation with monoenergetic 250 keV neutrons. This is not a field resembles the radiation field at spent fuel transportation casks and it does fall in the region of the neutron energy range where the fluence to $H_p(10)$ conversion factors are changing rapidly, and is in a region where some dosemeter response functions are poor and where it is interesting to obtain response values. There was a very wide range of responses reported. Two *Track* type dosemeters failed to report any dose equivalent at this energy and two others reported significantly low readings. This is a little surprising as *Track* dosemeters would be expected to record 250 keV neutrons reasonably easily, as indeed most Track systems did.

3.4 Distribution of response values with dosemeter type

The responses are shown in Figure 15 in a format that allows the results for different dosemeter types to be compared. Figure 16 complements Figure 15 and shows the data as a series of histogram frequency distributions for the three types of dosemeters for the different radiation qualities.

The very high response values in Figure 15 for the D_2O moderated ^{252}Cf and ^{252}Cf behind shadow cone plots are for the same service (S13). This system, an *Albedo* dosemeter with no information provided on the shielding for direct thermal neutrons, gave very good results for the four bare ^{252}Cf fields, but high results for the 250 keV irradiations and very high results for the fields which included a significant low energy neutron fluence component. The data would imply that the dosemeters had been calibrated with radionuclide source neutrons with no allowance for the high response to low energy neutrons. Conversely, another service (S14) reported good results for the two fields with lower energy neutrons (D_2O moderated and with shadow cone) but low results for all other fields implying a calibration in a field with low energy neutrons.

For the three bare ^{252}Cf irradiations the narrowing of the frequency distribution as the dose increases is clear in Figure 16. Another feature which is brought out by the plots is the number of low results (R values in the 0 to 0.2 interval) for *Albedo* dosemeters for bare ^{252}Cf irradiations. Closer inspection reveals the very lowest responses are the results from just two services (S14 and S22) and these distort the distribution for *Albedo* detectors. Conversely, for the 250 keV irradiations, the incidence of low results is greater for *Track* devices than for *Albedo*.

The 250 keV results show some clear trends. The *Track* devices have results which cover a wide range from zero to about 2.5. The *Albedo* results divide into two groups, one low with all responses ≤ 1, and one high with results clustered around 3. There was no obvious reason for this;

the high results were a mixture of cadmium and boron shielded devices and similarly for the low results. It may just be a statistical anomaly or it may reflect the importance that the correct calibration is applied for a given field. Results for the dosemeter type *Other*, which are good for most of the radiation qualities, are low, i.e. ≤ 1, for 250 keV.

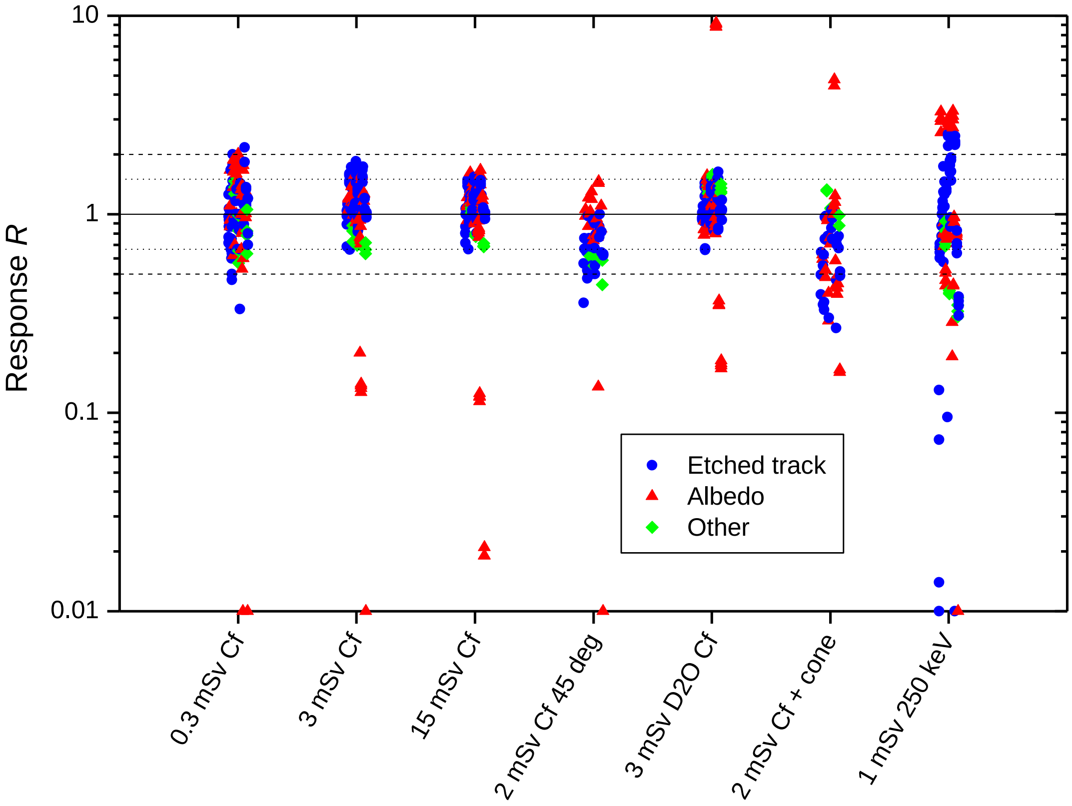

Figure 15: Individual response values for all dosemeters for the three different dosemeter types in the seven radiation fields used

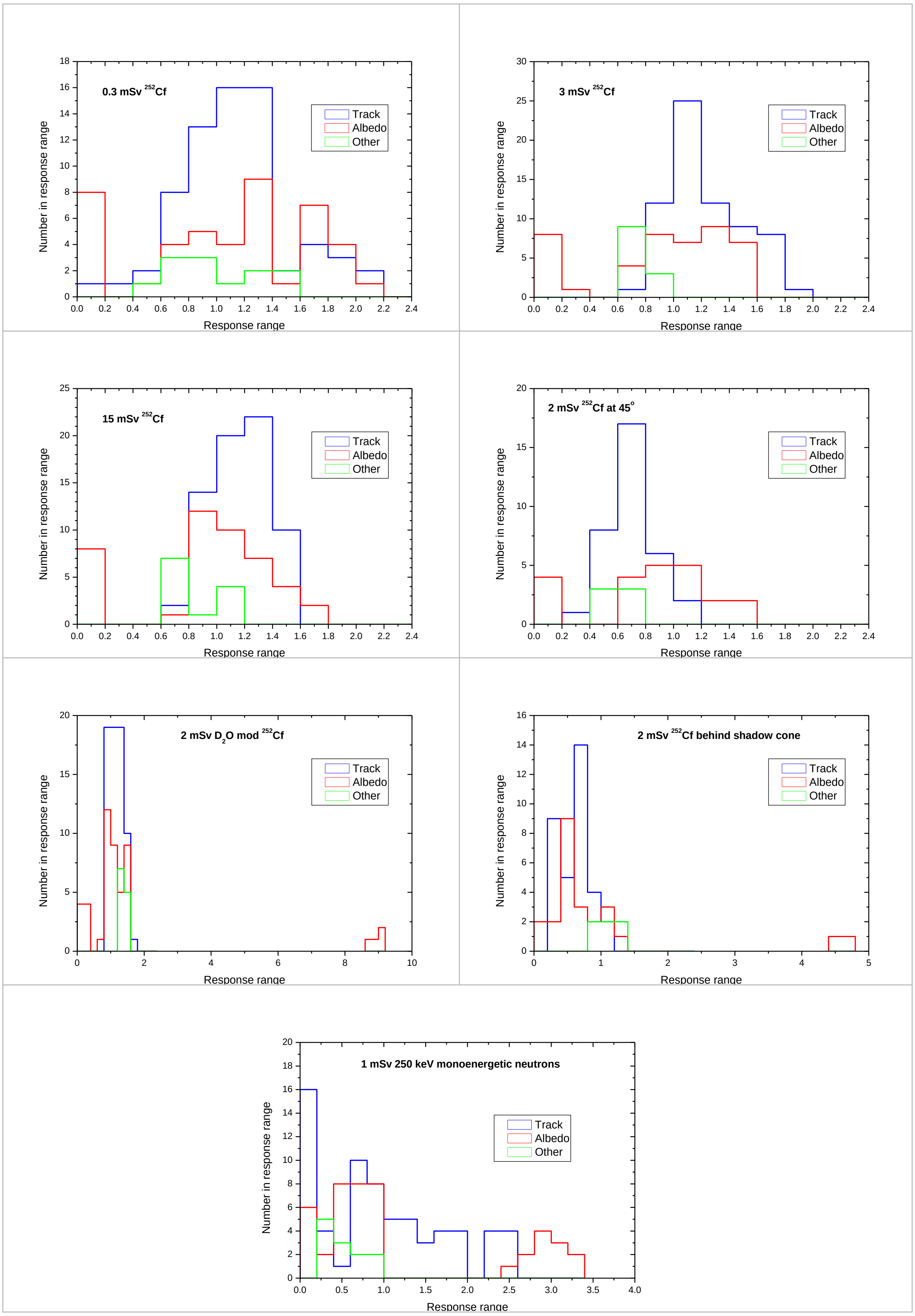

Figure. 16: Frequency distribution for responses of different dosemeter types

3.5 Step I and step II results

When the additional spectral information was provided at step II 13 services made no changes. This group was made up of 2 *Albedo*, 9 *Track*, and 2 *Other* services. Of the 19 services that made changes 10 were *Albedo*, 8 were *Track*, and 1 was *Other*. Of the 10 *Albedo* services that made changes 4 used the German *DIN albedo system*[a] for choosing a calibration field. One service (S18) had provided results for all fields, but at step II withdrew all except those for the D_2O ^{252}Cf field and that for ^{252}Cf behind a shadow cone, saying that the others were "not applicable" for their dosemeter calibrations.

3.5.1 Changes step I to step II - excluding the DIN-albedo systems

Figure 17 shows the ratio of the step II to step I values for all services that made a change, excluding the four participants that used the *DIN-albedo systems*. Changes were sometimes an increase and sometimes a decrease and some of the changes were very large. Four of the results for 250 keV were changed by almost a factor of 10, two were *Albedo*, where the change was a reduction, and two were *Track* where the results were an increase. For the 0.3 mSv ^{252}Cf field, one *Track* service (S34) increased their results by a factor of nearly 9 and one *Albedo* service (S12) changed their results from “not irradiated?” to values which gave responses with a mean very close to 1.0 (point on the upper X-axis). One *Albedo* service increased its D_2O ^{252}Cf result by a factor of 10. The other large change, was for one of the *Albedo* services (S01) that decreased the results for the fields with low energy components (D_2O ^{252}Cf and ^{252}Cf + cone) and the results for the 250 keV field by almost a factor of 10. The withdrawn results from service S18 are shown on the lower X-axis. It is clear that there was no particular uniformity in the changes applied by the services.

Table 11 lists the mean and standard deviation values for the services that changed their results at step II for all system types and for *Track*, *Albedo*, and *Other* systems separately. The results of the *DIN- albedo systems* are not included, and neither is S18 where some results were withdrawn as being not applicable and the others were unchanged. The table includes, in the rows marked ‘Change’, an indication whether the mean at step II was closer to 1 (B for better), further from 1 (W for worse), or the same (S for same) compared to step I. The ratios of the step II standard deviations divided by those for step I are presented as percentages. It is also indicated whether the standard deviation decreased or increased: a value less than 100% means the standard deviation decreased.

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[a] Such systems using the application areas according to DIN6802-Part 4 are referred in the present report as “*DIN-albedo systems*”

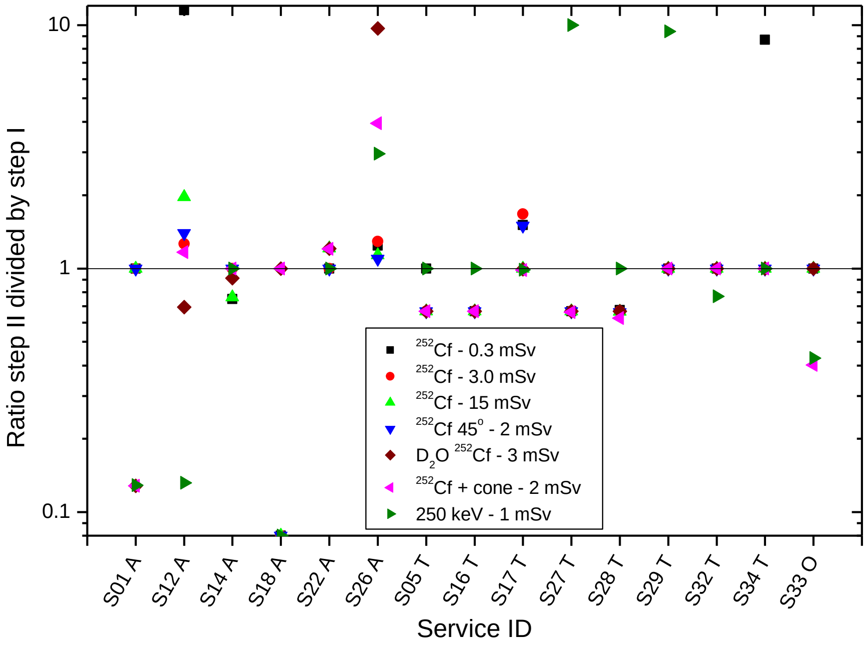

Figure 17: Changes on going from step I to step II for those services that changed their results. A ratio > 1 corresponds to an increase, < 1 corresponds to a decrease.

Figure 18 shows the data as frequency histograms of the number of responses between particular values, 0 to 0.2, 0.2 to 0.4, etc. for both data sets of Step I and step II.

On the whole the results improved noticeably both in terms of better mean values and smaller standard deviations. There were, however, some cases where the results got worse with the change. Of the 336 dosemeter responses from the 14 participants that changed some or all of their values on going from step I to step II 154 resulted in an improvement, 37 in the response being worse and 145 did not change. The service S18 where response values were changed to "not applicable" has not been included in this analysis. Only three services changed all results the other 11 changed only some of them.

The biggest improvement was for the *Albedo* service which originally reported the 0.3 mSv ^{252}Cf dose equivalent as zero with the comment "not irradiated?" to values with a mean response of 1.08. There were other examples of spectacular improvements, e.g. the Track system that increased their 250 keV response results from an average of 0.13 to 1.1. The cases where the results became worse were not so spectacular. One of the larger ones was for a Track system where two values for the 3 mSv ^{252}Cf field changed from 2.1 and 2.35 to 5.2 in both cases.

Table 11: Changes to the means and standard deviations for systems that revised their results between step I and step II.

Radiation field	Step	All (14)		Albedo (5)		Track (8)		Other (1)	
		Mean	SD	Mean	SD	Mean	SD	Mean	SD
^{252}Cf 0.3 mSv	I	0.97	0.76	0.55	0.72	1.18	0.72	1.39	0.1
	II	0.98	0.57	0.73	0.69	1.09	0.47	1.39	0.1
	Change	B	75%	B	96%	B	65%	S	100%
^{252}Cf 3.0 mSv	I	1.22	0.77	0.64	0.57	1.63	0.66	0.81	0.06
	II	1.04	0.50	0.63	0.53	1.32	0.28	0.81	0.06
	Change	B	65%	W	93%	B	42%	S	100%
^{252}Cf 15 mSv	I	1.19	0.69	0.58	0.51	1.59	0.54	1.07	0.04
	II	1.01	0.43	0.65	0.50	1.24	0.21	1.07	0.04
	Change	B	62%	B	98%	B	39%	S	100%
^{252}Cf at 45° 2 mSv	I	0.75	0.37	0.58	0.47	0.88	0.31	0.62	0.00
	II	0.68	0.31	0.61	0.47	0.73	0.18	0.62	0.00
	Change	W	84%	B	100%	W	58%	S	100%
D_2O mod ^{252}Cf 3 mSv	I	2.63	3.18	4.63	4.73	1.54	0.47	1.33	0.05
	II	1.10	0.33	0.89	0.42	1.21	0.21	1.33	0.05
	Change	B	10%	B	9%	B	45%	S	100%
^{252}Cf + cone 2 mSv	I	1.59	1.99	2.71	2.80	0.65	0.26	3.52	1.31
	II	0.63	0.36	0.79	0.39	0.53	0.22	1.32	0.01
	Change	B	18%	B	14%	W	85%	B	1%
250 keV 1 mSv	I	1.10	1.27	1.81	1.50	0.55	0.85	1.91	0.50
	II	0.94	0.95	0.82	1.12	1.02	0.91	0.79	0.11
	Change	B	77%	B	75%	B	107%	B	22%

Note: The results of the *DIN-albedo systems* are not included, and neither is S18 where some results were withdrawn as being not applicable and the others were unchanged. The table includes, in the rows marked 'Change', an indication whether the mean at step II was closer to 1 (B for better), further from 1 (W for worse), or the same (S for same) compared to step I. The ratios of the step II standard deviations divided by those for step I are presented as percentages; a value less than 100% means the standard deviation decreased.

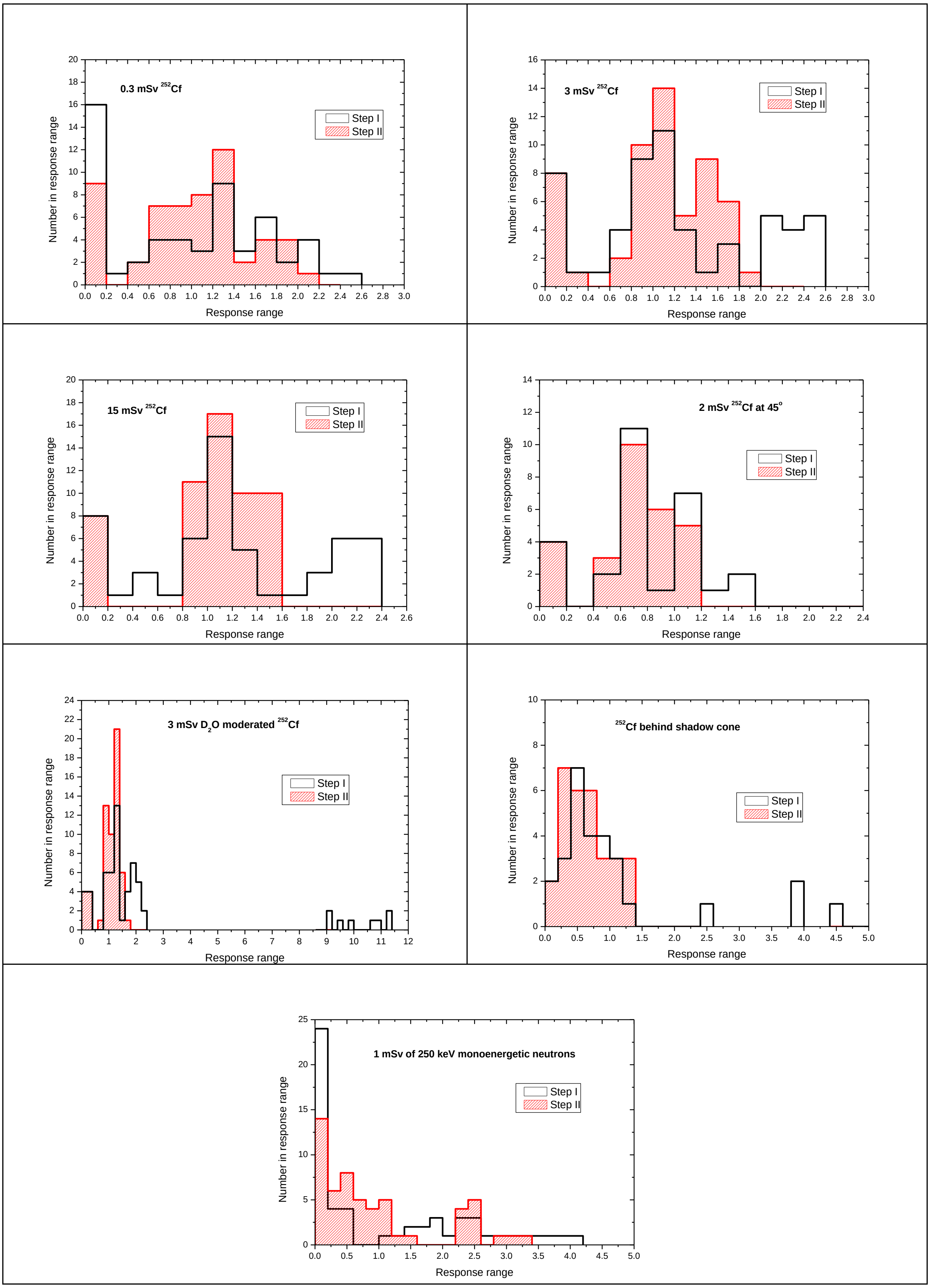

Figure 18: Frequency distribution for the results on going from step I to step II for the services that revised their results (excluding the 4 in the *DIN-albedo systems*)

3.5.2 Changes step I to step II - DIN-albedo systems

Figure 19 shows an example of the evaluation of a *DIN-albedo system*. According to DIN6802-4, there are specific calibration factors for the four different application areas N1 to N4, where N1 belongs to reactors and accelerators with heavy shielding, N2 to the fuel element cycle and criticality with low shielding, N3 to radionuclide neutron sources and N4 to accelerators for research and technology with high energies. For each application area, there is not a single calibration factor, but a calibration function which depends on the reading ratio of the field detector and the albedo detector $M_{n,f}/M_{n,a.}$ These functions have been determined at workplaces and take into account the variation due to scattered neutrons in each of the application areas into account.

Participants, who had used a DIN-albedo system (S03, S15, S19 and S31) delivered in the first step four values, one applicable for each application area, and decided in the second step – with additional field information – on the application area to be taken for each radiation quality and selected one of the four sets. In the example, as given in Figure 19, it was decided to take for the fields with information “Bare radionuclide source” (bare ^{252}Cf at 0° and at 45°, see Table 1), the application area N3, for the fields with information “Radionuclide source with significant moderated neutron fluence” (D_2O moderated ^{252}Cf and ^{252}Cf behind shadow cone) the application area N1 and for the field with information “250 keV neutrons” the application area N2.

The decision for the area N3 is quite clear, but the decision for the other fields depends on knowledge of the dosemeter type and calibration fields [53]. For this special Albedo capsule, D_2O moderated ^{252}Cf is routinely used to simulate readings in area N1 and ^{252}Cf behind shadow cone is used to simulate readings in area N2. In the latter case, the information given by the OG was not detailed enough to decide for N2, which would have given response values closer to unity (see Figure 19). In case of the “250 keV neutrons”, it was decided to take N2, since this is the most probable neutron energy at transport casks with used fuel.

The final results as shown in Figure 19 are satisfactory and could be even better with more detailed information. Nevertheless, the figure also shows clearly, that - without *a priori* information - the calibration factor can vary by roughly a factor of ten.

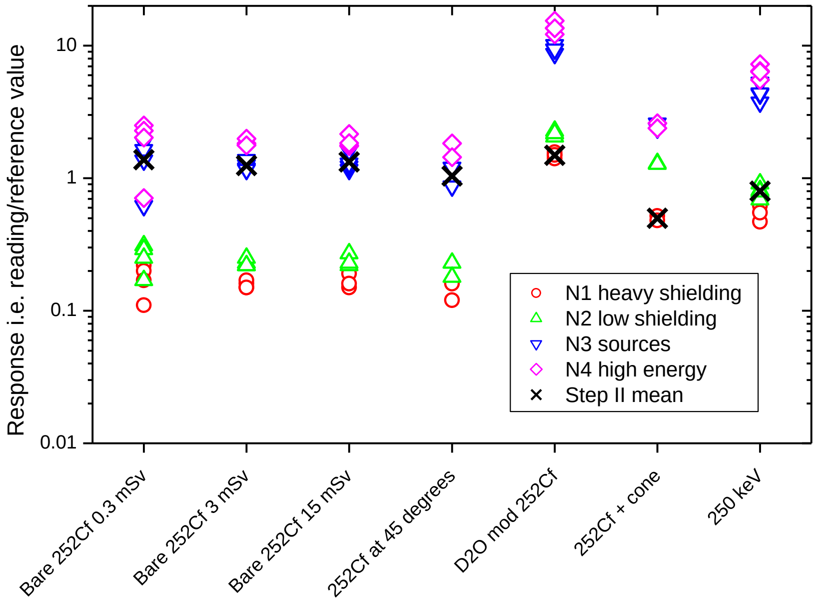

Fig.19: *DIN-albedo systems* evaluation. The crosses indicate the mean final value.

3.6 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 primarily from a comparison of the results for irradiation with ^{252}Cf neutrons at 0° and at 45°. A comparison of Figures 10 and 11 shows that the responses for 3 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* and *Other* dosemeters than for the *Albedo* ones which, except for two outliers that are very low, show rather good responses on average for 45° incidence (removing the outliers increases the mean response from 0.85 to 1.02). These 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 by which the neutrons are detected. The results for detectors of type *Other* are the lowest for 45° incidence but are also the lowest for the three 0° irradiations with ^{252}Cf.

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 cone. 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 data for the responses at the different dose in Tables 9 and 10 show that, on average, the dosemeter responses were very linear. There is some slight suggestion of a decrease for the dosemeters of type *Other*, but as noted earlier their responses for bare ^{252}Cf source irradiations tend to be a little low in general. Considering only the average responses for particular types of dosemeters does, however, hide some problems with individual albedo dosemeters e.g. two services who detected no dose for the 0.3 mSv ^{252}Cf irradiation and a very low or zero response for the other bare ^{252}Cf irradiations. These tend to distort the overall *Albedo* results.

3.7 Reproducibility

In figures such as 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 within a set. To present these data quantitatively the average values for the different irradiation fields are tabulated in Table 12 for all dosemeters and for the three types separately. It should be noted that the numbers are distorted to some extent by data where a service gave a value of zero for all responses for a particular field. The spread of the results is thus also zero, and this brings down the average standard error of the mean for this field. Nevertheless, the figures highlight some of the properties of the data discussed earlier, for example the decrease in the spread of the results as the dose equivalent increases for the 0° bare ^{252}Cf irradiations. The spread of the results for D_2O moderated ^{252}Cf is significantly smaller than for ^{252}Cf at 45°. Although it is evident from Figure 9 that there are some fairly large spreads, particularly for some irradiation fields the data of Table 12 indicate that overall the spreads were relatively small; i.e. that although some results were poor they were usually reproducible.

Table 12: Average values of the standard errors of the means for the different irradiation fields and dosemeter types

Irradiation field	Average values for the standard errors of the means			
	All	Albedo	Track	Other
^{252}Cf 0.3 mSv	11.6%	12.5%	11.5%	8.8%
^{252}Cf 3.0 mSv	4.3%	5.0%	4.2%	2.8%
^{252}Cf 15 mSv	2.2%	3.2%	1.8%	1.2%
^{252}Cf all 0° data	6.1%	6.9%	5.8%	4.3%
^{252}Cf at 45°	6.2%	4.9%	6.9%	6.6%
D_2O mod ^{252}Cf	3.2%	2.5%	4.1%	1.7%
^{252}Cf + cone	6.1%	5.4%	7.2%	2.3%
250 keV	5.6%	3.5%	7.2%	4.1%

3.8 Response values as a function of reference doses

In Figure 20 all the reported responses are plotted as a function of the reference dose delivered. Doses of 2 mSv and 3 mSv were delivered for two radiation fields: the bare ^{252}Cf at 45° and the ^{252}Cf behind shadow cone at 2 mSv, and a bare ^{252}Cf and the D_2O moderated ^{252}Cf at 3 mSv. Open symbols have been used for the ^{252}Cf behind shadow cone and the D_2O moderated results to differentiate between the fields at these energies.

The fact that, except for the three 0° irradiations with a bare ^{253}Cf source, different angles and different spectra were used means 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.

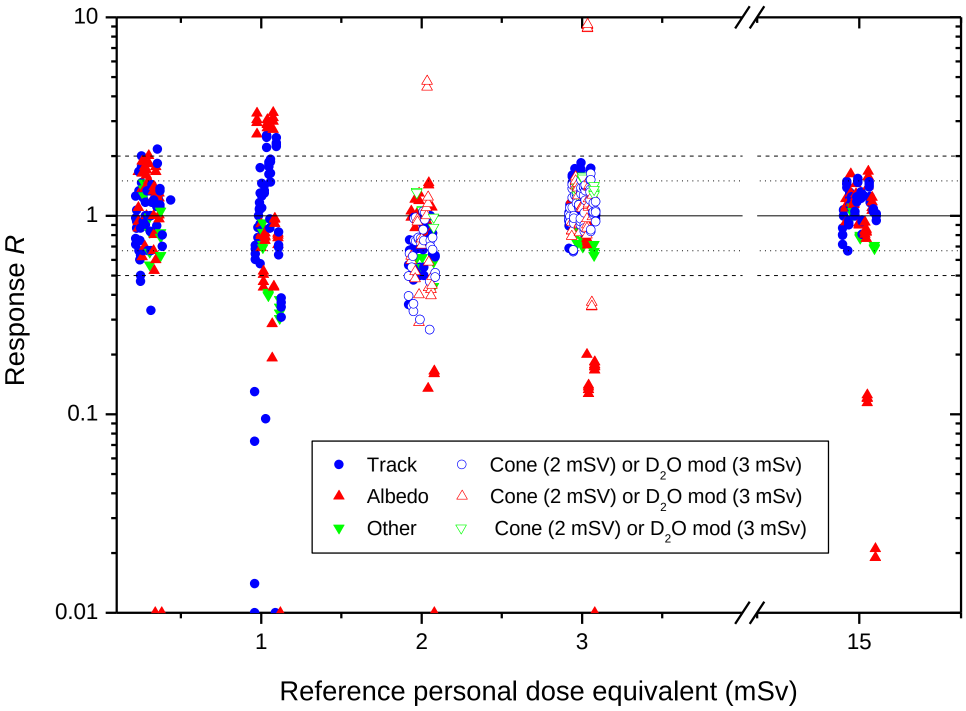

Figure 20. All reported responses plotted against the reference dose delivered. There were two irradiation fields where the reference dose was 2 mSv (bare ^{252}Cf at 45° and ^{252}Cf + shadow cone) and two where the dose was 3 mSv (bare ^{252}Cf and D_2O moderated ^{252}Cf). To differentiate these in the plot the ^{252}Cf + shadow cone and the D_2O moderated ^{252}Cf data are plotted with open symbols whereas all the other data are plotted with closed symbols.

3.9 Values outside "the factor 2"

Table 14 details the number of reported responses that were greater than 2 or less than 0.5 for the seven irradiation fields and the all reported results. In total 18% of the results were outside the factor of 2 range. One aspect of obvious concern is the number of responses < 0.5; there were 107 of these in total compared to 28 with responses > 2. Although over-reading is undesirable, under-reading is of even greater concern. The number < 0.5 for the ^{252}Cf + shadow cone field is worrying since it is probably the nearest of the fields used to simulate a typical workplace field. The large number outside the factor of 2 for the 250 keV monoenergetic irradiations is an indication of the difficulties in this region for present day passive dosemeters.

One other aspect which is clear from Table 13, and is also evident from Figure 15, is that more *Albedo* systems than *Track* systems have results which are out by a factor of greater than 2. One reason for this may be the choice of fields used, in particular the irradiations with neutrons from a bare ^{252}Cf source which is a field that is not ideally suited to Albedo systems. There were also some *Albedo* systems which had clear problems, e.g. very low responses in all fields.

Table 14: Values for all data where *R* was > 2 or < 0,5 for the different radiation fields and for the different dosemeter types

	^{252}Cf 0.3 mSv 0°	^{252}Cf 3.0 mSv 0°	^{252}Cf 15 mSv 0°	^{252}Cf 2 mSv 45°	D_2O ^{252}Cf 3 mSv	^{252}Cf+cone 2 mSv	250 keV 1 mSv	Total
Albedo								
Total	44	44	44	22	48	24	44	270
>2	1	0	0	0	4	2	12	19
<0.5	8	9	8	4	8	10	14	61
Track								
Total	68	68	68	34	68	34	68	408
>2	1	0	0	0	0	0	8	9
<0.5	3	0	0	3	0	11	20	37
Other								
Total	12	12	12	6	12	6	12	72
>2	0	0	0	0	0	0	0	0
<0.5	0	0	0	1	0	0	8	9
All dosemeters								
Total	124	124	124	62	128	64	124	750
>2	2	0	0	0	4	2	20	28
<0.5	11	9	8	8	8	21	42	107

4 Conclusions

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

About half of the systems (14 out of 32 who delivered results) show response values within a factor of roughly 2; 7 of them were *Track* detector systems which needed no additional field information, i.e., no change from step I to step II results.

Mean responses were slightly (about 30%) lower than unity for ^{252}Cf behind shadow cone and ^{252}Cf at 45°, the latter chiefly track detectors.

No 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 slightly higher standard deviation was observed.

Three *Albedo* systems showed very bad results, i.e., response values higher or lower by roughly a factor of ten

Three *Track* detector systems showed bad response values for the 250 keV neutron field, being too low by more than a factor of 10 and two other *Track* systems changed the calibration factor by roughly a factor of ten from step I to step II.

Most, but not all, participants performed acceptably well (within a factor of 2) for all irradiation conditions. Good results were obtained in most radionuclide source radiation fields. A few participants reported poor results and some of them did not cover all irradiation conditions. The conclusion depends of the dosimetric techniques on which the dosemeters are based: *Albedo* dosemeters showed chiefly problems with field dependent calibration factors and *Track* dosemeters with low energy (250 keV) neutrons and at higher angles of radiation incidence.

The two-step process, which resulted from the need to be fair to all types of services, brought out some interesting data on the requirement for and eventual use of information on the field characteristics. More than half of the systems (10 *Albedo*, 8 *Track*, 1 *Other*) changed results from step I to step II.

In the case of the four services using the *DIN-albedo systems* approach this involved choosing the most appropriate of the four possible calibration factors. At step II these systems delivered acceptable dose values. Without information on the application area, calibration factors could vary by a factor of 10.

A little surprisingly, a number of systems which in principle do not require *a priori* field information made changes, in some cases large changes.

The *DIN-albedo systems* approach of requiring information about the neutron field in which the dosemeter is used is one valid approach to the problem of the poor overall response of neutron dosemeters, however, it does not address the problems of variations in the workplace field characteristics and of workers being exposed in different environments. It also requires preliminary work to characterise the field and there are inevitably questions about how accurately the chosen calibration field matches the workplace field, an issue which came out in the discussion of the present exercise with the participants.

The EURADOS IC2012n is an important action in the field of regular performance tests in neutron dosimetry, for which intercomparisons at international level have been performed only every 8-10 years. A performance criterion for neutron dosimetry should be agreed internationally and the present intercomparison results can assist with this aim.

5 Recommendations

The ISO Standard 14146 gives criteria and performance limits to be applied for the periodic evaluation of processors for personal dosemeters, but only for X and gamma radiation. A revision of this standard or a new version specific to neutrons would need, in addition to proposing tests, requirements and criteria specific to neutrons, to take into account the important factor of the cost of neutron irradiations and the actual world-wide availability of calibration laboratories and facilities which provide irradiations for neutrons, and in particular those with ISO reference radiation fields. Besides in a new standard, dosimetry for neutron-gamma mixed fields should be taken into account.

There is a need for harmonization around the world on the quantity to be measured. This intercomparison was undertaken using the quantity personal dose equivalent but some countries have not yet adopted this ICRP recommended quantity.

The exercise has emphasised once again the need for development work on neutron personal dosemeters to address the problems of the energy and angle dependence of response and the low sensitivity.

For the next intercomparison:

- more tests at low doses would be advisable, to check the behaviour of the dosemeters to similar conditions to the ones encountered at workplaces. This would be in accordance with the draft of the revision of the ISO 21909 standard;

- find a solution to avoid the two-step procedure or improve it. Depending on the detection technique, some information about the neutron spectra is needed. On the other hand, it is difficult to be fair to all systems. It was observed that only few IMS have asked for the information and could not give results in step 1 (*DIN-albedo systems*), although more than half of the systems changed results from step I to step II, even for techniques which do not require *a priori* some information about the spectra. One possible approach is to ask at registration if the IMSs need *a priori* information, according to their routine procedure which has to be described in the application form. Give then the information to every IMSs in a second step but only the IMSs which have stated at the registration that they will need spectral information will be allowed to change their results.

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Appendix A: Time schedule

Realized time schedule of IC2012n:

15 April 2012	Announcement - Call for participants
10 June 2012	Deadline for IMS sending Application Forms with information on their dosemeters
30 June 2012	Confirmation of participation by OG coordinator and instructions to provide dosemeters
3 August 2012	Deadline for IMS sending dosemeters to OG coordinator
October–November 2012	Irradiations at NPL and PTB and irradiation data to the OG coordinator
20 December 2012	Instructions to IMSs to provide results with general information on radiation fields
20-24 December 2012	Dosemeters sent back to IMSs for readout
31 January 2013	Deadline for IMS to send 1st step results
28 February 2013	OG coordinator sent radiation field information to provide the 2nd step-final results
10 March 2013	Deadline for IMS to send 2st step results
24 April 2013	Final and reference results from OG coordinator to the participants
3 May 2013	Deadline to confirm the results by IMS
4th June 2013	Participant's meeting
30 June 2013	Certificate of Participation to all IMSs

Appendix B: confidentiality clause template

European Radiation Dosimetry Group

EURADOS

CONFIDENTIALITY UNDERTAKING FOR INTERCOMPARISON ORGANIZATION GROUP MEMBERS

1. I hereby undertake, as part of the terms and conditions of my participation in the Organization Group (OG) of IC2012n - 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 ***Organization Group for the IC2012n - Intercomparison for neutron dosimetry (OG2012n)*** to any person, or organization not authorized 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 unauthorized use of such information to my private advantage or to that of any third party.

3. I undertake that, at all times following the termination of my involvement within the OG2012n, 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 inter-comparisons exercises.

4. I understand:

that a breach of my obligation not to disclose confidential information without appropriate authorization, 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: _______________________________________

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Version 1.2 - July 2008

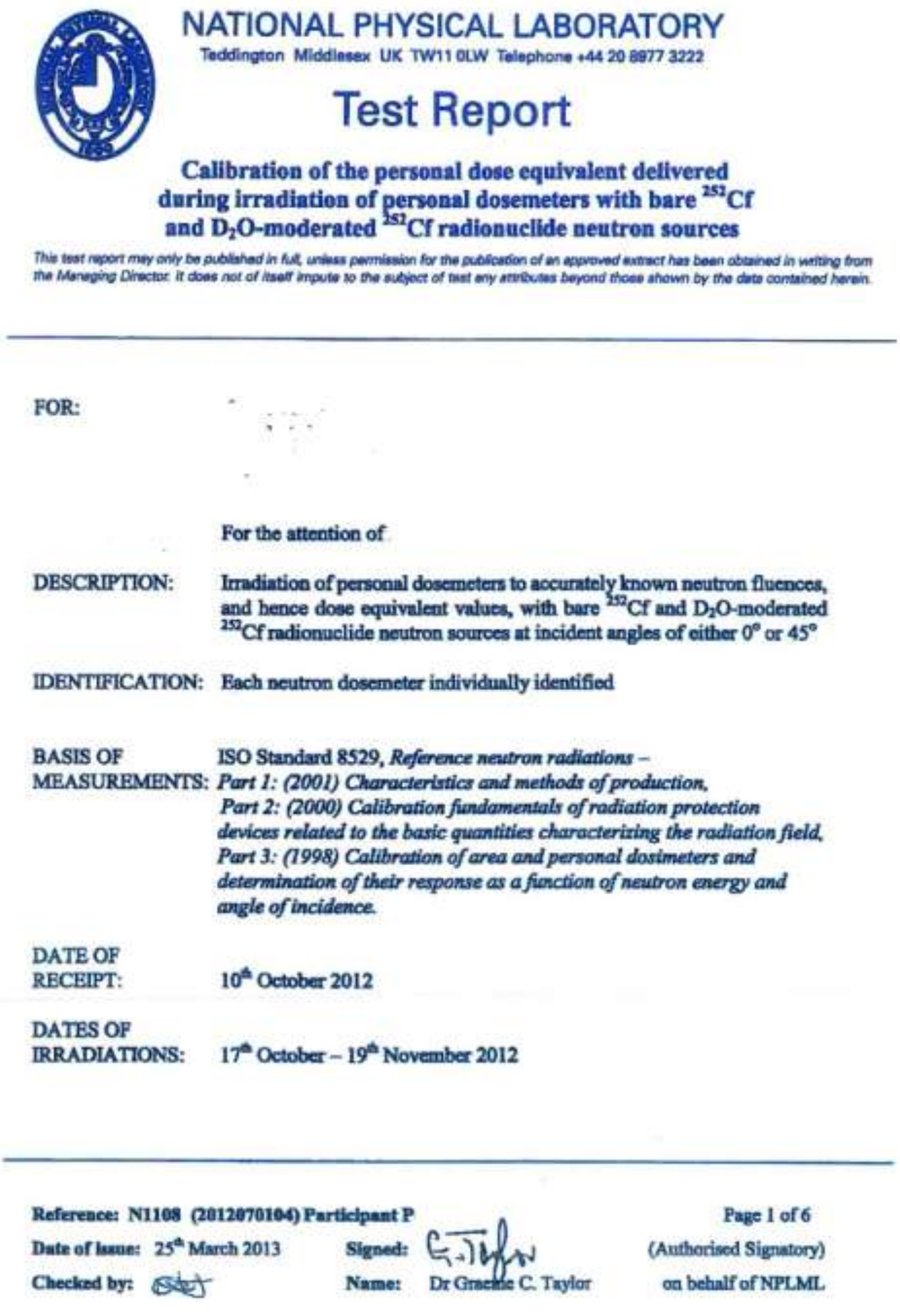
Appendix C: List of participants

Participants sorted alphabetically by country and IMS

Name of the IMS	***Place***	***Country***
Seibersdorf Labor GmbH - Dosimetry Service	Seibersdorf	AUSTRIA
INTERNATIONAL ATOMIC ENERGY AGENCY: Department of Nuclear Safety and Security - Division of Radiation, Transport and Waste - Safety Radiation Safety and Monitoring Section - Radiation Protection of Workers and Monitoring Unit	Wien	AUSTRIA
AV-CONTROLATOM	Vilvoorde	BELGIUM
Sluzba osobni dozimetrie, VF, a.s.	Cerna Hora	CZECH REPUBLIC
CSOD - Celostátni služba osobni dozimetrie, s.r.o. (NPDS - National Personal Dosimetry Service, Ltd)	Praha	CZECH REPUBLIC
Fortum, Loviisa Nuclear Power Plant	Loviisa	FINLAND
IRSN, Institut de Radioprotection et de Sûreté Nucléaire, PRP-LDI	Le Vésinet	FRANCE
Service de Protection Radiologique des Armées (SPRA) - French Army - Radiation Protection Service	Clamart	FRANCE
LANDAUER EUROPE	Fontenay-aux-Roses	FRANCE
Service de Dosimétrie - Institut de Pysique Nucléaire d'Orsay - Centre National de la Recherche Scientifique	Orsay	FRANCE
LPS, Landesantalt fuer Personendosimetrie und Strahlenschutzausbildung	Berlin	GERMANY
Senatsvenwaltung fuer Stadtentwicklung und Umwelt - Personendosismessstelle	Berlin	GERMANY
HMGU - Auswertungsstelle fuer Strahlendosimeter	Muenchen	GERMANY
Personal Dosimetry Department, Greek Atomic Energy Commission	Athens	GREECE
SNRC Personal Dosimetry Lab	Yavne	ISRAEL
Tecnorad s.r.l.	Verona	ITALY
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
Chiyoda Technol Corporation	Ibaraki	JAPAN
Nagase-Landauer, Ltd. Japan	Ibaraki-ken	JAPAN
Laboratory of individual and Environmental Dosimetry (LADIS)	Krakow	POLAND
DOZIMED S.R.L.	Magurele (Bucharest)	ROMANIA
Dosimetry Laboratory Krško NPP	Krško	SLOVENIA
Ringhals AB	Väröbacka	SWEDEN
Paul Scherrer Institut	Villigen	SWITZERLAND
CERN Dosimetry Service	Geneva	SWITZERLAND
NRG	ES Arnhem	THE NETHERLAND
The Personal Dosimetry Service of the Health Protection Agency (now Public Health England)	Chilton, Didcot	UNITED KINGDOM
Dstl, Environmental Sciences Department, INM	Alverstoke	UNITED KINGDOM
Berkeley Approved Dosimetry Service	Berkeley, Gloucestershire	UNITED KINGDOM
Mirion Technologies (GDS), Inc.	Irvine, California	USA

Appendix D: Example irradiation certificates



NATIONAL PHYSICAL LABORATORY
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Test Report

Calibration of the personal dose equivalent delivered during irradiation of personal dosemeters with bare ^{252}Cf and D_2O-moderated ^{252}Cf radionuclide neutron sources

This test report may only be published in full, unless permission for the publication of an approved extract has been obtained in writing from the Managing Director. It does not of itself impute to the subject of test any attributes beyond those shown by the data contained herein.

FOR:

For the attention of

DESCRIPTION: Irradiation of personal dosemeters to accurately known neutron fluences, and hence dose equivalent values, with bare ^{252}Cf and D_2O-moderated ^{252}Cf radionuclide neutron sources at incident angles of either 0° or 45°

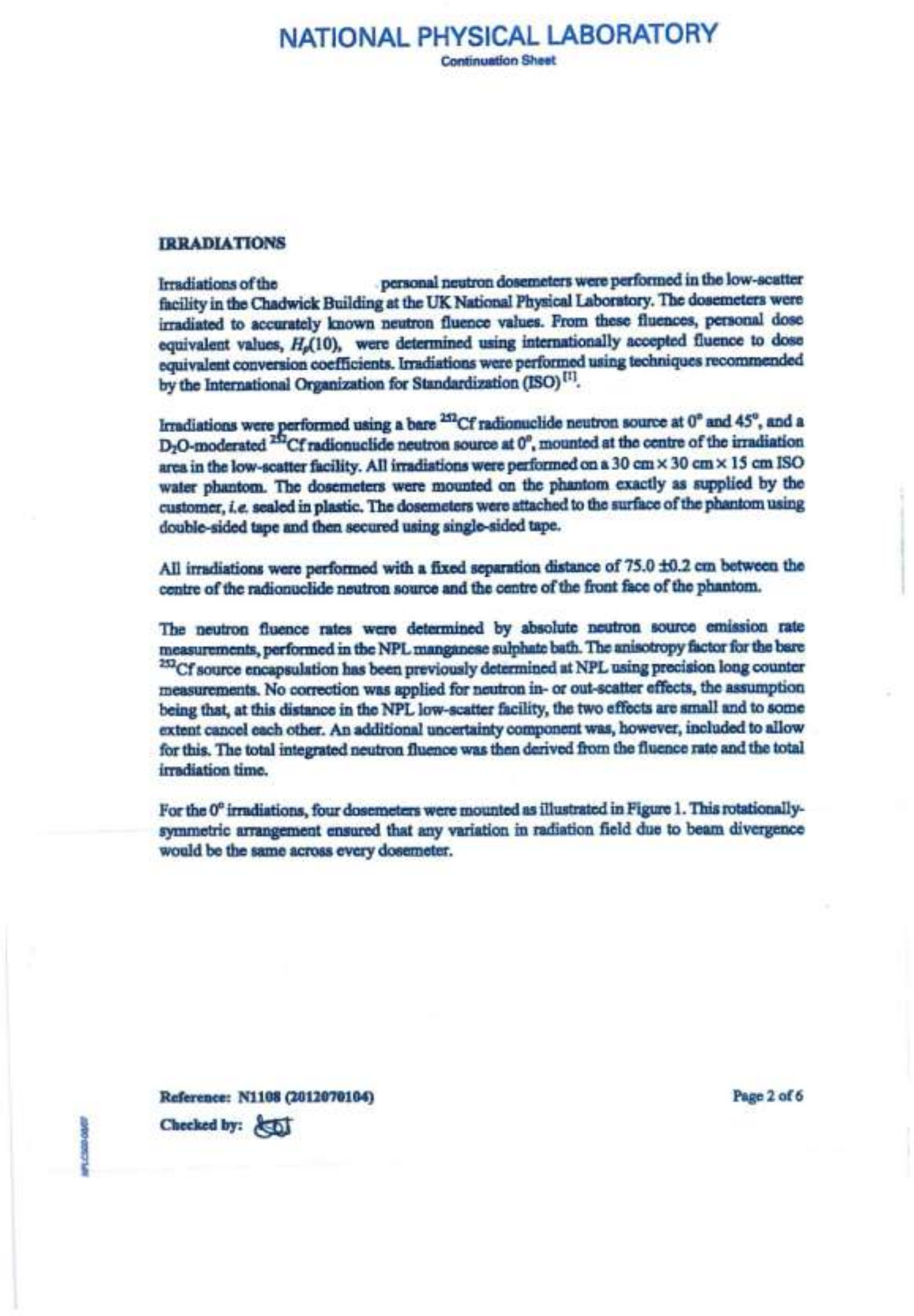
IDENTIFICATION: Each neutron dosemeter individually identified

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: 10th October 2012

DATES OF IRRADIATIONS: 17th October – 19th November 2012

Reference: N1108 (2012070104) Participant P
Page 1 of 6
Date of issue: 25th March 2013
Signed:
(Authorised Signatory)
Checked by:
Name: Dr Graeme C. Taylor
on behalf of NPLML



NATIONAL PHYSICAL LABORATORY

Continuation Sheet

IRRADIATIONS

Irradiations of the personal neutron dosemeters 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 D_2O-moderated ^{252}Cf radionuclide neutron source at 0°, mounted at the centre of the irradiation area in the low-scatter facility. All irradiations were performed on a 30 cm × 30 cm × 15 cm ISO water phantom. The dosemeters were mounted on the phantom exactly as supplied by the customer, *i.e.* sealed in plastic. 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 with a fixed separation 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 factor for the bare ^{252}Cf source encapsulation has 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.

Reference: N1108 (2012070104) **Page 2 of 6**

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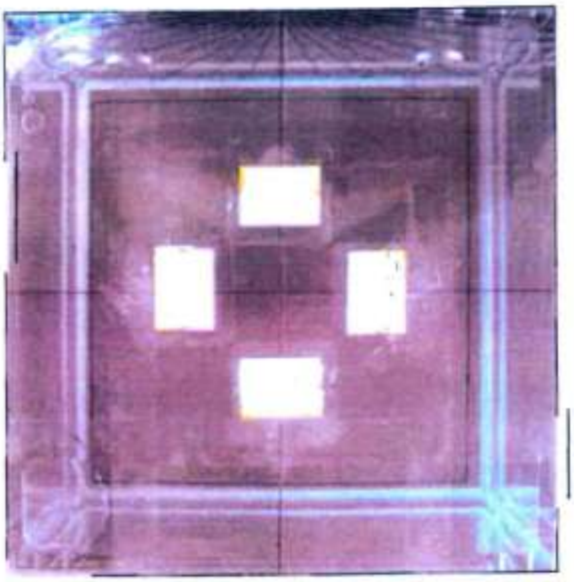


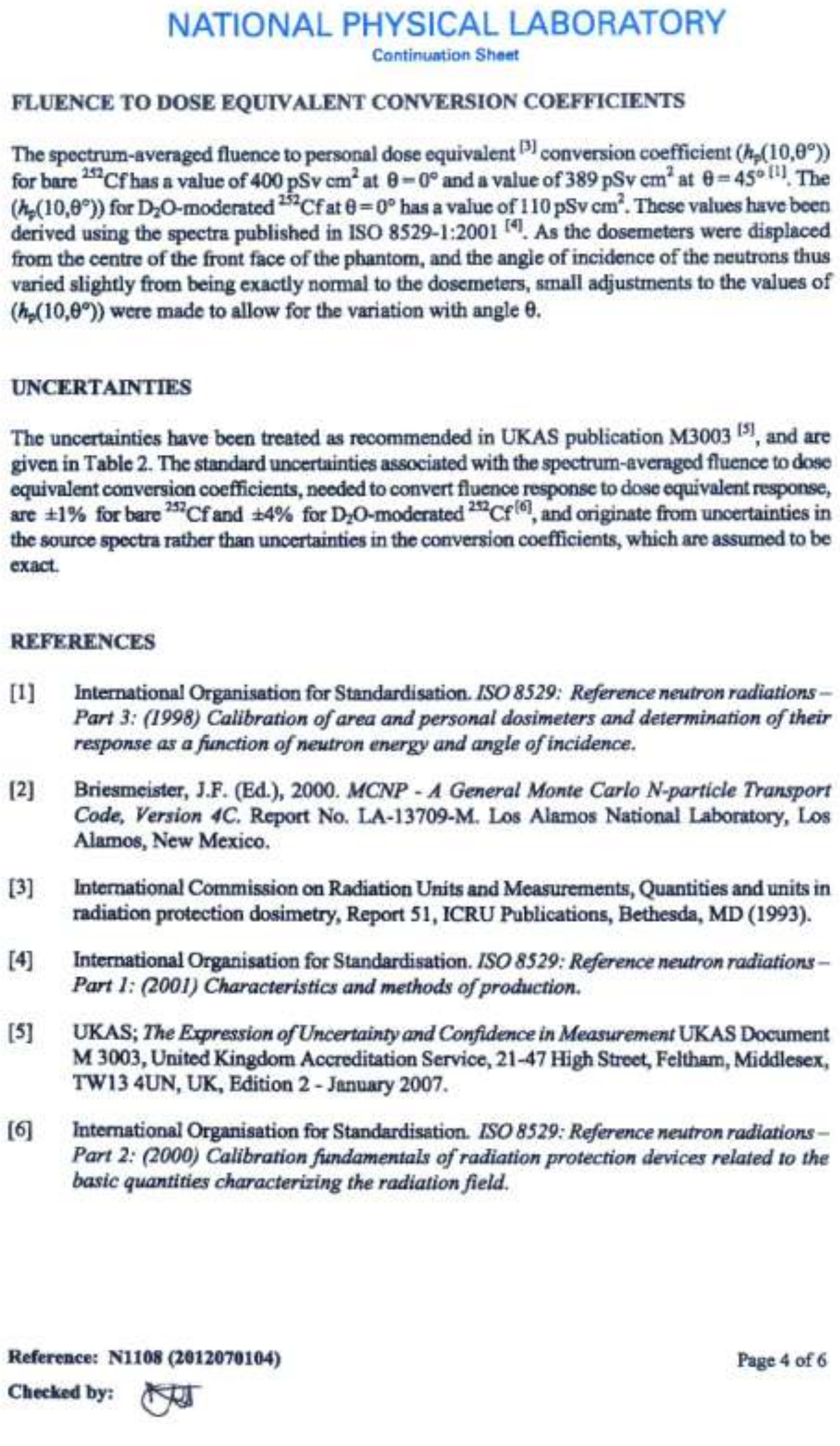
Figure 1: Rotationally symmetric arrangement employed for the irradiations of groups of four dosemeters.

For the 45° irradiation, two dosemeters were mounted on the axis of rotation, *i.e.* equivalent to the position of the two dosemeters mounted on the vertical axis in Figure 1.

Although the D_2O moderator has a 30 cm diameter, it behaves remarkably like a point source, *i.e.* the neutron fluence rate follows an inverse square law. This has been verified using Monte Carlo calculations, performed using the PTRAC option of MCNP [2].

RESULTS

Table 1 quotes the nominal exposure, dosemeter numbers, radial displacement (measured to the centre of the dosemeter holder), angle, source-to-dosemeter distance (measured from the centre of the source capsule to the point on the surface of the front face of the phantom directly behind the reference point of the dosemeter) and the neutron personal dose equivalent that each dosemeter received (subject to the above assumptions).



FLUENCE TO DOSE EQUIVALENT CONVERSION COEFFICIENTS

The spectrum-averaged fluence to personal dose equivalent [3] conversion coefficient $(h_p(10,\theta^\circ))$ for bare ^{252}Cf has a value of 400 pSv cm^2 at $\theta = 0^\circ$ and a value of 389 pSv cm^2 at $\theta = 45^\circ$ [1]. The $(h_p(10,\theta^\circ))$ for D_2O-moderated ^{252}Cf at $\theta = 0^\circ$ has a value of 110 pSv cm^2. These values have been derived using the spectra published in ISO 8529-1:2001 [4]. As the dosemeters were displaced from the centre of the front face of the phantom, and the angle of incidence of the neutrons thus varied slightly from being exactly normal to the dosemeters, small adjustments to the values of $(h_p(10,\theta^\circ))$ were made to allow for the variation with angle θ.

UNCERTAINTIES

The uncertainties have been treated as recommended in UKAS publication M3003 [5], 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 D_2O-moderated ^{252}Cf [6], and originate from uncertainties in the source spectra rather than uncertainties in the conversion coefficients, which are assumed to be exact.

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Reference: **N1108 (2012070104)**

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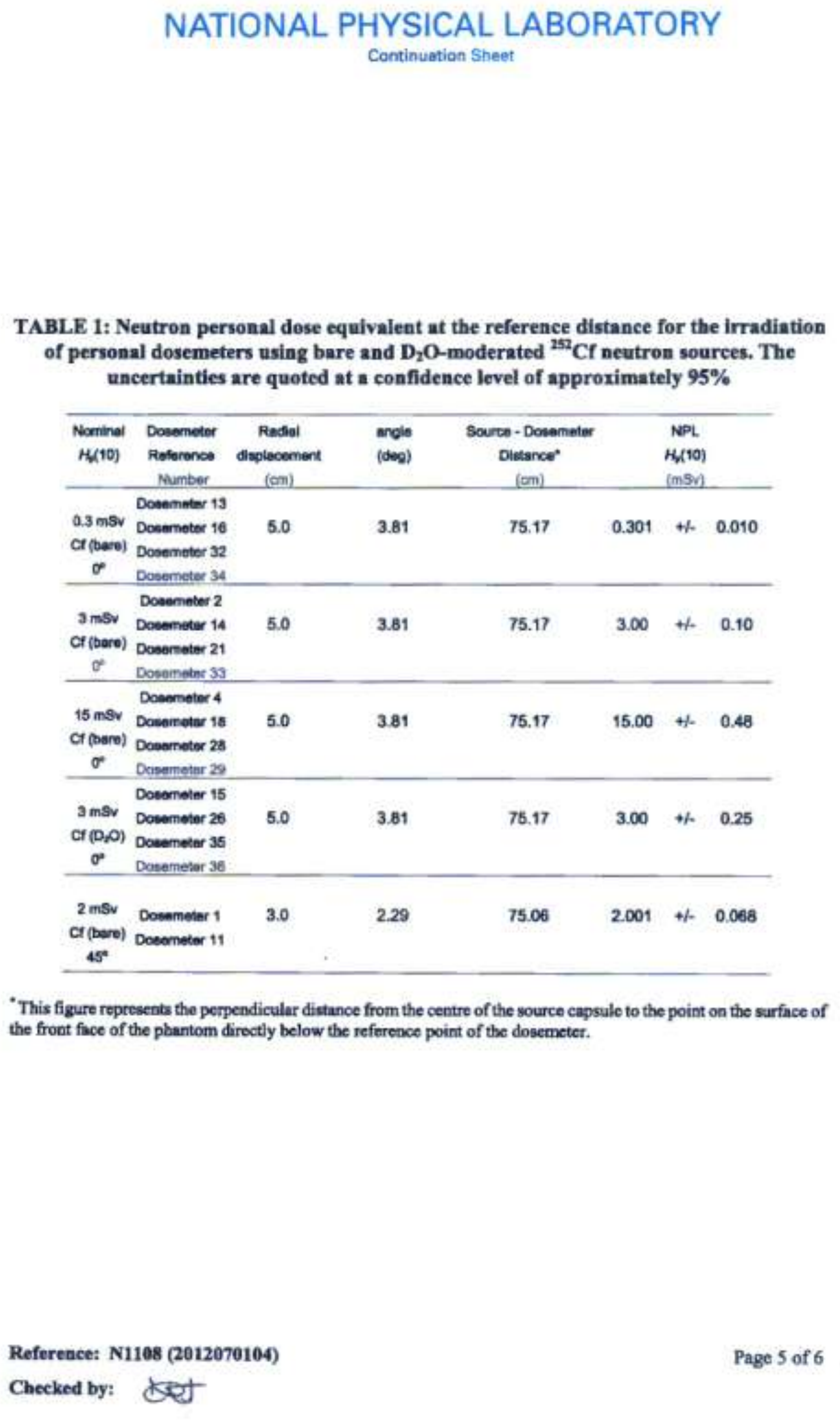

NATIONAL PHYSICAL LABORATORY
Continuation Sheet

TABLE 1: Neutron personal dose equivalent at the reference distance for the irradiation of personal dosemeters using bare and D_2O-moderated ^{252}Cf neutron sources. The uncertainties are quoted at a confidence level of approximately 95%

Nominal $H_p(10)$	Dosemeter Reference Number	Radial displacement (cm)	angle (deg)	Source - Dosemeter Distance* (cm)	NPL $H_p(10)$ (mSv)		
0.3 mSv Cf (bare) 0°	Dosemeter 13 Dosemeter 16 Dosemeter 32 Dosemeter 34	5.0	3.81	75.17	0.301	+/-	0.010
3 mSv Cf (bare) 0°	Dosemeter 2 Dosemeter 14 Dosemeter 21 Dosemeter 33	5.0	3.81	75.17	3.00	+/-	0.10
15 mSv Cf (bare) 0°	Dosemeter 4 Dosemeter 18 Dosemeter 28 Dosemeter 29	5.0	3.81	75.17	15.00	+/-	0.48
3 mSv Cf (D_2O) 0°	Dosemeter 15 Dosemeter 26 Dosemeter 35 Dosemeter 36	5.0	3.81	75.17	3.00	+/-	0.25
2 mSv Cf (bare) 45°	Dosemeter 1 Dosemeter 11	3.0	2.29	75.06	2.001	+/-	0.068

*This figure represents the perpendicular distance from the centre of the source capsule to the point on the surface of the front face of the phantom directly below the reference point of the dosemeter.

Reference: N1108 (2012070104)

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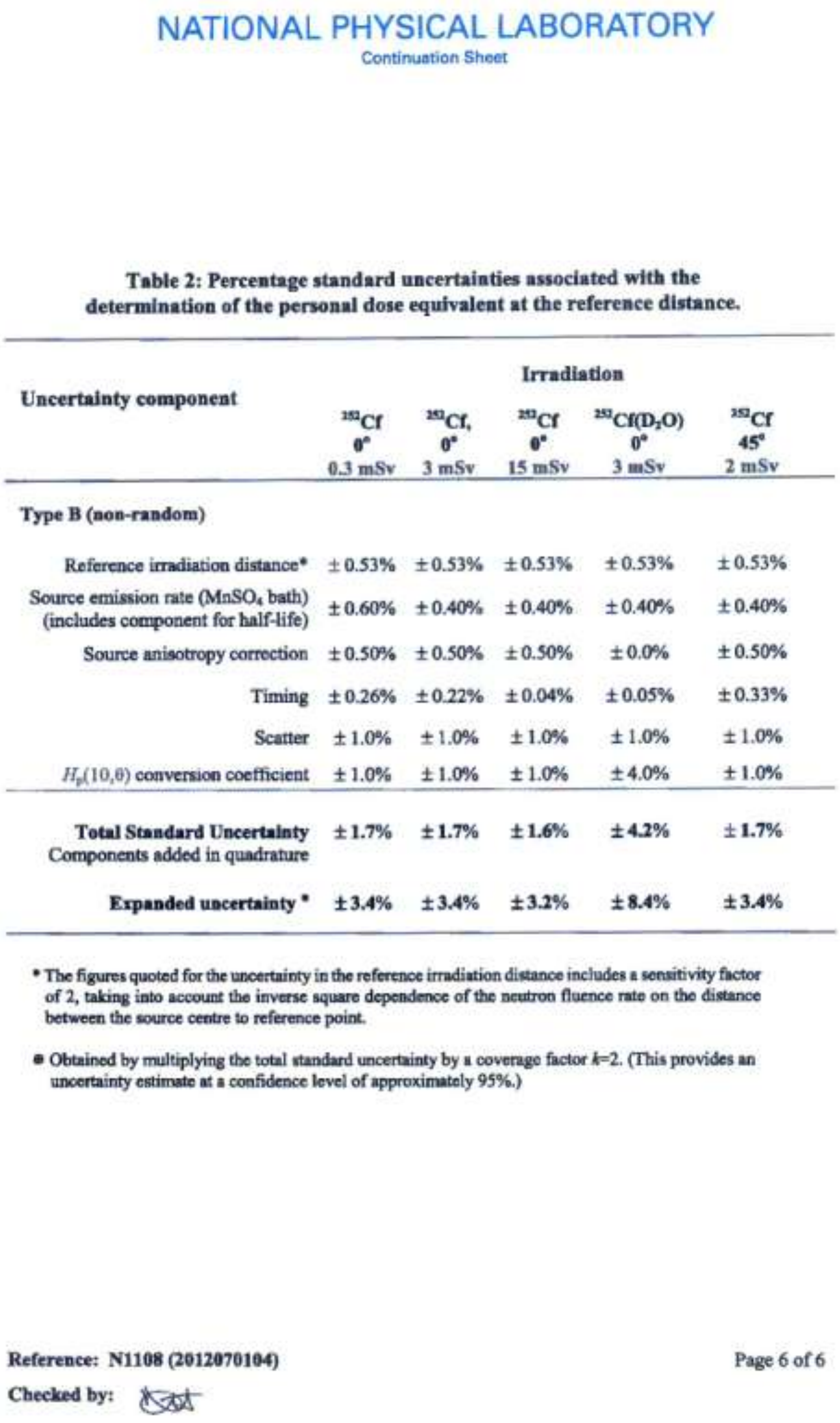

NATIONAL PHYSICAL LABORATORY
Continuation Sheet

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

Uncertainty component	Irradiation				
	^{252}Cf 0° 0.3 mSv	^{252}Cf, 0° 3 mSv	^{252}Cf 0° 15 mSv	^{252}Cf(D$_2$O) 0° 3 mSv	^{252}Cf 45° 2 mSv
Type B (non-random)					
Reference irradiation distance*	±0.53%	±0.53%	±0.53%	±0.53%	±0.53%
Source emission rate (MnSO$_4$ bath) (includes component for half-life)	±0.60%	±0.40%	±0.40%	±0.40%	±0.40%
Source anisotropy correction	±0.50%	±0.50%	±0.50%	±0.0%	±0.50%
Timing	±0.26%	±0.22%	±0.04%	±0.05%	±0.33%
Scatter	±1.0%	±1.0%	±1.0%	±1.0%	±1.0%
$H_p(10,\theta)$ conversion coefficient	±1.0%	±1.0%	±1.0%	±4.0%	±1.0%
Total Standard Uncertainty Components added in quadrature	±1.7%	±1.7%	±1.6%	±4.2%	±1.7%
Expanded uncertainty ●	±3.4%	±3.4%	±3.2%	±8.4%	±3.4%

* 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 at a confidence level of approximately 95%.)

Reference: N1108 (2012070104)

Page 6 of 6

Checked by:

Physikalisch-Technische Bundesanstalt

Braunschweig und Berlin

PTB

Prüfbericht

Test Report

Gegenstand: *Object:*	Irradiation of whole body dosemeters in neutron reference fields
Hersteller: *Manufacturer:*	-
Typ: *Type:*	Whole body dosemeters
Gerätenummer: *Serial No.:*	-
Auftraggeber: *Applicant:*	
Anzahl der Seiten: *Number of pages:*	7
Geschäftszeichen: *Reference No.:*	PTB-6.5-11/12_P XX
Prüfzeichen: *Test mark:*	-
Datum der Prüfung: *Date of test:*	2012-10-18 to 2012-11-18

Im Auftrag
On behalf of PTB

Dr. M. Luszik-Bhadra

Braunschweig, 2013-01-18

Siegel
Seal

15

Im Auftrag
On behalf of PTB

Dr. S. Röttger

393 038 I

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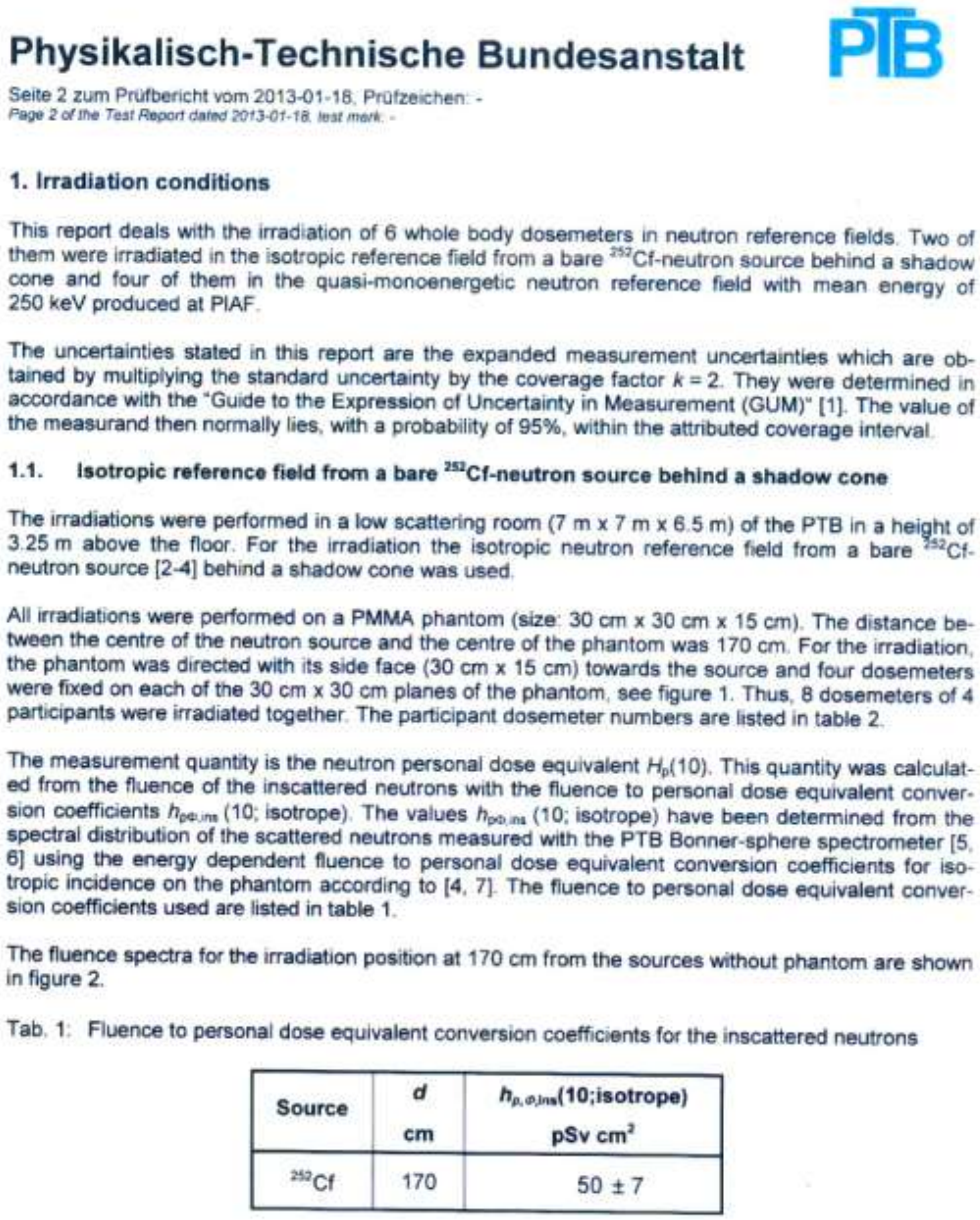


Physikalisch-Technische Bundesanstalt PTB

Seite 2 zum Prüfbericht vom 2013-01-18, Prüfzeichen: -
Page 2 of the Test Report dated 2013-01-18, test mark: -

1. Irradiation conditions

This report deals with the irradiation of 6 whole body dosemeters in neutron reference fields. Two of them were irradiated in the isotropic reference field from a bare ^{252}Cf-neutron source behind a shadow cone and four of them in the quasi-monoenergetic neutron reference field with mean energy of 250 keV produced at PIAF.

The uncertainties stated in this report are the expanded measurement uncertainties which are obtained by multiplying the standard uncertainty by the coverage factor $k = 2$. They were 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 interval.

1.1. Isotropic reference field from a bare ^{252}Cf-neutron source behind a shadow cone

The irradiations were performed in a low scattering room (7 m x 7 m x 6.5 m) of the PTB in a height of 3.25 m above the floor. For the irradiation the isotropic neutron reference field from a bare ^{252}Cf-neutron source [2-4] behind a shadow cone was used.

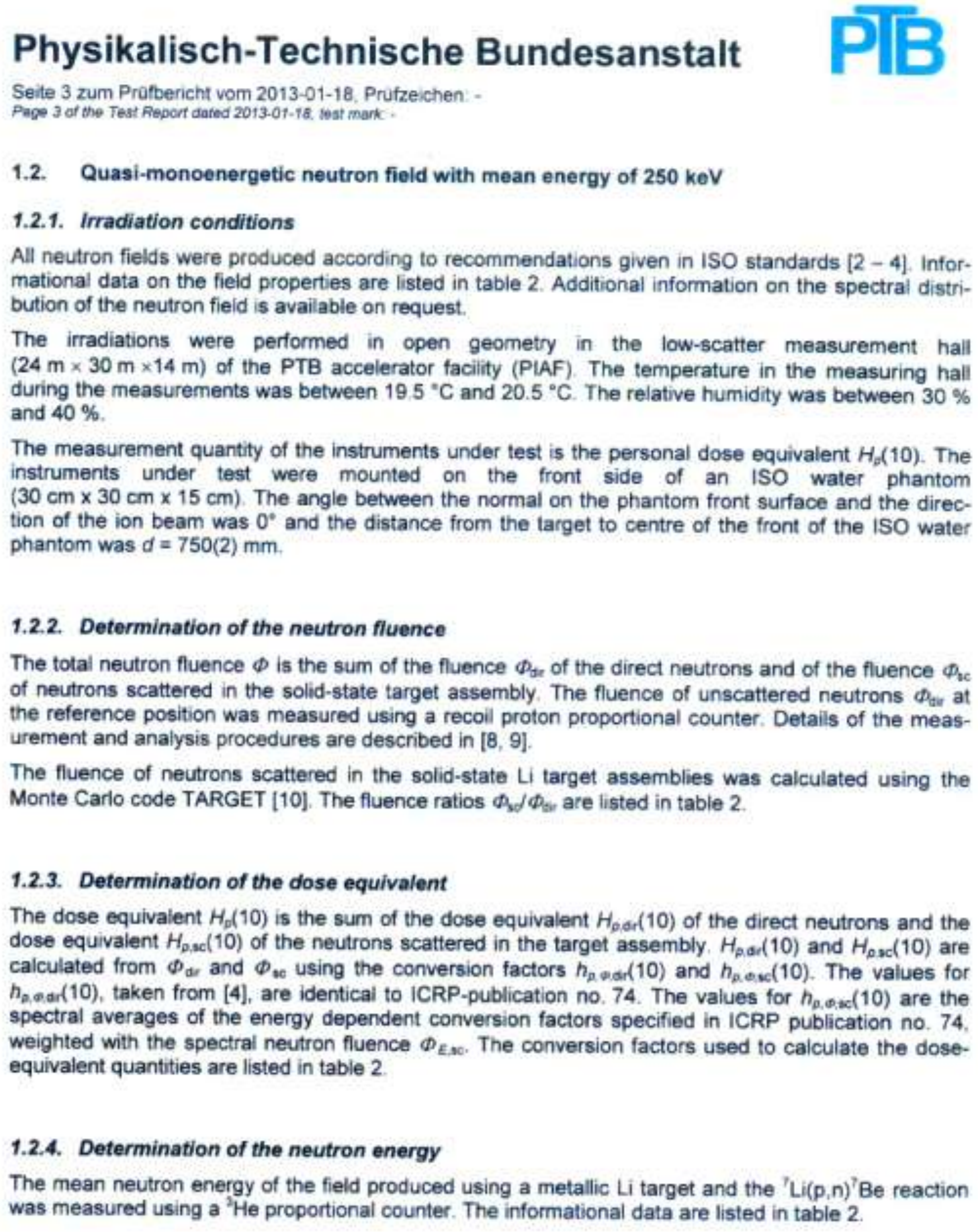
All irradiations were performed on a PMMA phantom (size: 30 cm x 30 cm x 15 cm). The distance between the centre of the neutron source and the centre of the phantom was 170 cm. For the irradiation, the phantom was directed with its side face (30 cm x 15 cm) towards the source and four dosemeters were fixed on each of the 30 cm x 30 cm planes of the phantom, see figure 1. Thus, 8 dosemeters of 4 participants were irradiated together. The participant dosemeter numbers are listed in table 2.

The measurement quantity is the neutron personal dose equivalent $H_p(10)$. This quantity was calculated from the fluence of the inscattered neutrons with the fluence to personal dose equivalent conversion coefficients $h_{p\Phi,\mathrm{ins}}$ (10; isotrope). The values $h_{p\Phi,\mathrm{ins}}$ (10; isotrope) have been determined from the spectral distribution of the scattered neutrons measured with the PTB Bonner-sphere spectrometer [5, 6] using the energy dependent fluence to personal dose equivalent conversion coefficients for isotropic incidence on the phantom according to [4, 7]. The fluence to personal dose equivalent conversion coefficients used are listed in table 1.

The fluence spectra for the irradiation position at 170 cm from the sources without phantom are shown in figure 2.

Tab. 1: Fluence to personal dose equivalent conversion coefficients for the inscattered neutrons

Source	***d*** **cm**	**$h_{p,\Phi,\mathrm{ins}}$(10;isotrope)** **pSv cm^2**
^{252}Cf	170	50 ± 7



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1.2. Quasi-monoenergetic neutron field with mean energy of 250 keV

1.2.1. Irradiation conditions

All neutron fields were produced according to recommendations given in ISO standards [2 – 4]. Informational data on the field properties are listed in table 2. Additional information on the spectral distribution of the neutron field is available on request.

The irradiations were performed in open geometry in the low-scatter measurement hall (24 m × 30 m ×14 m) of the PTB accelerator facility (PIAF). The temperature in the measuring hall during the measurements was between 19.5 °C and 20.5 °C. The relative humidity was between 30 % and 40 %.

The measurement quantity of the instruments under test is the personal dose equivalent $H_p(10)$. The instruments under test were mounted on the front side of an ISO water phantom (30 cm x 30 cm x 15 cm). The angle between the normal on the phantom front surface and the direction of the ion beam was 0° and the distance from the target to centre of the front of the ISO water phantom was d = 750(2) mm.

1.2.2. Determination of the neutron fluence

The total neutron fluence Φ is the sum of the fluence Φ_{dir} of the direct neutrons and of the fluence Φ_{sc} of neutrons scattered in the solid-state target assembly. The fluence of unscattered neutrons Φ_{dir} at the reference position was measured using a recoil proton proportional counter. Details of the measurement and analysis procedures are described in [8, 9].

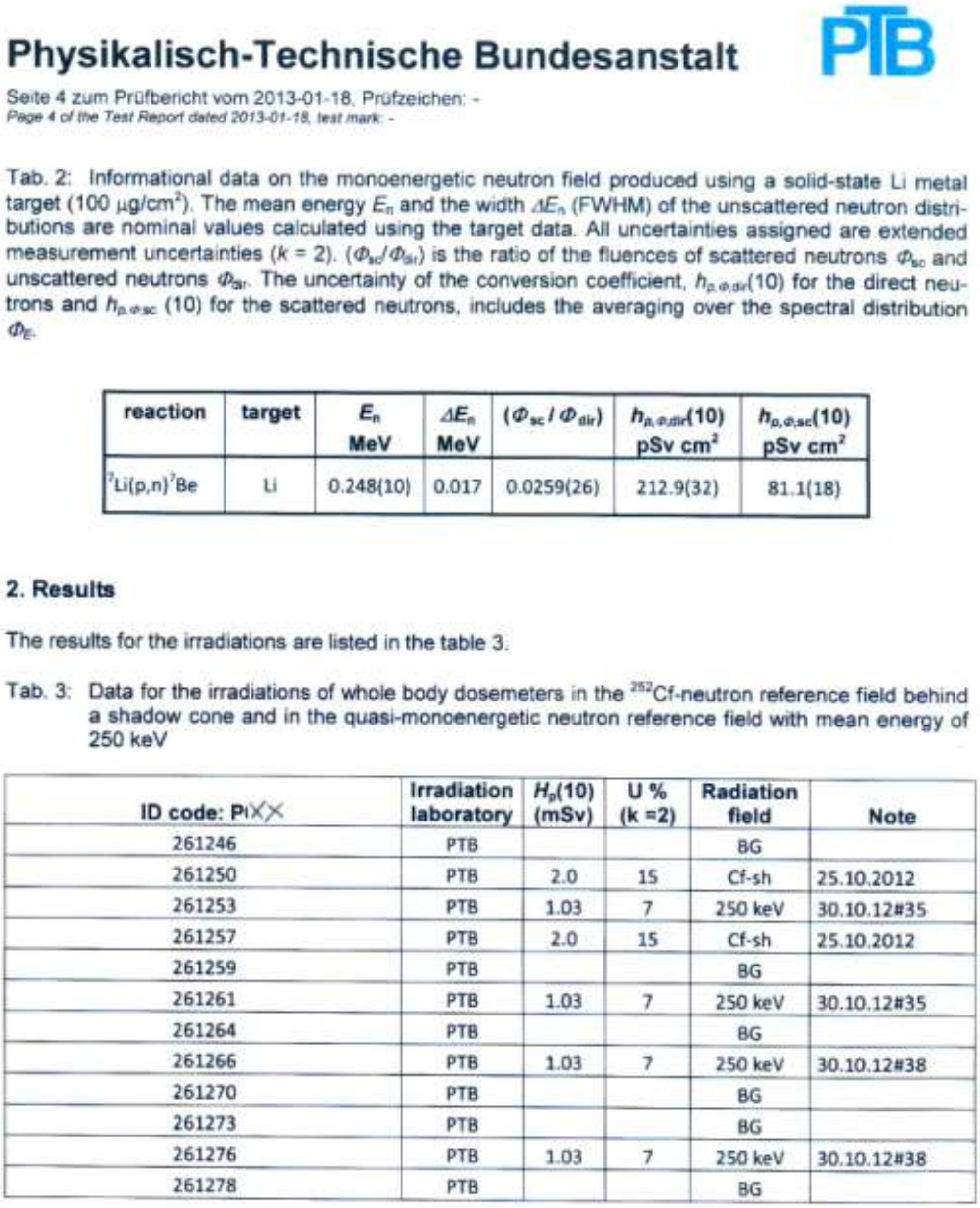
The fluence of neutrons scattered in the solid-state Li target assemblies was calculated using the Monte Carlo code TARGET [10]. The fluence ratios Φ_{sc}/Φ_{dir} are listed in table 2.

1.2.3. Determination of the dose equivalent

The dose equivalent $H_p(10)$ is the sum of the dose equivalent $H_{p,dir}(10)$ of the direct neutrons and the dose equivalent $H_{p,sc}(10)$ of the neutrons scattered in the target assembly. $H_{p,dir}(10)$ and $H_{p,sc}(10)$ are calculated from Φ_{dir} and Φ_{sc} using the conversion factors $h_{p,\Phi,dir}(10)$ and $h_{p,\Phi,sc}(10)$. The values for $h_{p,\Phi,dir}(10)$, taken from [4], are identical to ICRP-publication no. 74. The values for $h_{p,\Phi,sc}(10)$ are the spectral averages of the energy dependent conversion factors specified in ICRP publication no. 74, weighted with the spectral neutron fluence $\Phi_{E,sc}$. The conversion factors used to calculate the dose-equivalent quantities are listed in table 2.

1.2.4. Determination of the neutron energy

The mean neutron energy of the field produced using a metallic Li target and the ^{7}Li(p,n)^{7}Be reaction was measured using a ^{3}He proportional counter. The informational data are listed in table 2.



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Tab. 2: Informational data on the monoenergetic neutron field produced using a solid-state Li metal target (100 µg/cm^2). The mean energy E_n and the width ΔE_n (FWHM) of the unscattered neutron distributions are nominal values calculated using the target data. All uncertainties assigned are extended measurement uncertainties (k = 2). (Φ_{sc}/Φ_{dir}) is the ratio of the fluences of scattered neutrons Φ_{sc} and unscattered neutrons Φ_{dir}. The uncertainty of the conversion coefficient, $h_{p,\Phi,dir}(10)$ for the direct neutrons and $h_{p,\Phi,sc}$ (10) for the scattered neutrons, includes the averaging over the spectral distribution Φ_E.

reaction	target	E_n MeV	ΔE_n MeV	(Φ_{sc} / Φ_{dir})	$h_{p,\Phi,dir}(10)$ pSv cm^2	$h_{p,\Phi,sc}(10)$ pSv cm^2
^{7}Li(p,n)^{7}Be	Li	0.248(10)	0.017	0.0259(26)	212.9(32)	81.1(18)

2. Results

The results for the irradiations are listed in the table 3.

Tab. 3: Data for the irradiations of whole body dosemeters in the ^{252}Cf-neutron reference field behind a shadow cone and in the quasi-monoenergetic neutron reference field with mean energy of 250 keV

ID code: PIXX	Irradiation laboratory	$H_p(10)$ (mSv)	U % (k =2)	Radiation field	Note
261246	PTB			BG	
261250	PTB	2.0	15	Cf-sh	25.10.2012
261253	PTB	1.03	7	250 keV	30.10.12#35
261257	PTB	2.0	15	Cf-sh	25.10.2012
261259	PTB			BG	
261261	PTB	1.03	7	250 keV	30.10.12#35
261264	PTB			BG	
261266	PTB	1.03	7	250 keV	30.10.12#38
261270	PTB			BG	
261273	PTB			BG	
261276	PTB	1.03	7	250 keV	30.10.12#38
261278	PTB			BG	

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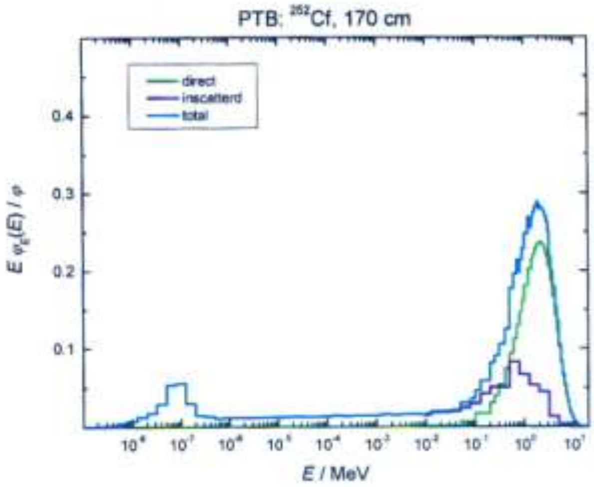
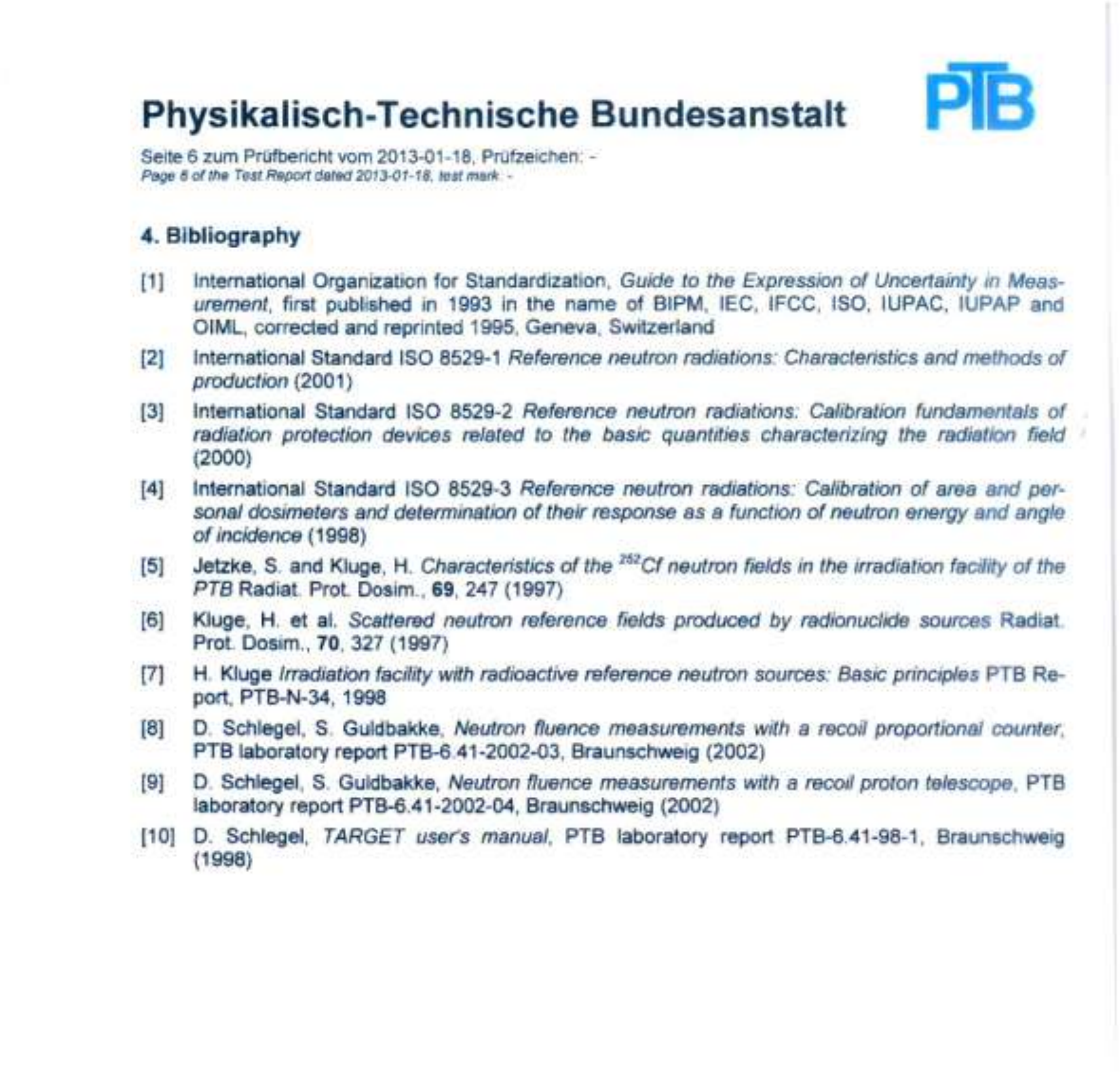
3. Figures

Figure 1: Picture for illustrating the neutron irradiation geometry for irradiations in the isotropic reference field from a bare ^{252}Cf-neutron source behind a shadow cone

Figure 2: Fluence spectrum for the direct and the inscattered part (without phantom) at 170 cm distance from the source for the ^{252}Cf source





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Page 6 of the Test Report dated 2013-01-18, test mark: -

4. Bibliography

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

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

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

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

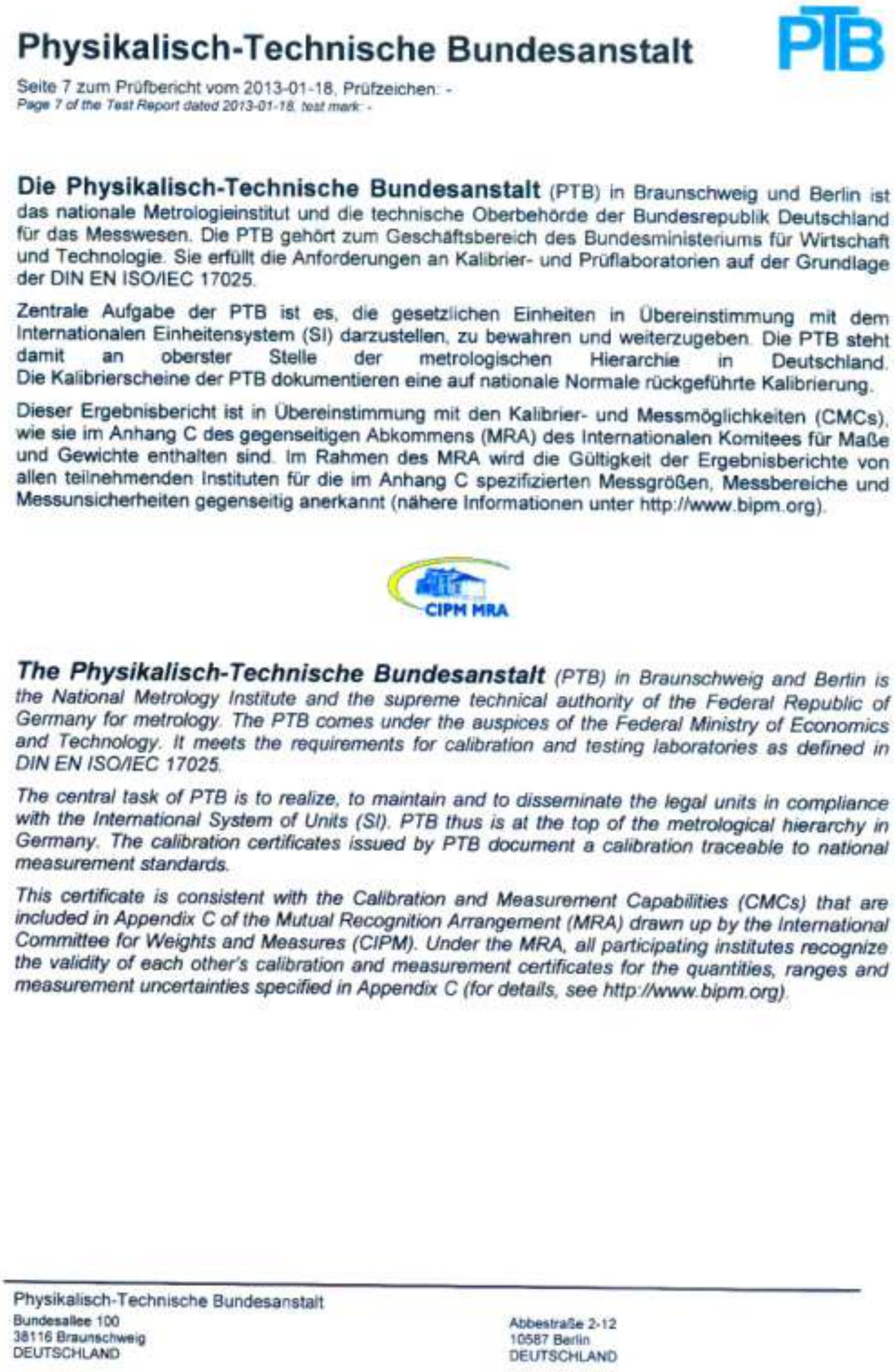
[6] Kluge, H. et al. *Scattered neutron reference fields produced by radionuclide sources* Radiat. Prot. Dosim., **70**, 327 (1997)

[7] H. Kluge *Irradiation facility with radioactive reference neutron sources: Basic principles* PTB Report, PTB-N-34, 1998

[8] D. Schlegel, S. Guldbakke, *Neutron fluence measurements with a recoil proportional counter*, PTB laboratory report PTB-6.41-2002-03, Braunschweig (2002)

[9] D. Schlegel, S. Guldbakke, *Neutron fluence measurements with a recoil proton telescope*, PTB laboratory report PTB-6.41-2002-04, Braunschweig (2002)

[10] D. Schlegel, *TARGET user's manual*, PTB laboratory report PTB-6.41-98-1, Braunschweig (1998)



Physikalisch-Technische Bundesanstalt

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Page 7 of the Test Report dated 2013-01-18, test mark: -

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 Technologie. 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 Technology. 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).

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Bundesallee 100
38116 Braunschweig
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10587 Berlin
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Appendix E: Example "Certificate of Participation

European Radiation Dosimetry Group

EURADOS

European Radiation Dosimetry Group e.V. • Bundesallee 100 • D-38116 Braunschweig

Certificate of Participation EURADOS- 2012n-SXX

Certificate of Participation

in the EURADOS Intercomparison 2012 for whole body neutron dosemeters

Certificate number: EURADOS- 2012n-SXX

Number of pages: 3

Date of Issue: *Example*

Participating institute: PXX: *Name of the IMS*

Dosimetry system: SXX: *description of the dosemeter as provided py the participant*

Intercomparison procedure:

The EURADOS Intercomparison 2012 for whole body neutron dosemeters (IC2012n) was managed and coordinated on behalf of EURADOS WG2 by the 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 February 2012.

On the application form candidate participants were asked to indicate details of the dosemeter, including its reference point. After completing subscription procedures the participants sent their dosemeters to the OGn Coordinator (July/August 2012). Each participant provided 36 dosemeters: 24 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 dosemeter according to the irradiation plan and then sent all the dosemeters back to the coordinator (November/December 2012).

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. The participant then sent the results of the dosemeter readings to the coordinator (January 2013).

As some participants need information on the radiation field prior to the evaluation procedure, the participants were asked to provide the results in 2 steps:

- 1st step: with no information on the radiation fields;
- 2nd step: with limited information on the radiation fields and it was up to the participant to choose the proper routine calibration factor to be applied.

Participants were allowed to change their results between the 1st and the 2nd step only according to their routine procedure.

After receipt of the participants' results, the coordinator sent the reference values for $H_p(10)$ together with the detailed description of the radiation field (April 2013).

Number of participants 31 Institutes participated in EURADOS IC2012n with a total of 34 systems.

Irradiation data: See certificates of the irradiation laboratories Nos: NXXXX, PTB-6.5-11/12_PXX (attached)

Participant results: See report of the participant (attached)

Intercomparison results: See the table on pages 2-3 of this certificate

On behalf of the IC2012n Organization Group:	On behalf of EURADOS:
Elena Fantuzzi Coordinator	Helmut Schumacher Chairperson

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European Radiation Dosimetry Group

EURADOS

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Certificate of Participation EURADOS- 2012n-SXX

Result of the intercomparison:

N	ID Code	Irradiation lab	Hp(10) Reference value (mSv)	Radiation Field	Hp(10) Participant's value (mSv)	Ratio = Part.'s value/Ref. value	Remark from participant	I step - Hp(10) participant's value (mSv)	I step - Remark from participant	Ratio I step
1	Dosemeter code as provided by participant	IL1	2	Bare Cf-252 source at 45°	0,713	0,36		0,713		0,36
2	Dosemeter code as provided by participant	IL1	3	Bare Cf-252 source at 0°	2,058	0,69		2,058		0,69
3	Dosemeter code as provided by participant	IL1		NIR				0		
4	Dosemeter code as provided by participant	IL1	15	Bare Cf-252 source at 0°	11,969	0,80		11,969		0,80
5	Dosemeter code as provided by participant	IL2		NIR				0		
6	Dosemeter code as provided by participant	IL2	1,04	250 keV mono-energetic neutrons at 0°	0,009	0,01		0,009		0,01
7	Dosemeter code as provided by participant	IL2		NIR				0		
8	Dosemeter code as provided by participant	IL2	1,04	250 keV mono-energetic neutrons at 0°	0,015	0,01		0,015		0,01
9	Dosemeter code as provided by participant	IL2	2,0	Bare Cf-252 source behind shadow cone (isotropic)	0,788	0,39		0,788		0,39
10	Dosemeter code as provided by participant	IL1		NIR				0		
11	Dosemeter code as provided by participant	IL1	2	Bare Cf-252 source at 45°	1,129	0,56		1,129		0,56
12	Dosemeter code as provided by participant	IL2	1,04	250 keV mono-energetic neutrons at 0°	0,076	0,07		0,076		0,07
13	Dosemeter code as provided by participant	IL1	0,3	Bare Cf-252 source at 0°	0,23	0,77		0,23		0,77
14	Dosemeter code as provided by participant	IL1	3	Bare Cf-252 source at 0°	2,943	0,98		2,943		0,98
15	Dosemeter code as provided by participant	IL1	3	Cf-252 (D2O moderated) at 0°	3,045	1,02		3,045		1,02
16	Dosemeter code as provided by participant	IL1	0,3	Bare Cf-252 source at 0°	0,292	0,97		0,292		0,97
17	Dosemeter code as provided by participant	IL2		NIR				0		
18	Dosemeter code as provided by participant	IL1	15	Bare Cf-252 source at 0°	13	0,87		13		0,87
19	Dosemeter code as provided by participant	IL2	2,0	Bare Cf-252 source behind shadow cone (isotropic)	0,992	0,50		0,992		0,50

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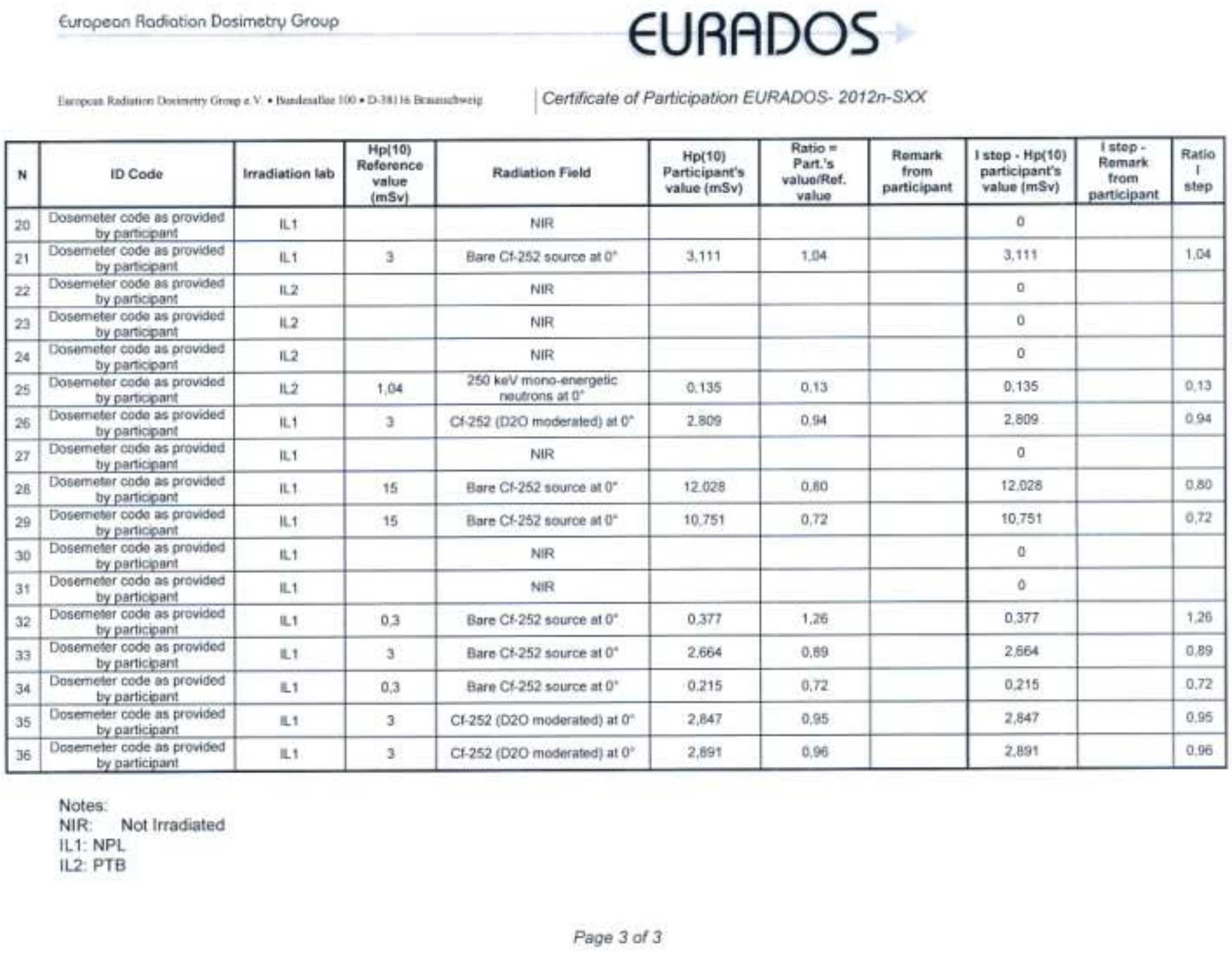

European Radiation Dosimetry Group

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Certificate of Participation EURADOS- 2012n-SXX

N	ID Code	Irradiation lab	Hp(10) Reference value (mSv)	Radiation Field	Hp(10) Participant's value (mSv)	Ratio = Part.'s value/Ref. value	Remark from participant	I step - Hp(10) participant's value (mSv)	I step - Remark from participant	Ratio I step
20	Dosemeter code as provided by participant	IL1		NIR				0		
21	Dosemeter code as provided by participant	IL1	3	Bare Cf-252 source at 0°	3,111	1,04		3,111		1,04
22	Dosemeter code as provided by participant	IL2		NIR				0		
23	Dosemeter code as provided by participant	IL2		NIR				0		
24	Dosemeter code as provided by participant	IL2		NIR				0		
25	Dosemeter code as provided by participant	IL2	1,04	250 keV mono-energetic neutrons at 0°	0,135	0,13		0,135		0,13
26	Dosemeter code as provided by participant	IL1	3	Cf-252 (D2O moderated) at 0°	2,809	0,94		2,809		0,94
27	Dosemeter code as provided by participant	IL1		NIR				0		
28	Dosemeter code as provided by participant	IL1	15	Bare Cf-252 source at 0°	12,028	0,80		12,028		0,80
29	Dosemeter code as provided by participant	IL1	15	Bare Cf-252 source at 0°	10,751	0,72		10,751		0,72
30	Dosemeter code as provided by participant	IL1		NIR				0		
31	Dosemeter code as provided by participant	IL1		NIR				0		
32	Dosemeter code as provided by participant	IL1	0,3	Bare Cf-252 source at 0°	0,377	1,26		0,377		1,26
33	Dosemeter code as provided by participant	IL1	3	Bare Cf-252 source at 0°	2,664	0,89		2,664		0,89
34	Dosemeter code as provided by participant	IL1	0,3	Bare Cf-252 source at 0°	0,215	0,72		0,215		0,72
35	Dosemeter code as provided by participant	IL1	3	Cf-252 (D2O moderated) at 0°	2,847	0,95		2,847		0,95
36	Dosemeter code as provided by participant	IL1	3	Cf-252 (D2O moderated) at 0°	2,891	0,96		2,891		0,96

Notes:
NIR: Not Irradiated
IL1: NPL
IL2: PTB

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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 source with source strength 1 s^{-1} behind a shadow cone at a distance of 170 cm.

Neutron energy (lower limit) (MeV)	$\Delta\varphi$ (cm^{-2} s^{-1})	$\Delta H_p(10)$ (pSv s^{-1})
7.9430E-10	9.7727E-11	1.78E-10
1.2590E-09	5.2993E-10	9.98E-10
1.9954E-09	1.4432E-09	2.83E-09
3.1623E-09	3.6736E-09	7.49E-09
5.0120E-09	8.9679E-09	1.90E-08
7.9436E-09	1.7824E-08	3.94E-08
1.2590E-08	2.9510E-08	6.96E-08
1.9954E-08	4.2768E-08	1.07E-07
3.1623E-08	7.1449E-08	1.86E-07
5.0120E-08	1.3278E-07	3.59E-07
7.9436E-08	1.3759E-07	3.87E-07
1.2590E-07	7.2188E-08	2.16E-07
1.9954E-07	3.5229E-08	1.11E-07
3.1623E-07	3.2215E-08	1.06E-07
5.0120E-07	2.6454E-08	9.00E-08
7.9436E-07	2.7845E-08	9.73E-08
1.2590E-06	2.8041E-08	9.91E-08
1.9954E-06	2.7617E-08	9.74E-08
3.1623E-06	2.8903E-08	1.01E-07
5.0120E-06	2.8751E-08	9.81E-08
7.9436E-06	3.0784E-08	1.02E-07
1.2590E-05	3.0946E-08	9.92E-08
1.9954E-05	3.1818E-08	9.81E-08
3.1623E-05	3.1497E-08	9.33E-08
5.0120E-05	3.1218E-08	8.85E-08
7.9436E-05	3.2798E-08	8.90E-08
1.2590E-04	3.4441E-08	9.09E-08

1.9954E-04	3.3395E-08	8.64E-08
3.1623E-04	3.5242E-08	8.98E-08
5.0120E-04	3.5350E-08	8.78E-08
7.9436E-04	3.6158E-08	8.71E-08
1.2590E-03	3.9458E-08	9.44E-08
1.9954E-03	3.7396E-08	9.06E-08
3.1623E-03	3.9190E-08	9.73E-08
5.0120E-03	4.0704E-08	1.07E-07
7.9436E-03	3.7463E-08	1.09E-07
1.2590E-02	4.4703E-08	1.64E-07
1.9954E-02	4.6285E-08	2.37E-07
3.1623E-02	4.8723E-08	3.75E-07
5.0120E-02	6.0368E-08	7.77E-07
7.9436E-02	7.3419E-08	1.68E-06
1.2590E-01	1.0398E-07	4.01E-06
1.9954E-01	1.2475E-07	7.51E-06
3.1623E-01	1.2445E-07	1.08E-05
5.0120E-01	2.0439E-07	2.42E-05
7.9436E-01	1.6429E-07	2.34E-05
1.2590E+00	1.3144E-07	2.30E-05
1.9954E+00	1.0987E-07	2.20E-05
3.1623E+00	3.1357E-08	7.03E-06
5.0120E+00	5.9117E-09	1.58E-06
7.9436E+00	3.1627E-10	1.00E-07
1.2590E+01	2.5920E-10	1.05E-07
1.9954E+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. etched tack or albedo or other) was done by the Organization Group (see paragraph 2.5).

Data are reported for Step I as well as for the Step II; i.e.the final result.

S01, dosemeter type: Albedo

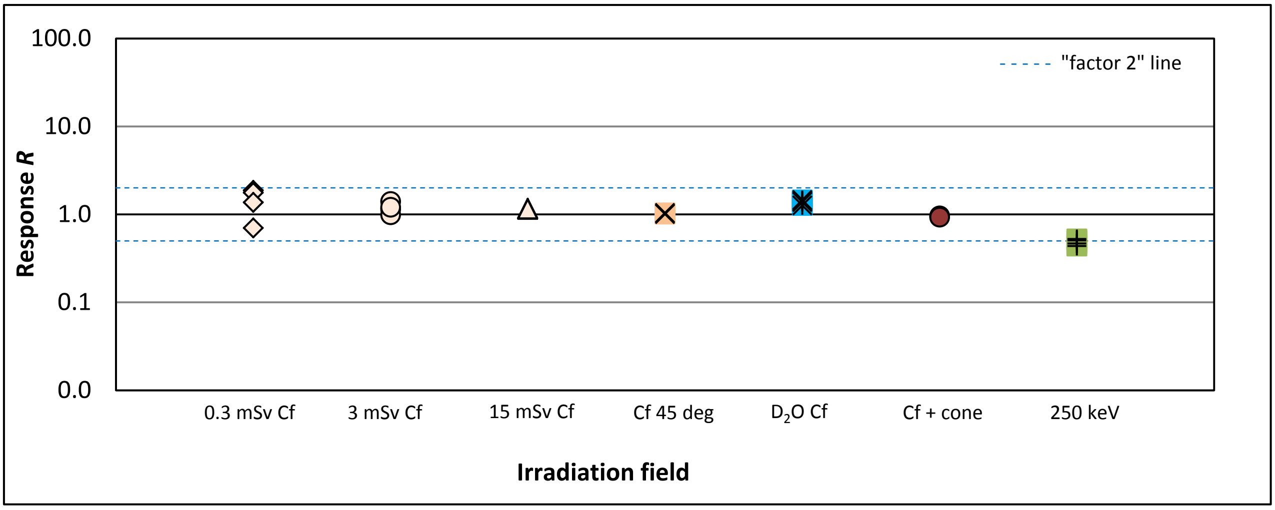
Reference values reported by the irradiating laboratory			Step I			Final step		
Radiation quality	Dosemeter code	$H_p(10)$ Reference value (mSv)	$H_p(10)$ Participant's value (mSv)	R	Remark	$H_p(10)$ Participant's value (mSv)	R	Remark
Cf-252; 0°	2	0.3	0.21	0.70		0.21	0.70	
	16	0.3	0.56	1.87		0.56	1.87	
	27	0.3	0.53	1.77		0.53	1.77	
	33	0.3	4.21	14.03		0.41	1.37	
	1	3	3.43	1.14		3.43	1.14	
	12	3	2.97	0.99		2.97	0.99	
	32	3	0.41	0.14		4.21	1.40	
	36	3	3.61	1.20		3.61	1.20	
	3	15	17.66	1.18		17.66	1.18	
	5	15	17.19	1.15		17.19	1.15	
	17	15	17.07	1.14		17.07	1.14	
	20	15	17.23	1.15		17.23	1.15	
Cf-252; 45°	7	2	2.01	1.01		2.01	1.01	
	35	2	2.07	1.04		2.07	1.04	
Cf-252 (D_2O); 0°	22	3	32.97	10.99		4.23	1.41	
	23	3	34.06	11.35		4.37	1.46	
	30	3	32.21	10.74		4.14	1.38	
	31	3	29.42	9.81		3.78	1.26	
Cf-252 + cone; 0°	4	2	14.98	7.49		1.92	0.96	
	13	2	14.45	7.23		1.86	0.93	
250 keV; 0°	10	1.01	4.14	4.10		0.53	0.52	
	21	1.01	3.91	3.87		0.51	0.50	
	24	1.01	3.66	3.62		0.47	0.47	
	26	1.01	3.46	3.43		0.44	0.44	

"out by factor >2"

Radiation quality	Number of values	Median of R	Mean of R
Cf-252; 0°	12	1.16	1.25
Cf-252; 45°	2	1.02	1.02
Cf-252 (D_2O); 0°	4	1.40	1.38
Cf-252 + cone; 0°	2	0.95	0.95
250 keV; 0°	4	0.49	0.48
All	24	1.14	1.10

Number of "out by factor >2": 2 of 24

Fraction of "out by factor >2": 8%



S02, dosemeter type: Etched track

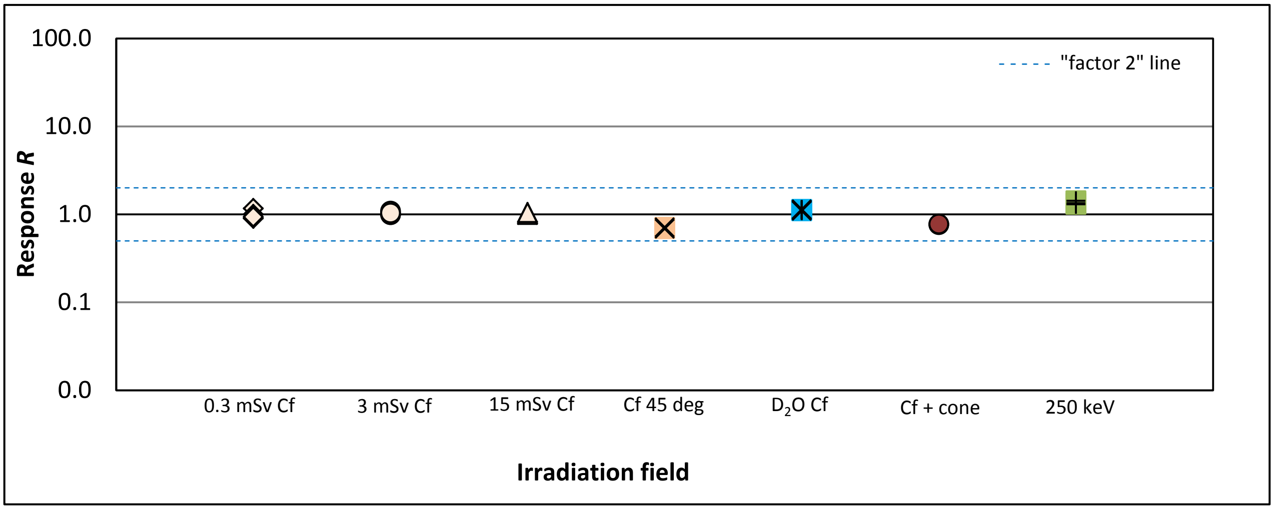
Reference values reported by the irradiating laboratory			Step I			Final step		
Radiation quality	Dosemeter code	$H_p(10)$ Reference value (mSv)	$H_p(10)$ Participant's value (mSv)	*R*	Remark	$H_p(10)$ Participant's value (mSv)	*R*	Remark
Cf-252; 0°	9	0.3	0.27	0.90		0.27	0.90	
	19	0.3	0.35	1.17		0.35	1.17	
	27	0.3	0.30	1.00		0.30	1.00	
	29	0.3	0.28	0.93		0.28	0.93	
	3	3	2.97	0.99		2.97	0.99	
	13	3	3.02	1.01		3.02	1.01	
	25	3	3.27	1.09		3.27	1.09	
	32	3	3.11	1.04		3.11	1.04	
	2	15	15.14	1.01		15.14	1.01	
	10	15	15.76	1.05		15.76	1.05	
	16	15	14.92	0.99		14.92	0.99	
	36	15	15.67	1.04		15.67	1.04	
Cf-252; 45°	8	2	1.42	0.71		1.42	0.71	
	34	2	1.37	0.69		1.37	0.69	
Cf-252 (D_2O); 0°	5	3	3.41	1.14		3.41	1.14	
	14	3	3.29	1.10		3.29	1.10	
	26	3	3.35	1.12		3.35	1.12	
	30	3	3.40	1.13		3.40	1.13	
Cf-252 + cone; 0°	1	2	1.53	0.77		1.53	0.77	
	7	2	1.55	0.78		1.55	0.78	
250 keV; 0°	4	1.04	1.39	1.34		1.39	1.34	
	17	1.04	1.35	1.30		1.35	1.30	
	28	1.04	1.35	1.30		1.35	1.30	
	35	1.04	1.48	1.42		1.48	1.42	

"out by factor >2"

Radiation quality	Number of values	Median of *R*	Mean of *R*
Cf-252; 0°	12	1.01	1.02
Cf-252; 45°	2	0.70	0.70
Cf-252 (D_2O); 0°	4	1.13	1.12
Cf-252 + cone; 0°	2	0.77	0.77
250 keV; 0°	4	1.32	1.34
All	24	1.04	1.04

Number of "out by factor >2": 0 of 24

Fraction of "out by factor >2": 0%



S03, dosemeter type: Albedo

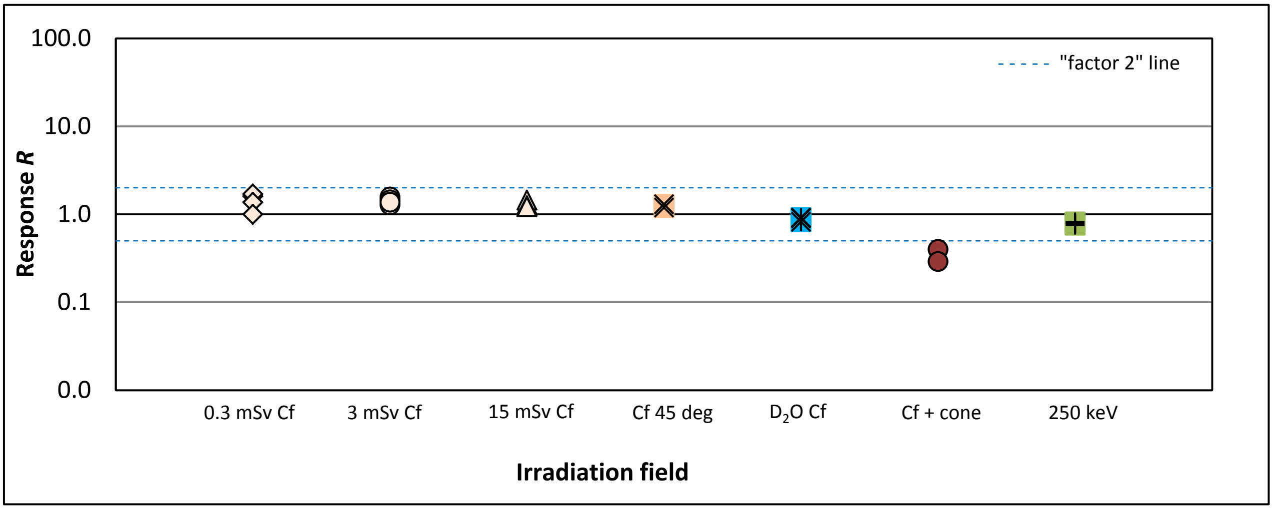
Reference values reported by the irradiating laboratory			Step I	Final step		
Radiation quality	Dosemeter code	$H_p(10)$ Reference value (mSv)	see next page	$H_p(10)$ Participant's value (mSv)	R	Remark
Cf-252; 0°	11	0.3		0.48	1.60	N3
	18	0.3		0.51	1.70	N3
	30	0.3		0.41	1.37	N3
	36	0.3		0.30	1.00	N3
	3	3		4.72	1.57	N3
	13	3		3.84	1.28	N3
	21	3		4.38	1.46	N3
	26	3		4.12	1.37	N3
	4	15		19.30	1.29	N3
	15	15		21.70	1.45	N3
	27	15		18.70	1.25	N3
	29	15		18.30	1.22	N3
Cf-252; 45°	7	2		2.60	1.30	N3
	23	2		2.38	1.19	N3
Cf-252 (D_2O); 0°	6	3		2.70	0.90	N1
	22	3		2.74	0.91	N1
	28	3		2.73	0.91	N1
	33	3		2.46	0.82	N1
Cf-252 + cone; 0°	16	2		0.80	0.40	N1
	24	2		0.58	0.29	N1
250 keV; 0°	2	1.04		0.78	0.75	N2
	9	1.04		0.81	0.78	N2
	10	1.04		0.85	0.82	N2
	14	1.04		0.82	0.79	N2

"out by factor >2"

Radiation quality	Number of values	Median of R	Mean of R
Cf-252; 0°	12	1.37	1.38
Cf-252; 45°	2	1.25	1.25
Cf-252 (D_2O); 0°	4	0.91	0.89
Cf-252 + cone; 0°	2	0.35	0.35
250 keV; 0°	4	0.78	0.78
All	24	1.21	1.10

Number of "out by factor >2": 2 of 24

Fraction of "out by factor >2": 8%



S03, dosemeter type: Albedo (continued)

Reference values reported by the irradiating laboratory			Step I Participant's value											
Radiation quality	Dosemeter code	$Hp(10)$ Reference value (mSv)	$H_p(10)$ (mSv)	R	Remark	$H_p(10)$ (mSv)	R	Remark	$H_p(10)$ (mSv)	R	Remark	$H_p(10)$ (mSv)	R	Remark
Cf-252; 0°	11	0.3	< 0,1		N1	0.09	0.30	N2	0.48	1.60	N3	0.71	2.37	N4
	18	0.3	< 0,1		N1	0.10	0.33	N2	0.51	1.69	N3	0.78	2.62	N4
	30	0.3	< 0,1		N1	0.09	0.30	N2	0.41	1.38	N3	0.66	2.18	N4
	36	0.3	< 0,1		N1	0.08	0.26	N2	0.30	0.99	N3	0.36	1.19	N4
	3	3	0.35	0.12	N1	0.79	0.26	N2	4.72	1.57	N3	6.29	2.10	N4
	13	3	0.29	0.10	N1	0.66	0.22	N2	3.84	1.28	N3	5.25	1.75	N4
	21	3	0.33	0.11	N1	0.75	0.25	N2	4.38	1.46	N3	5.98	1.99	N4
	26	3	0.30	0.10	N1	0.69	0.23	N2	4.12	1.37	N3	5.49	1.83	N4
	4	15	1.45	0.10	N1	3.30	0.22	N2	19.35	1.29	N3	26.43	1.76	N4
	15	15	1.59	0.11	N1	3.61	0.24	N2	21.67	1.44	N3	28.90	1.93	N4
	27	15	1.37	0.09	N1	3.12	0.21	N2	18.73	1.25	N3	24.97	1.66	N4
	29	15	1.40	0.09	N1	3.18	0.21	N2	18.30	1.22	N3	25.44	1.70	N4
Cf-252; 45°	7	2	0.21	0.10	N1	0.47	0.23	N2	2.60	1.30	N3	3.74	1.87	N4
	23	2	0.18	0.09	N1	0.41	0.21	N2	2.38	1.19	N3	3.30	1.65	N4
Cf-252 (D_2O); 0°	6	3	2.70	0.90	N1	6.13	2.04	N2	27.65	9.22	N3	42.71	14.24	N4
	22	3	2.74	0.91	N1	6.22	2.07	N2	28.34	9.45	N3	44.35	14.78	N4
	28	3	2.73	0.91	N1	6.21	2.07	N2	28.45	9.48	N3	44.96	14.99	N4
	33	3	2.46	0.82	N1	5.58	1.86	N2	24.57	8.19	N3	36.46	12.15	N4
Cf-252 + cone; 0°	16	2	0.80	0.40	N1	2.61	1.30	N2	6.16	3.08	N3	6.16	3.08	N4
	24	2	0.58	0.29	N1	2.25	1.12	N2	4.51	2.26	N3	4.51	2.26	N4
250 keV; 0°	2	1.04	0.34	0.33	N1	0.78	0.75	N2	3.57	3.43	N3	5.68	5.46	N4
	9	1.04	0.36	0.34	N1	0.81	0.78	N2	4.88	4.69	N3	6.50	6.25	N4
	10	1.04	0.38	0.36	N1	0.85	0.82	N2	4.83	4.64	N3	6.83	6.56	N4
	14	1.04	0.36	0.35	N1	0.82	0.79	N2	4.71	4.53	N3	6.59	6.34	N4

S04, dosemeter type: Etched track

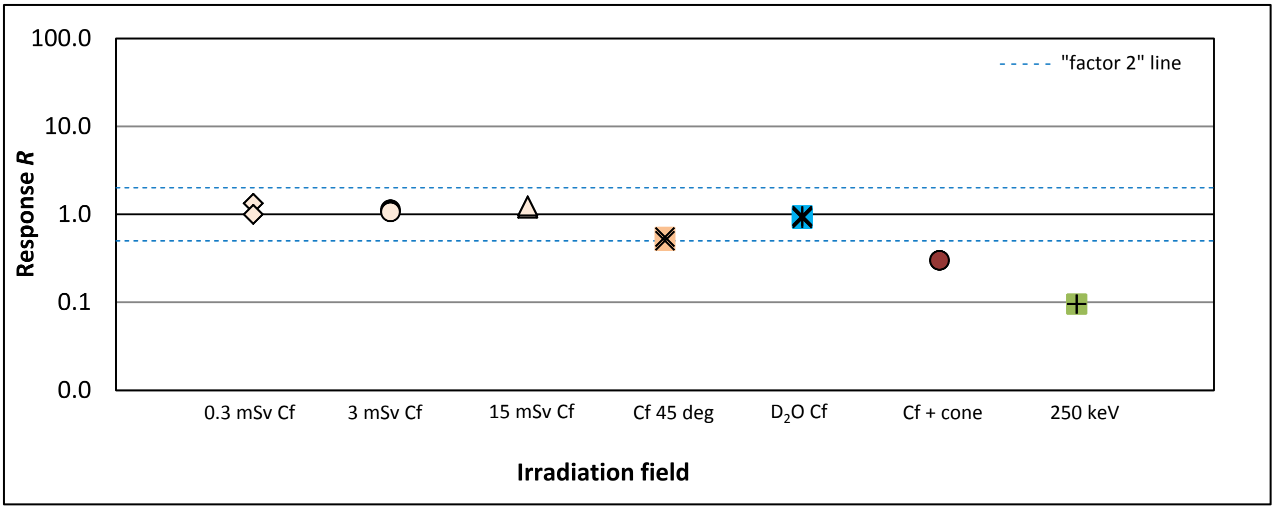
Reference values reported by the irradiating laboratory			Step I			Final step		
Radiation quality	Dosemeter code	$H_p(10)$ Reference value (mSv)	$H_p(10)$ Participant's value (mSv)	*R*	Remark	$H_p(10)$ Participant's value (mSv)	*R*	Remark
Cf-252; 0°	3	0.3	0.40	1.33	uncertainty 60% - fast neutron dosemeter	0.40	1.33	uncertainty 60% - fast neutron dosemeter
	10	0.3	0.40	1.33		0.40	1.33	
	15	0.3	0.30	1.00		0.30	1.00	
	24	0.3	0.30	1.00		0.30	1.00	
	5	3	3.40	1.13	uncertainty 54% - fast neutron dosemeter	3.40	1.13	uncertainty 54% - fast neutron dosemeter
	8	3	3.30	1.10		3.30	1.10	
	11	3	3.30	1.10		3.30	1.10	
	20	3	3.20	1.07		3.20	1.07	
	2	15	17.70	1.18	uncertainty 54% - fast neutron dosemeter	17.70	1.18	uncertainty 54% - fast neutron dosemeter
	16	15	18.70	1.25		18.70	1.25	
	18	15	17.60	1.17		17.60	1.17	
	27	15	18.60	1.24		18.60	1.24	
Cf-252; 45°	1	2	1.00	0.50	uncertainty 56% - fast neutron dosemeter	1.00	0.50	uncertainty 60% - fast neutron dosemeter
	33	2	1.10	0.55		1.10	0.55	
Cf-252 (D_2O); 0°	7	3	2.70	0.90	uncertainty 54% - fast neutron dosemeter	2.70	0.90	uncertainty 54% - fast neutron dosemeter
	13	3	2.80	0.93		2.80	0.93	
	31	3	2.80	0.93		2.80	0.93	
	35	3	2.90	0.97		2.90	0.97	
Cf-252 + cone; 0°	32	2	0.60	0.30	uncertainty 58% - fast neutron dosemeter	0.60	0.30	uncertainty 60% - fast neutron dosemeter
	36	2	0.60	0.30		0.60	0.30	
250 keV; 0°	4	1.05	0.10	0.10		0.10	0.10	
	9	1.05	0.10	0.10		0.10	0.10	
	17	1.05	0.10	0.10		0.10	0.10	
	22	1.05	0.10	0.10		0.10	0.10	

"out by factor >2"

Radiation quality	Number of values	Median of *R*	Mean of *R*
Cf-252; 0°	12	1.15	1.16
Cf-252; 45°	2	0.53	0.53
Cf-252 (D_2O); 0°	4	0.93	0.93
Cf-252 + cone; 0°	2	0.30	0.30
250 keV; 0°	4	0.10	0.10
All	24	0.98	0.82

Number of "out by factor >2": 6 of 24

Fraction of "out by factor >2": 25%



S05, dosemeter type: Etched track

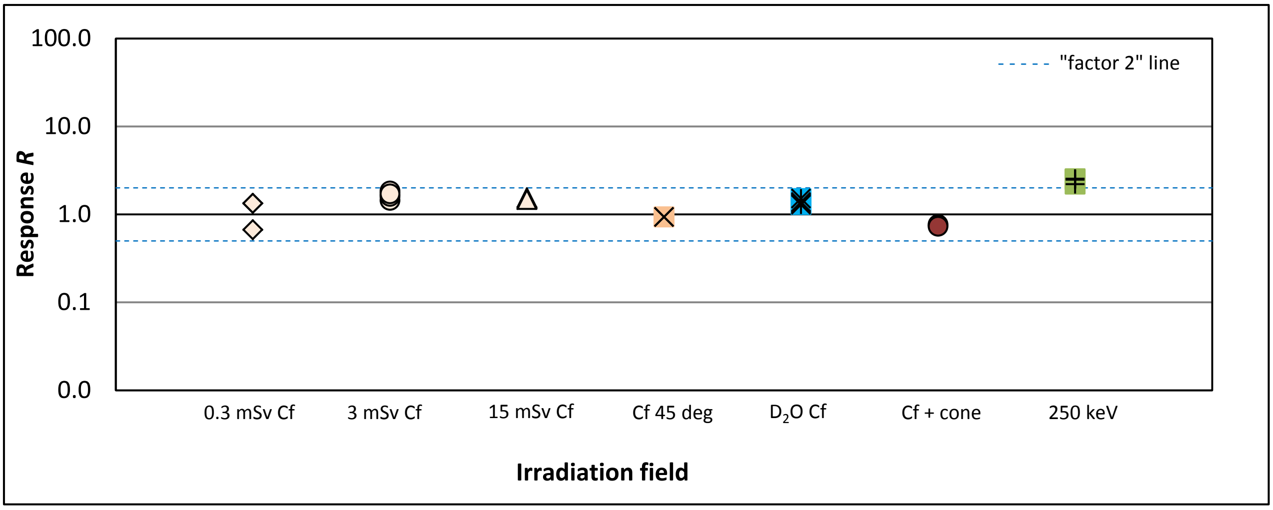
Reference values reported by the irradiating laboratory			Step I			Final step		
Radiation quality	Dosemeter code	$H_p(10)$ Reference value (mSv)	$H_p(10)$ Participant's value (mSv)	*R*	Remark	$H_p(10)$ Participant's value (mSv)	*R*	Remark
Cf-252; 0°	9	0.3	0.60	2.00		0.40	1.33	
	23	0.3	0.60	2.00		0.40	1.33	
	27	0.3	0.30	1.00		0.20	0.67	
	32	0.3	< 0.3			0.00	0.00	
	6	3	6.50	2.17		4.33	1.44	
	12	3	7.20	2.40		4.80	1.60	
	16	3	8.30	2.77		5.53	1.84	
	36	3	7.70	2.57		5.13	1.71	
	1	15	34.70	2.31		23.13	1.54	
	10	15	33.90	2.26		22.60	1.51	
	14	15	33.40	2.23		22.27	1.48	
	25	15	33.10	2.21		22.07	1.47	
Cf-252; 45°	13	2	2.80	1.40		1.87	0.93	
	31	2	2.80	1.40		1.87	0.93	
Cf-252 (D_2O); 0°	4	3	6.00	2.00		4.00	1.33	
	8	3	5.80	1.93		3.87	1.29	
	21	3	6.20	2.07		4.13	1.38	
	28	3	6.80	2.27		4.53	1.51	
Cf-252 + cone; 0°	5	2	2.30	1.15		1.53	0.77	
	35	2	2.20	1.10		1.47	0.73	
250 keV; 0°	7	1.05	< 0.15			2.66	2.54	
	20	1.05	< 0.15			2.60	2.48	
	26	1.05	< 0.15			2.31	2.20	
	33	1.05	< 0.15			2.66	2.53	

"out by factor >2"

Radiation quality	Number of values	Median of *R*	Mean of *R*
Cf-252; 0°	12	1.48	1.33
Cf-252; 45°	2	0.93	0.93
Cf-252 (D_2O); 0°	4	1.36	1.38
Cf-252 + cone; 0°	2	0.75	0.75
250 keV; 0°	4	2.51	2.44
All	24	1.46	1.44

Number of "out by factor >2": 5 of 24

Fraction of "out by factor >2": 21%



S06, dosemeter type: Albedo

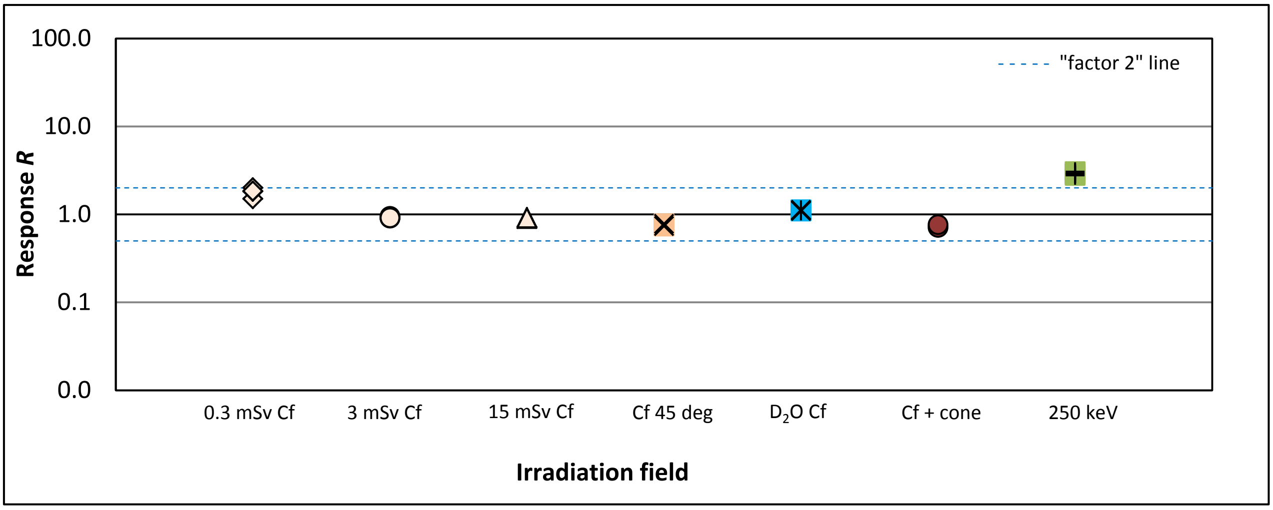
Reference values reported by the irradiating laboratory			Step I			Final step		
Radiation quality	Dosemeter code	*H*$_p$(10) Reference value (mSv)	*H*$_p$(10) Participant's value (mSv)	*R*	Remark	*H*$_p$(10) Participant's value (mSv)	*R*	Remark
Cf-252; 0°	4	0.3	0.45	1.51		0.45	1.51	
	20	0.3	0.60	2.01		0.60	2.01	
	27	0.3	0.55	1.82		0.55	1.82	
	30	0.3	0.55	1.84		0.55	1.84	
	5	3	2.85	0.95		2.85	0.95	
	16	3	2.73	0.91		2.73	0.91	
	18	3	2.74	0.91		2.74	0.91	
	28	3	2.74	0.91		2.74	0.91	
	7	15	13.42	0.89		13.42	0.89	
	9	15	13.84	0.92		13.84	0.92	
	14	15	13.56	0.90		13.56	0.90	
	21	15	13.64	0.91		13.64	0.91	
Cf-252; 45°	12	2	1.47	0.74		1.47	0.74	
	34	2	1.56	0.78		1.56	0.78	
Cf-252 (D_2O); 0°	3	3	3.35	1.12		3.35	1.12	
	11	3	3.37	1.12		3.37	1.12	
	25	3	3.36	1.12		3.36	1.12	
	32	3	3.27	1.09		3.27	1.09	
Cf-252 + cone; 0°	26	2	1.42	0.71		1.42	0.71	
	33	2	1.53	0.76		1.53	0.76	
250 keV; 0°	2	1.05	3.02	2.87		3.02	2.87	
	13	1.05	3.06	2.91		3.06	2.91	
	22	1.05	2.91	2.77		2.91	2.77	
	31	1.05	3.20	3.05		3.20	3.05	

"out by factor >2"

Radiation quality	Number of values	Median of *R*	Mean of *R*
Cf-252; 0°	12	0.92	1.21
Cf-252; 45°	2	0.76	0.76
Cf-252 (D_2O); 0°	4	1.12	1.11
Cf-252 + cone; 0°	2	0.74	0.74
250 keV; 0°	4	2.89	2.90
All	24	1.02	1.40

Number of "out by factor >2": 5 of 24

Fraction of "out by factor >2": 21%



S07, dosemeter type: Other

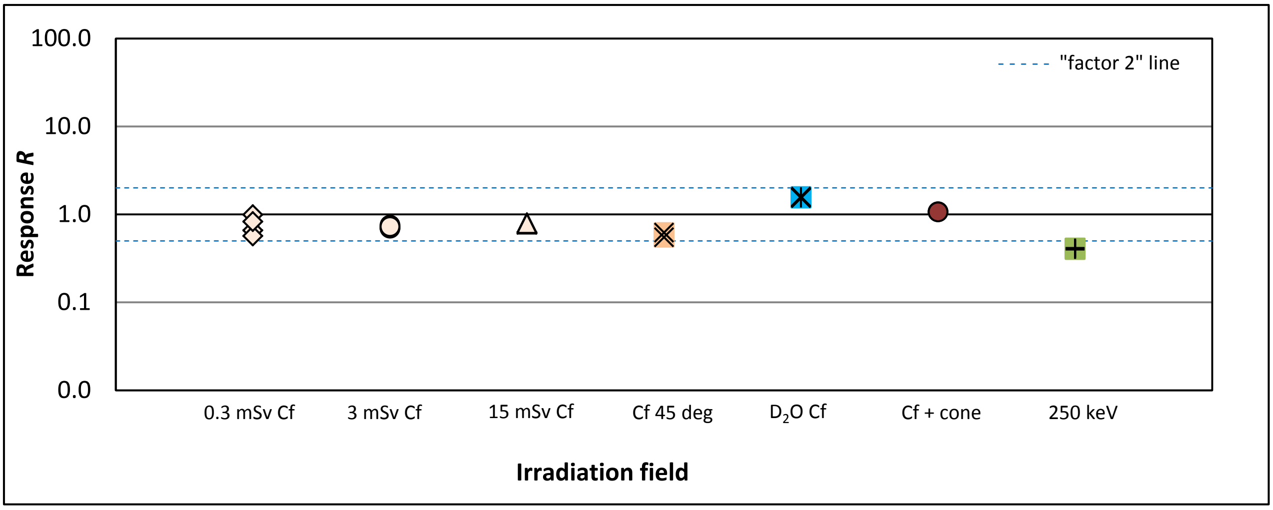
Reference values reported by the irradiating laboratory			Step I			Final step		
Radiation quality	Dosemeter code	$H_p(10)$ Reference value (mSv)	$H_p(10)$ Participant's value (mSv)	*R*	Remark	$H_p(10)$ Participant's value (mSv)	*R*	Remark
Cf-252; 0°	4	0.3	0.30	0.99		0.30	0.99	
	17	0.3	0.20	0.66		0.20	0.66	
	25	0.3	0.17	0.57		0.17	0.57	
	35	0.3	0.25	0.83		0.25	0.83	
	3	3	2.26	0.75		2.26	0.75	
	8	3	2.09	0.70		2.09	0.70	
	11	3	2.11	0.70		2.11	0.70	
	19	3	2.18	0.73		2.18	0.73	
	1	15	11.60	0.77		11.60	0.77	
	23	15	12.02	0.80		12.02	0.80	
	26	15	11.70	0.78		11.70	0.78	
	31	15	11.77	0.78		11.77	0.78	
Cf-252; 45°	13	2	1.24	0.62		1.24	0.62	
	28	2	1.10	0.55		1.10	0.55	
Cf-252 (D_2O); 0°	5	3	4.77	1.59		4.77	1.59	
	15	3	4.59	1.53		4.59	1.53	
	30	3	4.66	1.55		4.66	1.55	
	32	3	4.66	1.55		4.66	1.55	
Cf-252 + cone; 0°	29	2	2.15	1.07		2.15	1.07	
	36	2	2.13	1.07		2.13	1.07	
250 keV; 0°	10	1.05	0.42	0.40		0.42	0.40	
	14	1.05	0.43	0.41		0.43	0.41	
	27	1.05	0.42	0.40		0.42	0.40	
	33	1.05	0.43	0.41		0.43	0.41	

"out by factor >2"

Radiation quality	Number of values	Median of *R*	Mean of *R*
Cf-252; 0°	12	0.76	0.75
Cf-252; 45°	2	0.58	0.58
Cf-252 (D_2O); 0°	4	1.55	1.56
Cf-252 + cone; 0°	2	1.07	1.07
250 keV; 0°	4	0.41	0.41
All	24	0.76	0.84

Number of "out by factor >2": 4 of 24

Fraction of "out by factor >2": 17%



S08, dosemeter type: Etched track

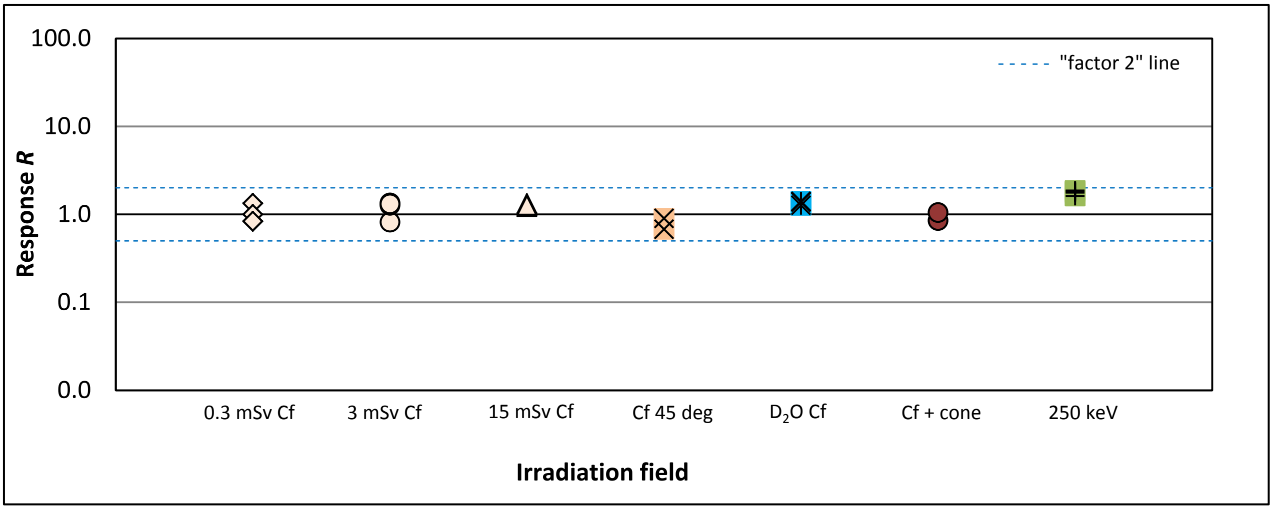
Reference values reported by the irradiating laboratory			Step I			Final step		
Radiation quality	Dosemeter code	$H_p(10)$ Reference value (mSv)	$H_p(10)$ Participant's value (mSv)	*R*	Remark	$H_p(10)$ Participant's value (mSv)	*R*	Remark
Cf-252; 0°	3	0.3	0.40	1.33		0.40	1.33	
	6	0.3	0.25	0.83		0.25	0.83	
	18	0.3	0.30	1.00		0.30	1.00	
	22	0.3	0.25	0.83		0.25	0.83	
	10	3	4.05	1.35		4.05	1.35	
	11	3	2.45	0.82		2.45	0.82	
	23	3	3.80	1.27		3.80	1.27	
	25	3	3.95	1.32		3.95	1.32	
	13	15	18.35	1.22		18.35	1.22	
	15	15	19.05	1.27		19.05	1.27	
	21	15	19.80	1.32		19.80	1.32	
	34	15	19.00	1.27		19.00	1.27	
Cf-252; 45°	12	2	1.35	0.68		1.35	0.68	
	27	2	1.80	0.90		1.80	0.90	
Cf-252 (D_2O); 0°	4	3	4.15	1.38		4.15	1.38	
	5	3	4.15	1.38		4.15	1.38	
	14	3	3.80	1.27		3.80	1.27	
	26	3	4.20	1.40		4.20	1.40	
Cf-252 + cone; 0°	9	2	1.70	0.85		1.70	0.85	
	31	2	2.10	1.05		2.10	1.05	
250 keV; 0°	19	1.02	1.85	1.81		1.85	1.81	
	28	1.02	1.90	1.86		1.90	1.86	
	32	1.02	1.65	1.62		1.65	1.62	
	35	1.02	1.80	1.76		1.80	1.76	

"out by factor >2"

Radiation quality	Number of values	Median of *R*	Mean of *R*
Cf-252; 0°	12	1.27	1.15
Cf-252; 45°	2	0.79	0.79
Cf-252 (D_2O); 0°	4	1.38	1.36
Cf-252 + cone; 0°	2	0.95	0.95
250 keV; 0°	4	1.79	1.76
All	24	1.27	1.24

Number of "out by factor >2": 0 of 24

Fraction of "out by factor >2": 0%



S09, dosemeter type: Etched track

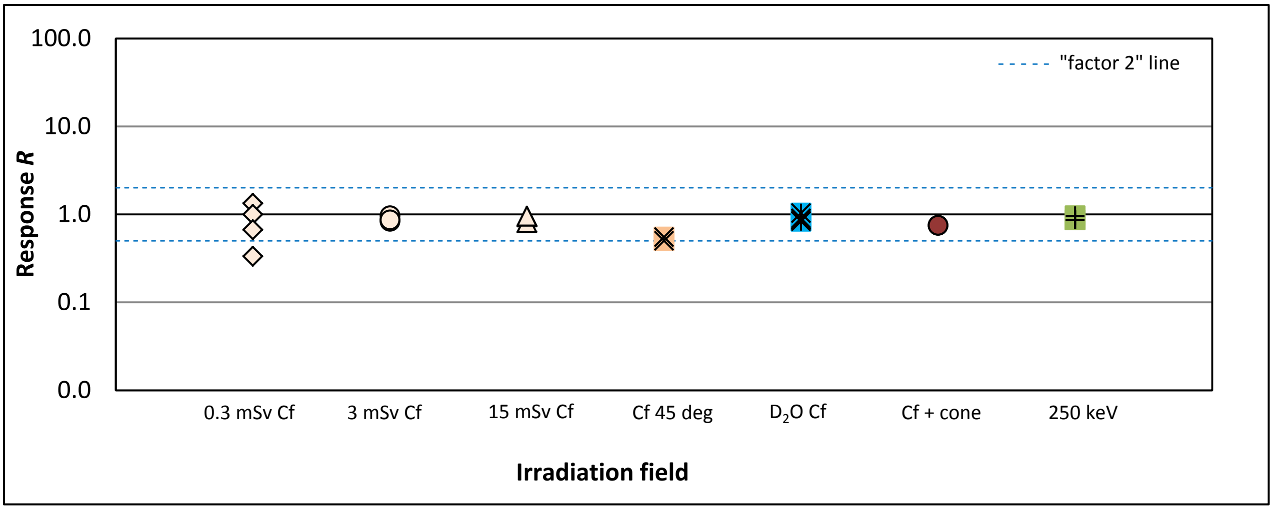
Reference values reported by the irradiating laboratory			Step I			Final step		
Radiation quality	Dosemeter code	$H_p(10)$ Reference value (mSv)	$H_p(10)$ Participant's value (mSv)	*R*	Remark	$H_p(10)$ Participant's value (mSv)	*R*	Remark
Cf-252; 0°	2	0.3	0.40	1.33		0.40	1.33	
	22	0.3	0.10	0.33		0.10	0.33	
	28	0.3	0.30	1.00		0.30	1.00	
	34	0.3	0.20	0.67		0.20	0.67	
	14	3	2.50	0.83		2.50	0.83	
	17	3	2.60	0.87		2.60	0.87	
	26	3	2.90	0.97		2.90	0.97	
	33	3	2.60	0.87		2.60	0.87	
	7	15	14.00	0.93		14.00	0.93	
	9	15	12.10	0.81		12.10	0.81	
	12	15	14.30	0.95		14.30	0.95	
	23	15	14.30	0.95		14.30	0.95	
Cf-252; 45°	3	2	1.00	0.50		1.00	0.50	
	24	2	1.10	0.55		1.10	0.55	
Cf-252 (D_2O); 0°	4	3	2.70	0.90		2.70	0.90	
	6	3	2.50	0.83		2.50	0.83	
	16	3	2.60	0.87		2.60	0.87	
	20	3	3.10	1.03		3.10	1.03	
Cf-252 + cone; 0°	19	2	1.50	0.75		1.50	0.75	
	27	2	1.50	0.75		1.50	0.75	
250 keV; 0°	8	1.04	0.90	0.87		0.90	0.87	
	11	1.04	1.00	0.96		1.00	0.96	
	18	1.04	0.90	0.87		0.90	0.87	
	30	1.04	0.90	0.87		0.90	0.87	

"out by factor >2"

Radiation quality	Number of values	Median of *R*	Mean of *R*
Cf-252; 0°	12	0.90	0.88
Cf-252; 45°	2	0.53	0.53
Cf-252 (D_2O); 0°	4	0.88	0.91
Cf-252 + cone; 0°	2	0.75	0.75
250 keV; 0°	4	0.87	0.89
All	24	0.87	0.84

Number of "out by factor >2": 1 of 24

Fraction of "out by factor >2": 4%



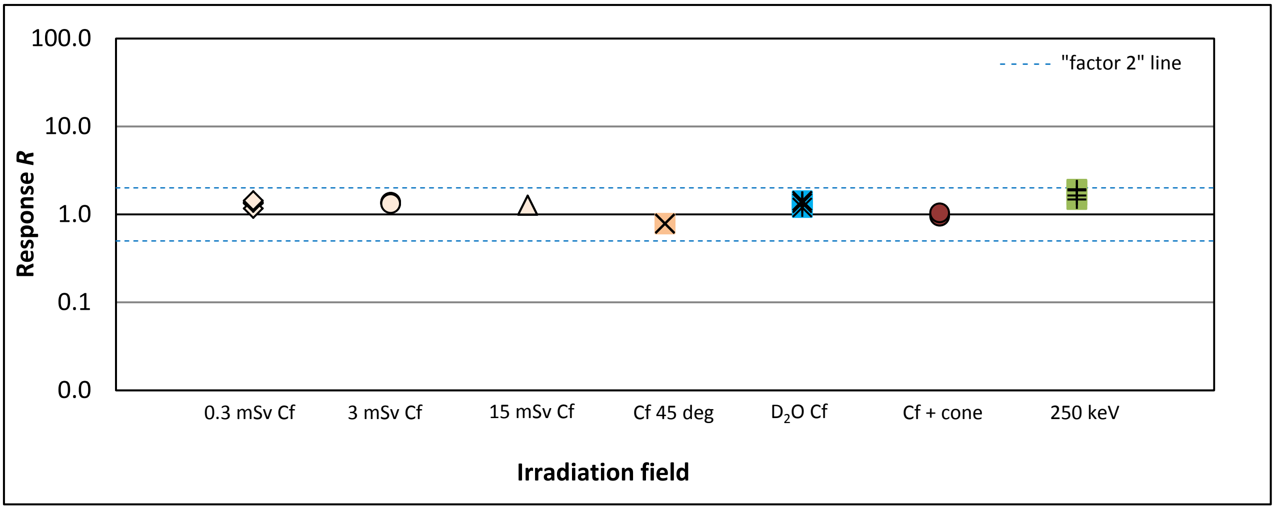
S10, dosemeter type: Etched track

Reference values reported by the irradiating laboratory			Step I			Final step		
Radiation quality	Dosemeter code	$H_p(10)$ Reference value (mSv)	$H_p(10)$ Participant's value (mSv)	*R*	Remark	$H_p(10)$ Participant's value (mSv)	*R*	Remark
Cf-252; 0°	14	0.3	0.40	1.33		0.40	1.33	
	20	0.3	0.35	1.17		0.35	1.17	
	28	0.3	0.41	1.37		0.41	1.37	
	30	0.3	0.43	1.43		0.43	1.43	
	1	3	4.11	1.37		4.11	1.37	
	5	3	4.01	1.34		4.01	1.34	
	11	3	4.12	1.37		4.12	1.37	
	18	3	3.98	1.33		3.98	1.33	
	9	15	19.01	1.27		19.01	1.27	
	16	15	19.05	1.27		19.05	1.27	
	32	15	19.01	1.27		19.01	1.27	
	35	15	19.05	1.27		19.05	1.27	
Cf-252; 45°	24	2	1.58	0.79		1.58	0.79	
	33	2	1.55	0.78		1.55	0.78	
Cf-252 (D_2O); 0°	4	3	4.02	1.34		4.02	1.34	
	6	3	4.24	1.41		4.24	1.41	
	22	3	3.59	1.20		3.59	1.20	
	23	3	4.28	1.43		4.28	1.43	
Cf-252 + cone; 0°	15	2	1.91	0.96		1.91	0.96	
	17	2	2.08	1.04		2.08	1.04	
250 keV; 0°	3	1.05	2.02	1.92		2.02	1.92	
	26	1.05	1.96	1.87		1.96	1.87	
	34	1.05	1.55	1.48		1.55	1.48	
	36	1.05	1.72	1.64		1.72	1.64	

"out by factor >2"

Radiation quality	Number of values	Median of *R*	Mean of *R*
Cf-252; 0°	12	1.33	1.32
Cf-252; 45°	2	0.78	0.78
Cf-252 (D_2O); 0°	4	1.38	1.34
Cf-252 + cone; 0°	2	1.00	1.00
250 keV; 0°	4	1.75	1.73
All	24	1.34	1.32

Number of "out by factor >2":	0 of 24
Fraction of "out by factor >2":	0%



S11, dosemeter type: Albedo

Reference values reported by the irradiating laboratory			Step I			Final step		
Radiation quality	Dosemeter code	$H_p(10)$ Reference value (mSv)	$H_p(10)$ Participant's value (mSv)	*R*	Remark	$H_p(10)$ Participant's value (mSv)	*R*	Remark
Cf-252; 0°	1	0.3						
	2	0.3						
	3	0.3						
	4	0.3						
	5	3						
	6	3						
	7	3						
	8	3						
	9	15						
	10	15						
	11	15						
	12	15						
Cf-252; 45°	13	2						
	14	2						
Cf-252 (D_2O); 0°	15	3						
	16	3						
	17	3						
	18	3						
Cf-252 + cone; 0°	19	2						
	20	2						
250 keV; 0°	21	1.04						
	22	1.04						
	23	1.04						
	24	1.04						

No results submitted

S12, dosemeter type: Albedo

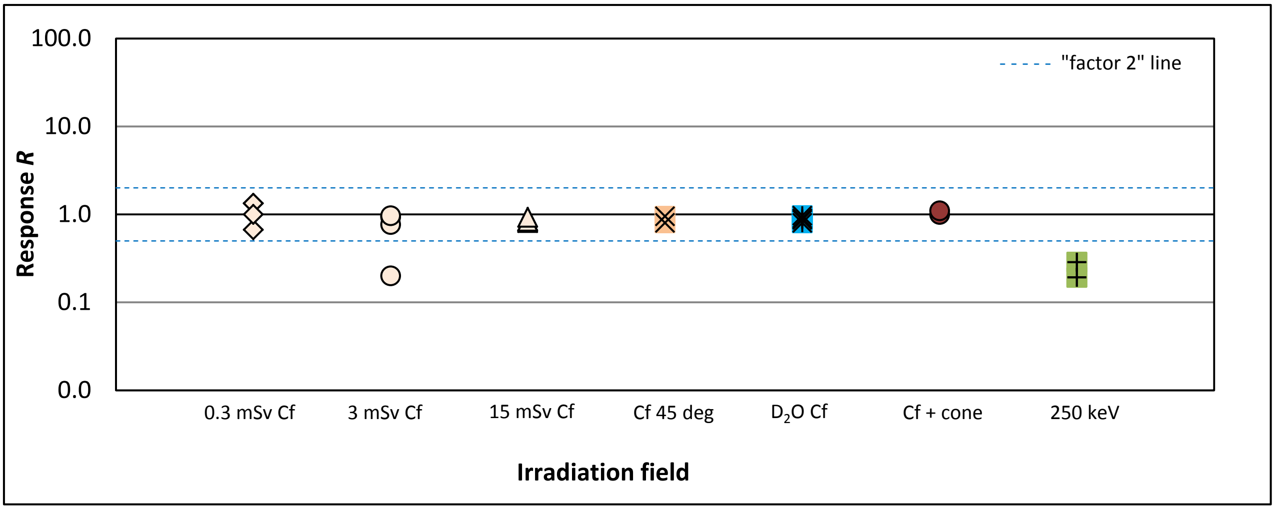
Reference values reported by the irradiating laboratory			Step I			Final step		
Radiation quality	Dosemeter code	$H_p(10)$ Reference value (mSv)	$H_p(10)$ Participant's value (mSv)	*R*	Remark	$H_p(10)$ Participant's value (mSv)	*R*	Remark
Cf-252; 0°	12	0.3	0.00	0.00		0.40	1.33	
	24	0.3	0.00	0.00		0.20	0.67	
	28	0.3	0.00	0.00		0.40	1.33	
	36	0.3	0.00	0.00		0.30	1.00	
	22	3	2.20	0.73		2.80	0.93	
	26	3	2.70	0.90		2.30	0.77	
	29	3	0.70	0.23		0.60	0.20	
	32	3	1.40	0.47		2.90	0.97	
	2	15	6.70	0.45		12.60	0.84	
	4	15	5.80	0.39		12.10	0.81	
	10	15	7.40	0.49		12.50	0.83	
	34	15	6.30	0.42		13.90	0.93	
Cf-252; 45°	16	2	1.30	0.65		1.90	0.95	
	31	2	1.20	0.60		1.60	0.80	
Cf-252 (D_2O); 0°	1	3	3.60	1.20		2.70	0.90	
	6	3	4.00	1.33		2.40	0.80	
	8	3	5.20	1.73		2.90	0.97	
	18	3	3.00	1.00		2.60	0.87	
Cf-252 + cone; 0°	3	2	1.70	0.85		2.00	1.00	
	17	2	1.90	0.95		2.20	1.10	
250 keV; 0°	9	1.04	1.70	1.63		0.20	0.19	
	11	1.04	1.90	1.83		0.20	0.19	
	27	1.05	2.90	2.76		0.30	0.29	
	35	1.05	1.50	1.43		0.30	0.29	

"out by factor >2"

Radiation quality	Number of values	Median of *R*	Mean of *R*
Cf-252; 0°	12	0.88	0.88
Cf-252; 45°	2	0.88	0.88
Cf-252 (D_2O); 0°	4	0.88	0.88
Cf-252 + cone; 0°	2	1.05	1.05
250 keV; 0°	4	0.24	0.24
All	24	0.85	0.79

Number of "out by factor >2": 5 of 24

Fraction of "out by factor >2": 21%



S13, dosemeter type: Albedo

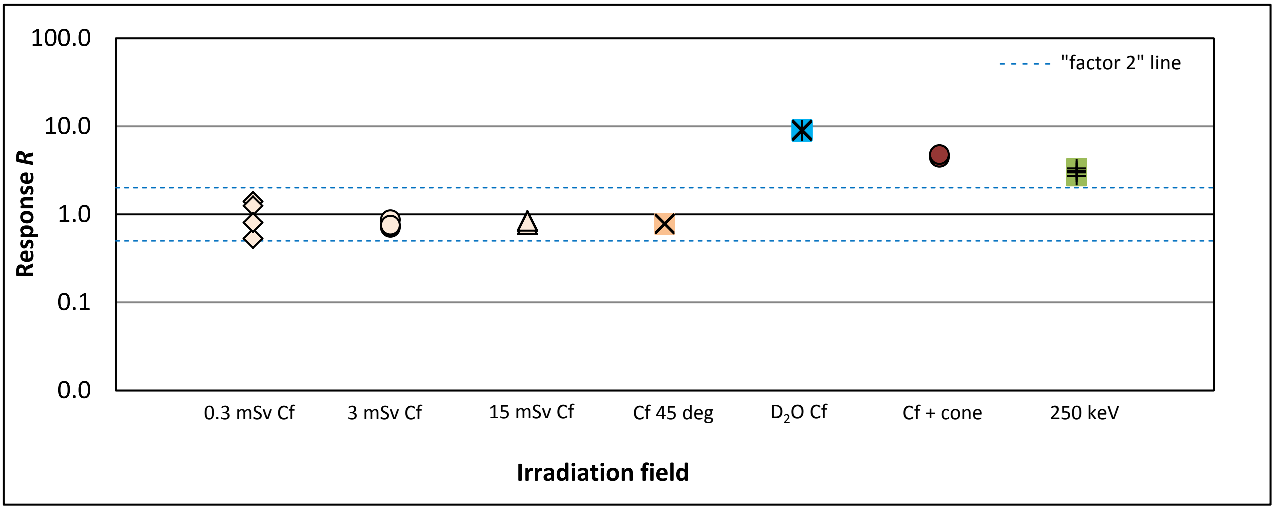
Reference values reported by the irradiating laboratory			Step I			Final step		
Radiation quality	Dosemeter code	$H_p(10)$ Reference value (mSv)	$H_p(10)$ Participant's value (mSv)	*R*	Remark	$H_p(10)$ Participant's value (mSv)	*R*	Remark
Cf-252; 0°	15	0.3	0.42	1.40		0.42	1.40	
	21	0.3	0.37	1.25		0.37	1.25	
	26	0.3	0.16	0.53		0.16	0.53	
	35	0.3	0.24	0.80		0.24	0.80	
	4	3	2.13	0.71		2.13	0.71	
	8	3	2.61	0.87		2.61	0.87	
	14	3	2.21	0.74		2.21	0.74	
	23	3	2.26	0.75		2.26	0.75	
	3	15	12.37	0.82		12.37	0.82	
	5	15	11.51	0.77		11.51	0.77	
	19	15	12.78	0.85		12.78	0.85	
	29	15	12.53	0.84		12.53	0.84	
Cf-252; 45°	6	2	1.58	0.79		1.58	0.79	
	36	2	1.53	0.77		1.53	0.77	
Cf-252 (D_2O); 0°	11	3	27.19	9.06		27.19	9.06	
	16	3	26.29	8.76		26.29	8.76	
	20	3	26.45	8.82		26.45	8.82	
	33	3	27.57	9.19		27.57	9.19	
Cf-252 + cone; 0°	18	2	8.88	4.44		8.88	4.44	
	22	2	9.54	4.77		9.54	4.77	
250 keV; 0°	2	1.02	3.38	3.31		3.38	3.31	
	7	1.02	3.05	2.99		3.05	2.99	
	17	1.02	2.78	2.72		2.78	2.72	
	30	1.02	3.18	3.12		3.18	3.12	

"out by factor >2"

Radiation quality	Number of values	Median of *R*	Mean of *R*
Cf-252; 0°	12	0.81	0.86
Cf-252; 45°	2	0.78	0.78
Cf-252 (D_2O); 0°	4	8.94	8.96
Cf-252 + cone; 0°	2	4.61	4.61
250 keV; 0°	4	3.05	3.04
All	24	1.06	2.88

Number of "out by factor >2": 10 of 24

Fraction of "out by factor >2": 42%



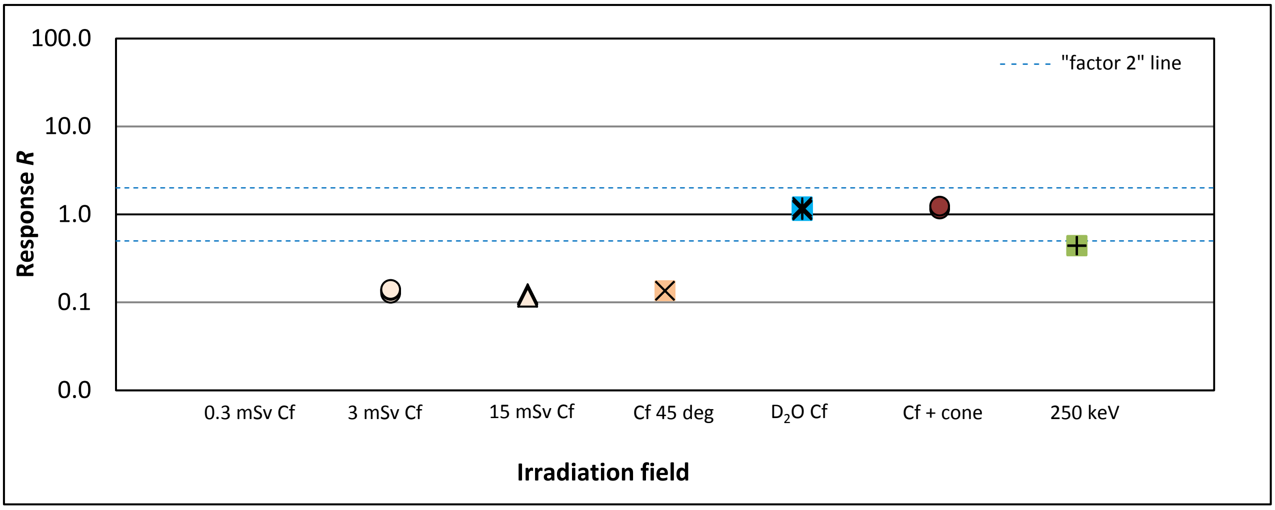
S14, dosemeter type: Albedo

Reference values reported by the irradiating laboratory			Step I			Final step		
Radiation quality	Dosemeter code	$H_p(10)$ Reference value (mSv)	$H_p(10)$ Participant's value (mSv)	*R*	Remark	$H_p(10)$ Participant's value (mSv)	*R*	Remark
Cf-252; 0°	7	0.3	0.00	0.00		0.00	0.00	
	23	0.3	0.00	0.00		0.00	0.00	
	26	0.3	0.10	0.33		0.00	0.00	
	33	0.3	0.00	0.00		0.00	0.00	
	1	3	0.40	0.13		0.40	0.13	
	8	3	0.38	0.13		0.38	0.13	
	24	3	0.41	0.14		0.41	0.14	
	27	3	0.42	0.14		0.42	0.14	
	16	15	2.34	0.16		1.80	0.12	
	19	15	2.39	0.16		1.82	0.12	
	21	15	2.45	0.16		1.87	0.12	
	25	15	2.27	0.15		1.71	0.11	
Cf-252; 45°	10	2	0.27	0.14		0.27	0.14	
	13	2	0.27	0.14		0.27	0.14	
Cf-252 (D_2O); 0°	3	3	4.00	1.33		3.65	1.22	
	15	3	3.63	1.21		3.31	1.10	
	31	3	3.70	1.23		3.37	1.12	
	32	3	3.77	1.26		3.44	1.15	
Cf-252 + cone; 0°	6	2	2.30	1.15		2.30	1.15	
	11	2	2.48	1.24		2.48	1.24	
250 keV; 0°	12	1.03	0.45	0.44		0.45	0.44	
	22	1.03	0.45	0.44		0.45	0.44	
	28	1.02	0.45	0.44		0.45	0.44	
	35	1.02	0.45	0.44		0.45	0.44	

"out by factor >2"

Radiation quality	Number of values	Median of *R*	Mean of *R*
Cf-252; 0°	12	0.12	0.08
Cf-252; 45°	2	0.14	0.14
Cf-252 (D_2O); 0°	4	1.14	1.15
Cf-252 + cone; 0°	2	1.20	1.20
250 keV; 0°	4	0.44	0.44
All	24	0.14	0.42

Number of "out by factor >2":	18 of 24
Fraction of "out by factor >2":	75%



S15, dosemeter type: Albedo

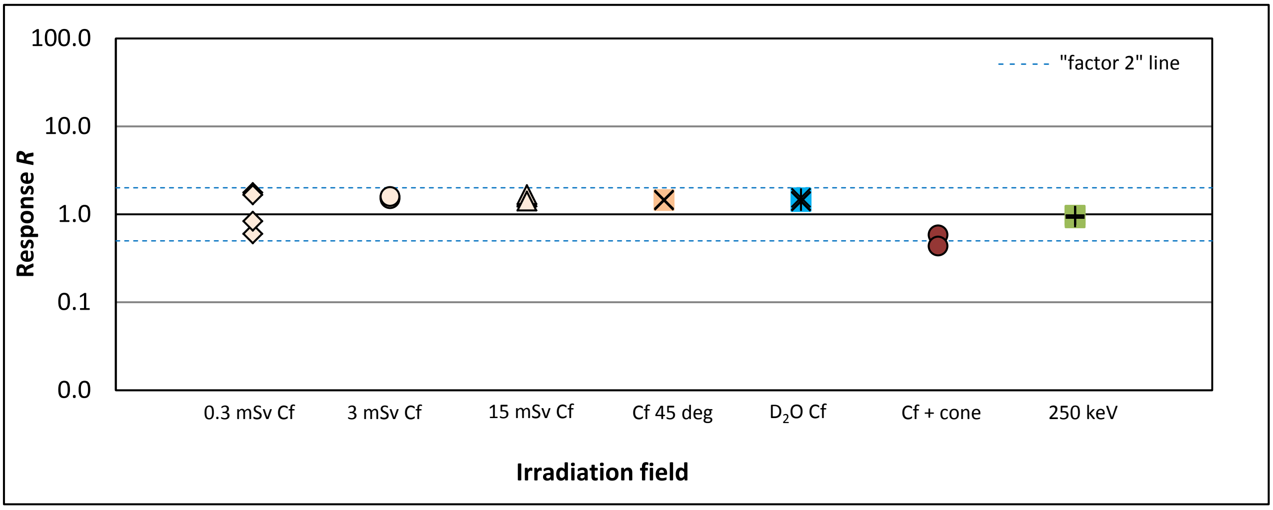
Reference values reported by the irradiating laboratory			Step I	Final step		
Radiation quality	Dosemeter code	$H_p(10)$ Reference value (mSv)	see next page	$H_p(10)$ Participant's value (mSv)	*R*	Remark
Cf-252; 0°	23	0.3		0.53	1.77	N3
	30	0.3		0.50	1.67	N3
	32	0.3		0.18	0.60	N3
	36	0.3		0.25	0.83	N3
	11	3		4.65	1.55	N3
	16	3		4.69	1.56	N3
	24	3		4.51	1.50	N3
	25	3		4.78	1.59	N3
	4	15		23.60	1.57	N3
	8	15		23.57	1.57	N3
	9	15		25.06	1.67	N3
	27	15		21.15	1.41	N3
Cf-252; 45°	1	2		2.93	1.47	N3
	18	2		2.86	1.43	N3
Cf-252 (D_2O); 0°	2	3		4.60	1.53	N1
	6	3		4.18	1.39	N1
	22	3		4.23	1.41	N1
	29	3		4.26	1.42	N1
Cf-252 + cone; 0°	3	2		1.17	0.59	N1
	33	2		0.87	0.44	N1
250 keV; 0°	7	1.02		0.99	0.97	N2
	12	1.02		0.99	0.97	N2
	20	1.02		0.93	0.91	N2
	35	1.02		0.98	0.96	N2

"out by factor >2"

Radiation quality	Number of values	Median of *R*	Mean of *R*
Cf-252; 0°	12	1.57	1.44
Cf-252; 45°	2	1.45	1.45
Cf-252 (D_2O); 0°	4	1.42	1.44
Cf-252 + cone; 0°	2	0.51	0.51
250 keV; 0°	4	0.97	0.95
All	24	1.43	1.28

Number of "out by factor >2": 1 of 24

Fraction of "out by factor >2": 4%



S15, dosemeter type: Albedo (continued)

Reference values reported by the irradiating laboratory			Step I Participant's value								
Radiation quality	Dosemeter code	*Hp* (10) Reference value (mSv)	H_p(10) (mSv)	*R*	Remark	H_p(10) (mSv)	*R*	Remark	H_p(10) (mSv)	*R*	Remark
Cf-252; 0°	23	0.3	0.00	0.00	N1	0.00	0.00	N2	0.53	1.77	N3
	30	0.3	0.00	0.00	N1	0.00	0.00	N2	0.50	1.67	N3
	32	0.3	0.00	0.00	N1	0.00	0.00	N2	0.18	0.60	N3
	36	0.3	0.00	0.00	N1	0.00	0.00	N2	0.25	0.83	N3
	11	3	0.49	0.16	N1	0.90	0.30	N2	4.65	1.55	N3
	16	3	0.47	0.16	N1	0.86	0.29	N2	4.69	1.56	N3
	24	3	0.45	0.15	N1	0.83	0.28	N2	4.51	1.50	N3
	25	3	0.48	0.16	N1	0.88	0.29	N2	4.78	1.59	N3
	4	15	2.38	0.16	N1	4.35	0.29	N2	23.60	1.57	N3
	8	15	2.36	0.16	N1	4.31	0.29	N2	23.57	1.57	N3
	9	15	2.51	0.17	N1	4.59	0.31	N2	25.06	1.67	N3
	27	15	2.12	0.14	N1	3.88	0.26	N2	21.15	1.41	N3
Cf-252; 45°	1	2	0.30	0.15	N1	0.54	0.27	N2	2.93	1.47	N3
	18	2	0.29	0.15	N1	0.52	0.26	N2	2.86	1.43	N3
Cf-252 (D_2O); 0°	2	3	4.60	1.53	N1	8.41	2.80	N2	36.83	12.28	N3
	6	3	4.18	1.39	N1	7.63	2.54	N2	31.56	10.52	N3
	22	3	4.23	1.41	N1	7.74	2.58	N2	31.77	10.59	N3
	29	3	4.26	1.42	N1	7.78	2.59	N2	32.74	10.91	N3
Cf-252 + cone; 0°	3	2	1.17	0.59	N1	3.05	1.53	N2	6.63	3.32	N3
	33	2	0.87	0.44	N1	2.74	1.37	N2	4.94	2.47	N3
250 keV; 0°	7	1.02	0.54	0.53	N1	0.99	0.97	N2	5.11	5.01	N3
	12	1.02	0.54	0.53	N1	0.99	0.97	N2	5.40	5.29	N3
	20	1.02	0.51	0.50	N1	0.93	0.91	N2	4.85	4.75	N3
	35	1.02	0.53	0.52	N1	0.98	0.96	N2	5.24	5.14	N3

S16, dosemeter type: Etched track

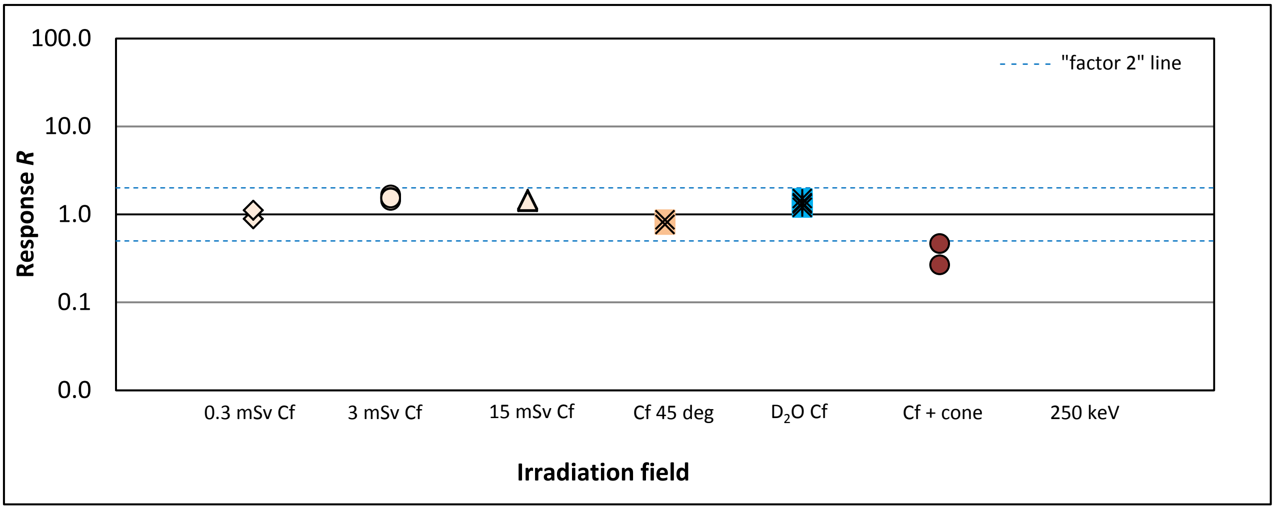
Reference values reported by the irradiating laboratory			Step I			Final step		
Radiation quality	Dosemeter code	$H_p(10)$ Reference value (mSv)	$H_p(10)$ Participant's value (mSv)	*R*	Remark	$H_p(10)$ Participant's value (mSv)	*R*	Remark
Cf-252; 0°	2	0.3	0.40	1.33		0.27	0.89	
	5	0.3	0.40	1.33		0.27	0.89	
	18	0.3	0.50	1.67		0.33	1.11	
	32	0.3	0.50	1.67		0.33	1.11	
	1	3	6.50	2.17		4.33	1.44	
	11	3	7.50	2.50		5.00	1.67	
	17	3	7.00	2.33		4.67	1.56	
	31	3	6.90	2.30		4.60	1.53	
	4	15	33.40	2.23		22.27	1.48	
	24	15	32.90	2.19		21.93	1.46	
	25	15	31.40	2.09		20.93	1.40	
	35	15	32.10	2.14		21.40	1.43	
Cf-252; 45°	7	2	2.30	1.15		1.53	0.77	
	22	2	2.60	1.30		1.73	0.87	
Cf-252 (D_2O); 0°	6	3	6.10	2.03		4.07	1.36	
	9	3	5.90	1.97		3.93	1.31	
	12	3	5.40	1.80		3.60	1.20	
	27	3	6.80	2.27		4.53	1.51	
Cf-252 + cone; 0°	8	2	1.40	0.70		0.93	0.47	
	20	2	0.80	0.40		0.53	0.27	
250 keV; 0°	15	1.03	0.00	0.00		0.00	0.00	
	28	1.03	0.00	0.00		0.00	0.00	
	29	1.02	0.00	0.00		0.00	0.00	
	33	1.02	0.00	0.00		0.00	0.00	

"out by factor >2"

Radiation quality	Number of values	Median of *R*	Mean of *R*
Cf-252; 0°	12	1.44	1.33
Cf-252; 45°	2	0.82	0.82
Cf-252 (D_2O); 0°	4	1.33	1.34
Cf-252 + cone; 0°	2	0.37	0.37
250 keV; 0°	4	0.00	0.00
All	24	1.16	0.99

Number of "out by factor >2": 6 of 24

Fraction of "out by factor >2": 25%



S17, dosemeter type: Etched track

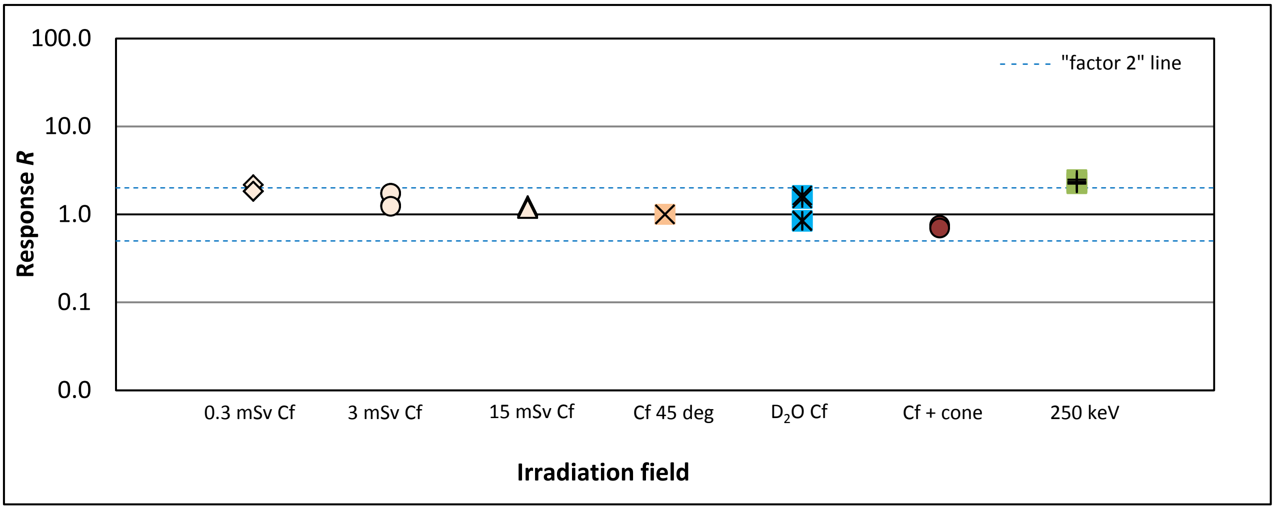
Reference values reported by the irradiating laboratory			Step I			Final step		
Radiation quality	Dosemeter code	$H_p(10)$ Reference value (mSv)	$H_p(10)$ Participant's value (mSv)	*R*	Remark	$H_p(10)$ Participant's value (mSv)	*R*	Remark
Cf-252; 0°	5	0.3	0.65	2.17		0.65	2.17	
	13	0.3	0.25	0.83		0.55	1.83	
	16	0.3	0.55	1.83		0.55	1.83	
	17	0.3	0.30	1.00		0.55	1.83	
	1	3	2.10	0.70		5.20	1.73	
	11	3	3.85	1.28		3.80	1.27	
	18	3	2.35	0.78		5.20	1.73	
	32	3	3.60	1.20		3.70	1.23	
	2	15	18.75	1.25		18.75	1.25	
	4	15	17.90	1.19		17.90	1.19	
	7	15	18.65	1.24		18.60	1.24	
	36	15	17.45	1.16		17.45	1.16	
Cf-252; 45°	14	2	1.50	0.75		2.00	1.00	
	27	2	1.20	0.60		2.00	1.00	
Cf-252 (D_2O); 0°	6	3	4.95	1.65		4.90	1.63	
	9	3	4.55	1.52		4.55	1.52	
	25	3	2.55	0.85		2.50	0.83	
	29	3	2.55	0.85		2.55	0.85	
Cf-252 + cone; 0°	12	2	1.55	0.78		1.50	0.75	
	26	2	1.40	0.70		1.40	0.70	
250 keV; 0°	20	1.03	2.40	2.33		2.35	2.28	
	28	1.03	2.55	2.48		2.55	2.48	
	30	1.03	2.40	2.33		2.40	2.33	
	33	1.03	2.35	2.28		2.30	2.23	

"out by factor >2"

Radiation quality	Number of values	Median of *R*	Mean of *R*
Cf-252; 0°	12	1.50	1.54
Cf-252; 45°	2	1.00	1.00
Cf-252 (D_2O); 0°	4	1.18	1.21
Cf-252 + cone; 0°	2	0.73	0.73
250 keV; 0°	4	2.31	2.33
All	24	1.39	1.50

Number of "out by factor >2": 5 of 24

Fraction of "out by factor >2": 21%



S18, dosemeter type: Albedo

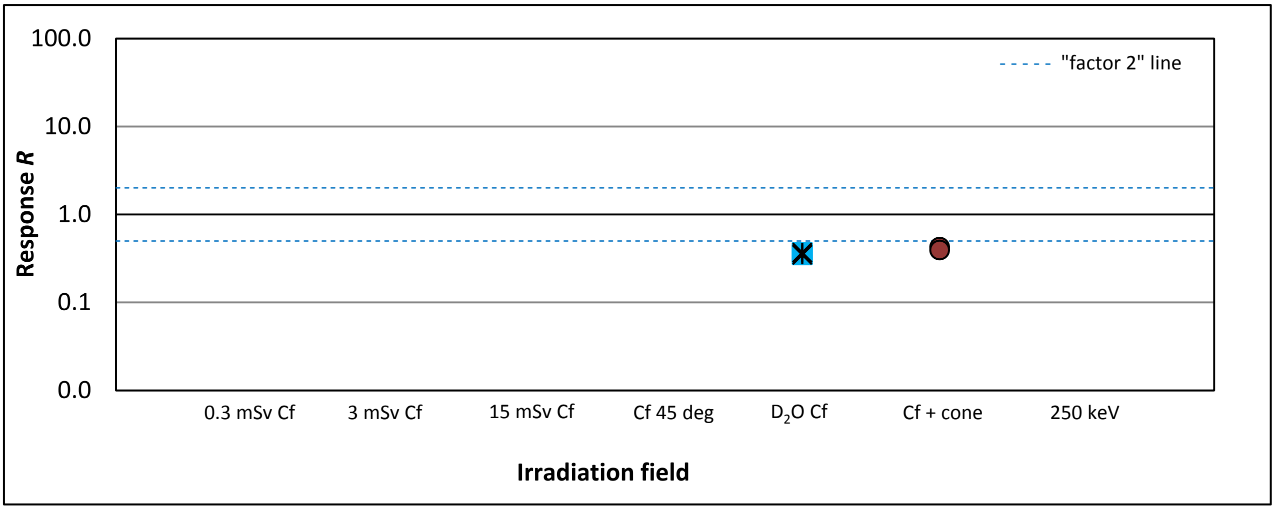
Reference values reported by the irradiating laboratory			Step I			Final step		
Radiation quality	Dosemeter code	$H_p(10)$ Reference value (mSv)	$H_p(10)$ Participant's value (mSv)	*R*	Remark	$H_p(10)$ Participant's value (mSv)	*R*	Remark
Cf-252; 0°	11	0.3	0.00	0.00		0.00	0.00	
	18	0.3	0.00	0.00		0.00	0.00	
	21	0.3	0.00	0.00		0.00	0.00	
	29	0.3	0.00	0.00		0.00	0.00	
	13	3	0.14	0.05		0.00	0.00	Not applicable
	27	3	0.12	0.04		0.00	0.00	
	32	3	0.14	0.05		0.00	0.00	
	35	3	0.14	0.05		0.00	0.00	
	12	15	0.62	0.04		0.00	0.00	Not applicable
	19	15	0.54	0.04		0.00	0.00	
	22	15	0.62	0.04		0.00	0.00	
	25	15	0.63	0.04		0.00	0.00	
Cf-252; 45°	20	2	0.08	0.04		0.00	0.00	Not applicable
	30	2	0.08	0.04		0.00	0.00	
Cf-252 (D_2O); 0°	4	3	1.10	0.37		1.10	0.37	Calibrated in moderated reactor spectra
	10	3	1.10	0.37		1.10	0.37	
	15	3	1.04	0.35		1.04	0.35	
	23	3	1.05	0.35		1.05	0.35	
Cf-252 + cone; 0°	2	2	0.85	0.43		0.85	0.43	Calibrated in moderated reactor spectra
	17	2	0.79	0.40		0.79	0.40	
250 keV; 0°	6	1.02	0.15	0.15		0.00	0.00	Not applicable
	14	1.02	0.12	0.12		0.00	0.00	
	26	1.02	0.13	0.13		0.00	0.00	
	36	1.02	0.12	0.12		0.00	0.00	

"out by factor >2"

Radiation quality	Number of values	Median of *R*	Mean of *R*
Cf-252; 0°	12	0.00	0.00
Cf-252; 45°	2	0.00	0.00
Cf-252 (D_2O); 0°	4	0.36	0.36
Cf-252 + cone; 0°	2	0.41	0.41
250 keV; 0°	4	0.00	0.00
All	24	0.00	0.09

Number of "out by factor >2": 24 of 24

Fraction of "out by factor >2": 100%



S19, dosemeter type: Albedo

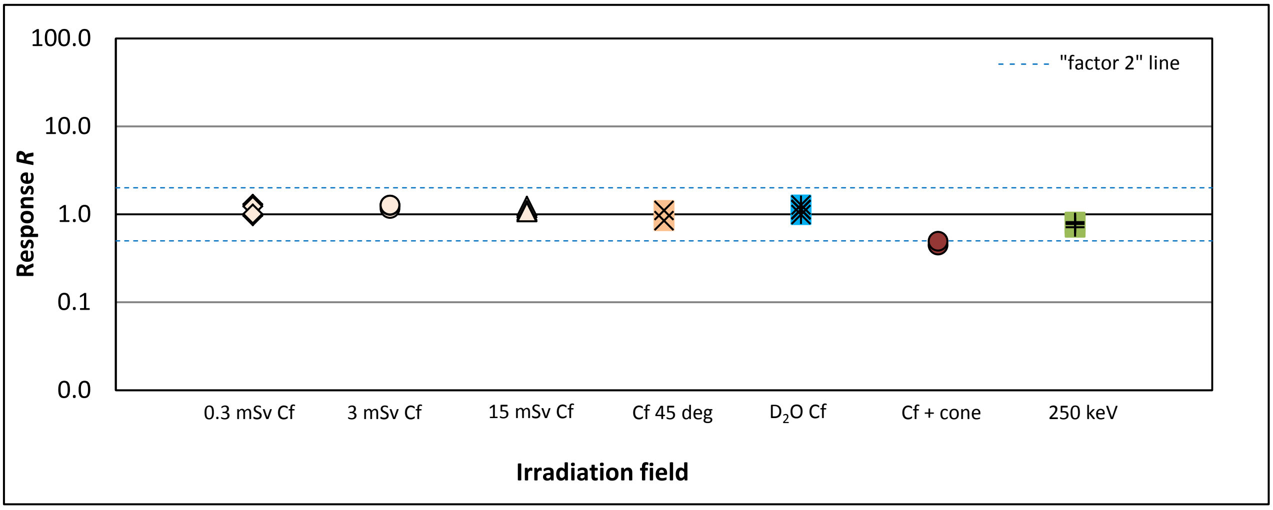
Reference values reported by the irradiating laboratory			Step I	Final step		
Radiation quality	Dosemeter code	$H_p(10)$ Reference value (mSv)	see next page	$H_p(10)$ Participant's value (mSv)	*R*	Remark
Cf-252; 0°	7	0.3		0.29	0.96	N3
	8	0.3		0.39	1.30	N3
	26	0.3		0.37	1.23	N3
	31	0.3		0.30	1.01	N3
	2	3		3.49	1.16	N3
	15	3		3.82	1.27	N3
	27	3		3.78	1.26	N3
	35	3		3.82	1.27	N3
	10	15		17.60	1.17	N3
	14	15		18.53	1.24	N3
	29	15		16.51	1.10	N3
	33	15		15.92	1.06	N3
Cf-252; 45°	6	2		1.69	0.85	N3
	28	2		2.21	1.10	N3
Cf-252 (D_2O); 0°	21	3		3.40	1.13	N1
	22	3		3.81	1.27	N1
	24	3		3.35	1.12	N1
	25	3		2.96	0.99	N1
Cf-252 + cone; 0°	4	2		0.89	0.45	N1
	12	2		0.99	0.49	N1
250 keV; 0°	5	1.03		0.80	0.77	N2
	11	1.04		0.83	0.80	N2
	18	1.03		0.73	0.71	N2
	23	1.04		0.85	0.81	N2

"out by factor >2"

Radiation quality	Number of values	Median of *R*	Mean of *R*
Cf-252; 0°	12	1.20	1.17
Cf-252; 45°	2	0.97	0.97
Cf-252 (D_2O); 0°	4	1.12	1.13
Cf-252 + cone; 0°	2	0.47	0.47
250 keV; 0°	4	0.79	0.77
All	24	1.10	1.02

Number of "out by factor >2": 2 of 24

Fraction of "out by factor >2": 8%



S19, dosemeter type: Albedo (continued)

Reference values reported by the irradiating laboratory			Step I Participant's value											
Radiation quality	Dosemeter code	*Hp* (10) Reference value (mSv)	$H_p(10)$ (mSv)	*R*	Remark	$H_p(10)$ (mSv)	*R*	Remark	$H_p(10)$ (mSv)	*R*	Remark	$H_p(10)$ (mSv)	*R*	Remark
Cf-252; 0°	7	0.3	0.04	0.13	N1	0.06	0.21	N2	0.29	0.96	N3	0.29	0.96	N4
	8	0.3	0.05	0.18	N1	0.09	0.29	N2	0.39	1.30	N3	0.39	1.30	N4
	26	0.3	0.05	0.17	N1	0.08	0.27	N2	0.37	1.23	N3	0.37	1.23	N4
	31	0.3	0.04	0.14	N1	0.07	0.22	N2	0.30	1.01	N3	0.30	1.01	N4
	2	3	0.38	0.13	N1	0.60	0.20	N2	3.49	1.16	N3	3.49	1.16	N4
	15	3	0.43	0.14	N1	0.69	0.23	N2	3.82	1.27	N3	3.82	1.27	N4
	27	3	0.41	0.14	N1	0.66	0.22	N2	3.78	1.26	N3	3.78	1.26	N4
	35	3	0.43	0.14	N1	0.69	0.23	N2	3.82	1.27	N3	3.82	1.27	N4
	10	15	2.10	0.14	N1	3.35	0.22	N2	17.60	1.17	N3	17.60	1.17	N4
	14	15	2.09	0.14	N1	3.35	0.22	N2	18.53	1.24	N3	18.53	1.24	N4
	29	15	1.93	0.13	N1	3.08	0.21	N2	16.51	1.10	N3	16.51	1.10	N4
	33	15	1.89	0.13	N1	3.03	0.20	N2	15.92	1.06	N3	15.92	1.06	N4
Cf-252; 45°	6	2	0.23	0.12	N1	0.37	0.19	N2	1.69	0.85	N3	1.69	0.85	N4
	28	2	0.24	0.12	N1	0.38	0.19	N2	2.21	1.10	N3	2.21	1.10	N4
Cf-252 (D_2O); 0°	21	3	3.40	1.13	N1	5.44	1.81	N2	22.45	7.48	N3	22.45	7.48	N4
	22	3	3.81	1.27	N1	6.10	2.03	N2	25.79	8.60	N3	25.79	8.60	N4
	24	3	3.35	1.12	N1	5.35	1.78	N2	22.95	7.65	N3	22.95	7.65	N4
	25	3	2.96	0.99	N1	4.74	1.58	N2	18.92	6.31	N3	18.92	6.31	N4
Cf-252 + cone; 0°	4	2	0.89	0.45	N1	2.36	1.18	N2	4.84	2.42	N3	4.84	2.42	N4
	12	2	0.99	0.49	N1	2.52	1.26	N2	5.37	2.68	N3	5.37	2.68	N4
250 keV; 0°	5	1.03	0.50	0.48	N1	0.80	0.77	N2	4.38	4.26	N3	4.38	4.26	N4
	11	1.04	0.52	0.50	N1	0.83	0.80	N2	4.21	4.05	N3	4.21	4.05	N4
	18	1.03	0.46	0.45	N1	0.73	0.71	N2	3.59	3.49	N3	3.59	3.49	N4
	23	1.04	0.53	0.51	N1	0.85	0.81	N2	4.52	4.35	N3	4.52	4.35	N4

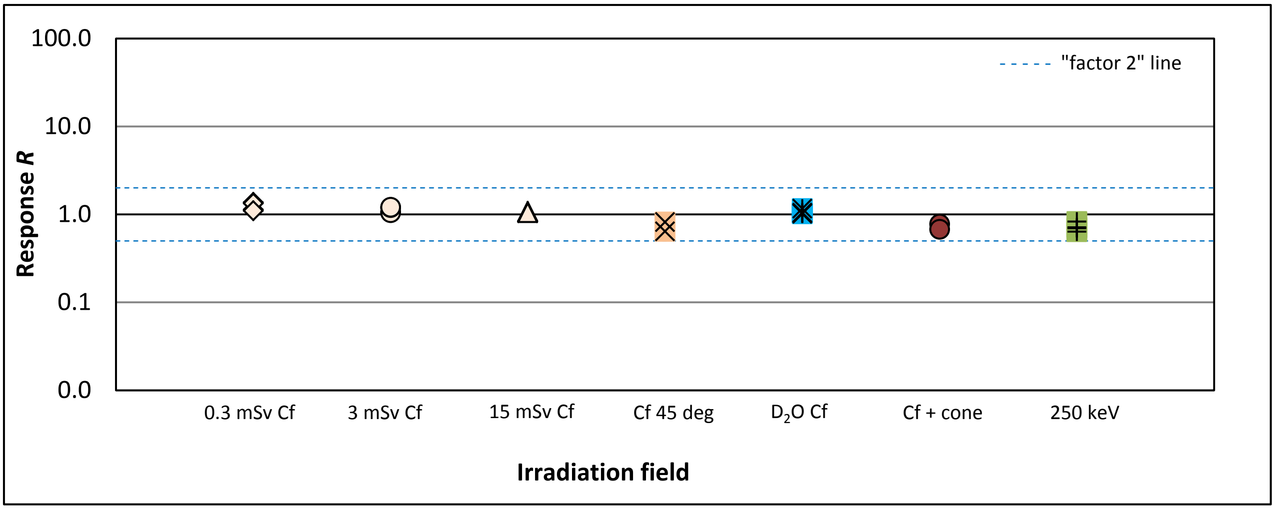
S20, dosemeter type: Etched track

Reference values reported by the irradiating laboratory			Step I			Final step		
Radiation quality	Dosemeter code	$H_p(10)$ Reference value (mSv)	$H_p(10)$ Participant's value (mSv)	*R*	Remark	$H_p(10)$ Participant's value (mSv)	*R*	Remark
Cf-252; 0°	3	0.3	0.41	1.37		0.41	1.37	
	7	0.3	0.34	1.13		0.34	1.13	
	18	0.3	0.40	1.33		0.40	1.33	
	33	0.3	0.33	1.10		0.33	1.10	
	8	3	3.20	1.07		3.20	1.07	
	16	3	3.13	1.04		3.13	1.04	
	21	3	3.59	1.20		3.59	1.20	
	35	3	3.61	1.20		3.61	1.20	
	1	15	16.22	1.08		16.22	1.08	
	29	15	15.99	1.07		15.99	1.07	
	32	15	16.03	1.07		16.03	1.07	
	36	15	15.69	1.05		15.69	1.05	
Cf-252; 45°	2	2	1.28	0.64		1.28	0.64	
	27	2	1.63	0.82		1.63	0.82	
Cf-252 (D_2O); 0°	5	3	3.04	1.01		3.04	1.01	
	17	3	3.10	1.03		3.10	1.03	
	26	3	3.14	1.05		3.14	1.05	
	30	3	3.48	1.16		3.48	1.16	
Cf-252 + cone; 0°	9	2	1.55	0.78		1.55	0.78	
	19	2	1.35	0.68		1.35	0.68	
250 keV; 0°	6	1.04	0.74	0.71		0.74	0.71	
	10	1.04	0.72	0.69		0.72	0.69	
	23	1.04	0.66	0.63		0.66	0.63	
	31	1.04	0.86	0.83		0.86	0.83	

"out by factor >2"

Radiation quality	Number of values	Median of *R*	Mean of *R*
Cf-252; 0°	12	1.09	1.14
Cf-252; 45°	2	0.73	0.73
Cf-252 (D_2O); 0°	4	1.04	1.06
Cf-252 + cone; 0°	2	0.73	0.73
250 keV; 0°	4	0.70	0.72
All	24	1.05	0.99

Number of "out by factor >2":	0 of 24
Fraction of "out by factor >2":	0%



S21, dosemeter type: Other

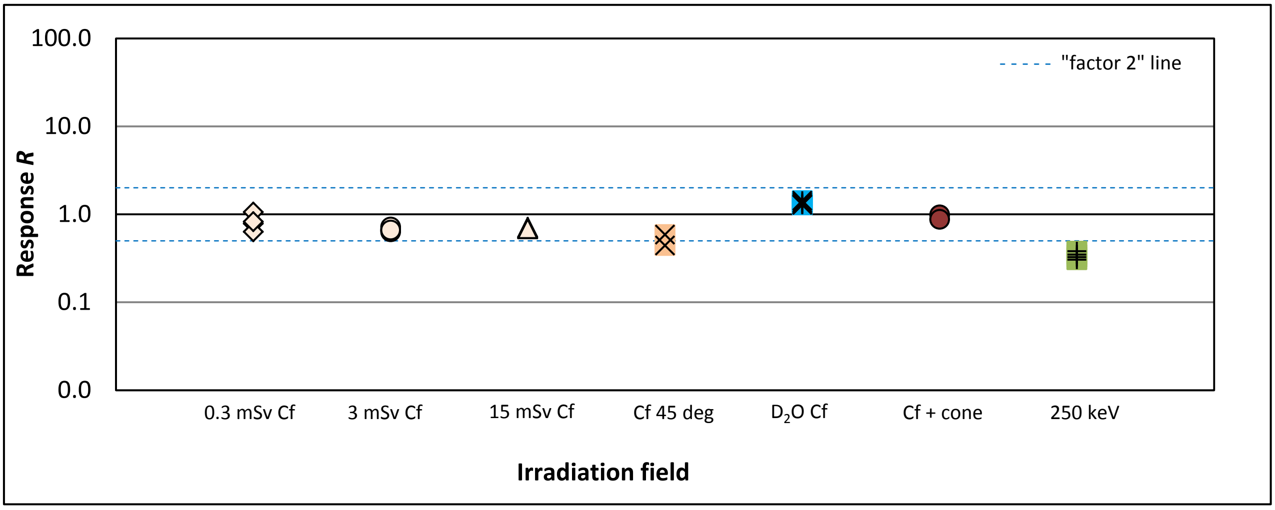
Reference values reported by the irradiating laboratory			Step I			Final step		
Radiation quality	Dosemeter code	$H_p(10)$ Reference value (mSv)	$H_p(10)$ Participant's value (mSv)	R	Remark	$H_p(10)$ Participant's value (mSv)	R	Remark
Cf-252; 0°	8	0.3	0.25	0.84	γ = 0.018 n = 0.235	0.24	0.78	neutron dose only
	10	0.3	0.33	1.11	γ = 0.017 n = 0.317	0.32	1.06	
	15	0.3	0.21	0.69	γ = 0.018 n = 0.190	0.19	0.63	
	18	0.3	0.40	1.32	γ = 0.15 n = 0.247	0.25	0.82	
	1	3	2.13	0.71	γ = 0.149 n = 1.985	1.99	0.66	neutron dose only
	4	3	2.05	0.68	γ = 0.149 n = 1.899	1.90	0.63	
	21	3	2.30	0.77	γ = 0.144 n = 2.156	2.16	0.72	
	23	3	2.14	0.71	γ = 0.147 n = 1.988	1.99	0.66	
	6	15	11.43	0.76	γ = 0.745 n = 10.68	10.68	0.71	neutron dose only
	11	15	11.13	0.74	γ = 0.741 n = 10.39	10.39	0.69	
	16	15	11.03	0.74	γ = 0.750 n = 10.28	10.28	0.69	
	20	15	11.05	0.74	γ = 0.758 n = 10.29	10.29	0.69	
Cf-252; 45°	7	2	0.98	0.49	γ = 0.099 n = 0.884	0.88	0.44	neutron dose only
	19	2	1.26	0.63	γ = 0.093 n = 1.171	1.17	0.59	
Cf-252 (D_2O); 0°	2	3	4.43	1.48	γ = 0.523 n = 3.905	3.91	1.30	neutron dose only
	9	3	4.37	1.46	γ = 0.531 n = 3.836	3.84	1.28	
	24	3	4.80	1.60	γ = 0.533 n = 4.27	4.27	1.42	
	26	3	4.60	1.53	γ = 0.530 n = 4.07	4.07	1.36	
Cf-252 + cone; 0°	5	2	2.12	1.06	γ = 0.150 n = 1.971	1.97	0.99	neutron dose only
	17	2	1.90	0.95	γ = 0.148 n = 1.752	1.75	0.88	
250 keV; 0°	12	1.06	0.39	0.36	γ = 0.017 n = 0.369	0.37	0.35	neutron dose only
	13	1.06	0.42	0.40	γ = 0.018 n = 0.402	0.40	0.38	
	22	1.06	0.36	0.34	γ = 0.017 n = 0.344	0.34	0.32	
	25	1.06	0.48	0.46	γ = 0.16 n = 0.323	0.32	0.30	

"out by factor >2"

Radiation quality	Number of values	Median of R	Mean of R
Cf-252; 0°	12	0.69	0.73
Cf-252; 45°	2	0.51	0.51
Cf-252 (D_2O); 0°	4	1.33	1.34
Cf-252 + cone; 0°	2	0.93	0.93
250 keV; 0°	4	0.34	0.34
All	24	0.69	0.76

Number of "out by factor >2": 5 of 24

Fraction of "out by factor >2": 21%



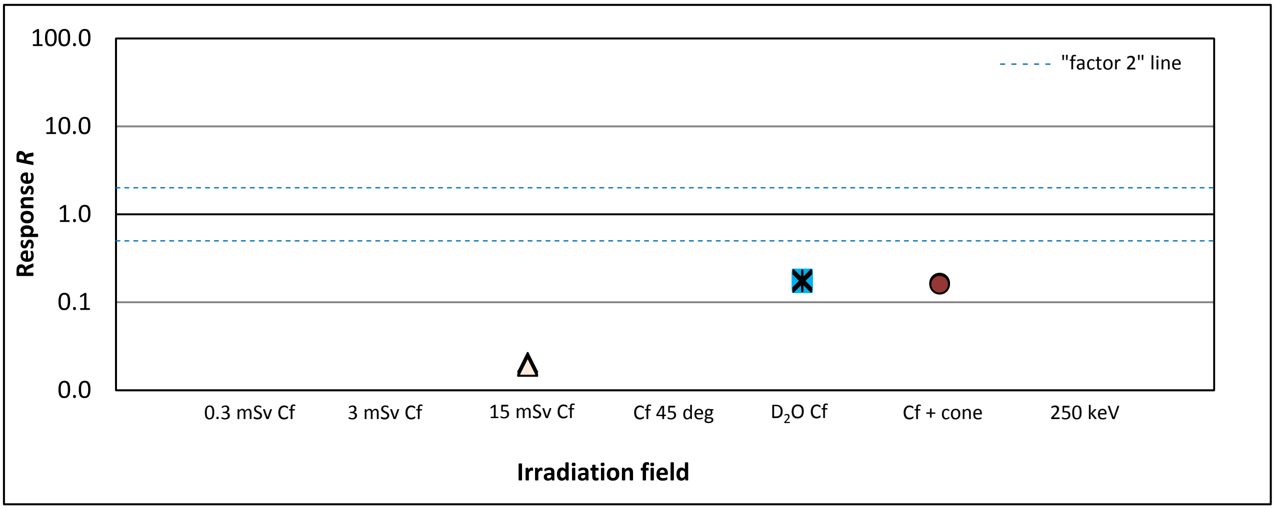
S22, dosemeter type: Albedo

Reference values reported by the irradiating laboratory			Step I			Final step		
Radiation quality	Dosemeter code	$H_p(10)$ Reference value (mSv)	$H_p(10)$ Participant's value (mSv)	*R*	Remark	$H_p(10)$ Participant's value (mSv)	*R*	Remark
Cf-252; 0°	5	0.3	0.00	0.00	Neutron doses <0.1 are not reported	0.00	0.00	Neutron doses <0.1 are not reported
	17	0.3	0.00	0.00		0.00	0.00	
	22	0.3	0.00	0.00		0.00	0.00	
	23	0.3	0.00	0.00		0.00	0.00	
	6	3	0.00	0.00	Neutron doses <0.1 are not reported	0.00	0.00	Neutron doses <0.1 are not reported
	12	3	0.00	0.00		0.00	0.00	
	34	3	0.00	0.00		0.00	0.00	
	36	3	0.00	0.00		0.00	0.00	
	7	15	0.23	0.02	Hp(10) from neutrons	0.28	0.02	Hp(10) from neutrons (kn=18)
	25	15	0.26	0.02		0.31	0.02	
	29	15	0.24	0.02		0.29	0.02	
	31	15	0.23	0.02		0.28	0.02	
Cf-252; 45°	2	2	0.00	0.00	Neutron doses <0.1 are not reported	0.00	0.00	Neutron doses <0.1 are not reported
	13	2	0.00	0.00		0.00	0.00	
Cf-252 (D_2O); 0°	1	3	0.43	0.14	Hp(10) from neutrons	0.52	0.17	Hp(10) from neutrons (kn=18)
	4	3	0.45	0.15		0.55	0.18	
	14	3	0.44	0.15		0.53	0.18	
	15	3	0.42	0.14		0.50	0.17	
Cf-252 + cone; 0°	18	2	0.27	0.14	Hp(10) from neutrons	0.33	0.17	Hp(10) from neutrons (kn=18)
	33	2	0.27	0.14		0.32	0.16	
250 keV; 0°	19	1.03	0.00	0.00	Neutron doses <0.1 are not reported	0.00	0.00	Neutron doses <0.1 are not reported
	20	1.03	0.00	0.00		0.00	0.00	
	21	1.04	0.00	0.00		0.00	0.00	
	27	1.04	0.00	0.00		0.00	0.00	

"out by factor >2"

Radiation quality	Number of values	Median of *R*	Mean of *R*
Cf-252; 0°	12	0.00	0.01
Cf-252; 45°	2	0.00	0.00
Cf-252 (D_2O); 0°	4	0.18	0.18
Cf-252 + cone; 0°	2	0.16	0.16
250 keV; 0°	4	0.00	0.00
All	24	0.00	0.05

Number of "out by factor >2":	24 of 24
Fraction of "out by factor >2":	100%



S23, dosemeter type: Etched track

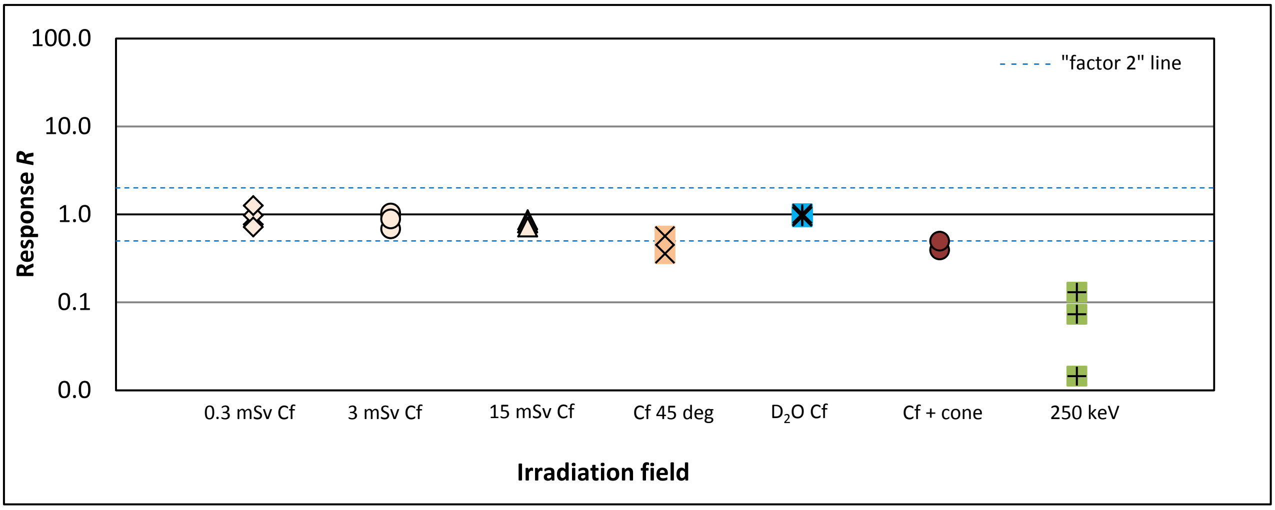
Reference values reported by the irradiating laboratory			Step I			Final step		
Radiation quality	Dosemeter code	$H_p(10)$ Reference value (mSv)	$H_p(10)$ Participant's value (mSv)	*R*	Remark	$H_p(10)$ Participant's value (mSv)	*R*	Remark
Cf-252; 0°	13	0.3	0.23	0.77		0.23	0.77	
	16	0.3	0.29	0.97		0.29	0.97	
	32	0.3	0.38	1.26		0.38	1.26	
	34	0.3	0.22	0.72		0.22	0.72	
	2	3	2.06	0.69		2.06	0.69	
	14	3	2.94	0.98		2.94	0.98	
	21	3	3.11	1.04		3.11	1.04	
	33	3	2.66	0.89		2.66	0.89	
	4	15	11.97	0.80		11.97	0.80	
	18	15	13.00	0.87		13.00	0.87	
	28	15	12.03	0.80		12.03	0.80	
	29	15	10.75	0.72		10.75	0.72	
Cf-252; 45°	1	2	0.71	0.36		0.71	0.36	
	11	2	1.13	0.56		1.13	0.56	
Cf-252 (D_2O); 0°	15	3	3.05	1.02		3.05	1.02	
	26	3	2.81	0.94		2.81	0.94	
	35	3	2.85	0.95		2.85	0.95	
	36	3	2.89	0.96		2.89	0.96	
Cf-252 + cone; 0°	9	2	0.79	0.39		0.79	0.39	
	19	2	0.99	0.50		0.99	0.50	
250 keV; 0°	6	1.04	0.01	0.01		0.01	0.01	
	8	1.04	0.02	0.01		0.02	0.01	
	12	1.04	0.08	0.07		0.08	0.07	
	25	1.04	0.14	0.13		0.14	0.13	

"out by factor >2"

Radiation quality	Number of values	Median of *R*	Mean of *R*
Cf-252; 0°	12	0.83	0.87
Cf-252; 45°	2	0.46	0.46
Cf-252 (D_2O); 0°	4	0.96	0.97
Cf-252 + cone; 0°	2	0.45	0.45
250 keV; 0°	4	0.04	0.06
All	24	0.78	0.68

Number of "out by factor >2": 6 of 24

Fraction of "out by factor >2": 25%



S24, dosemeter type: Etched track

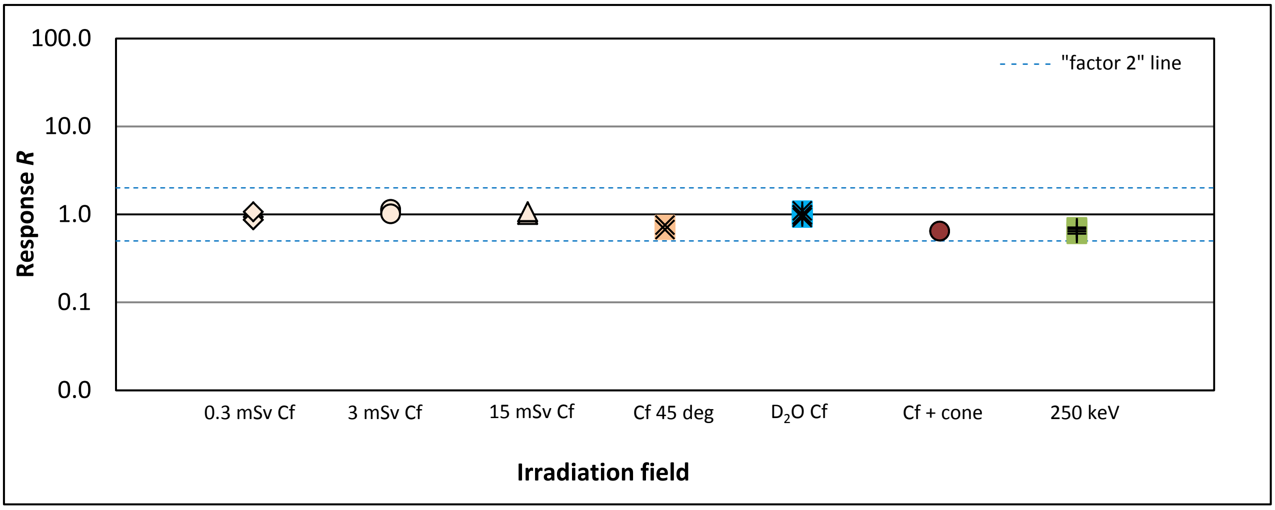
Reference values reported by the irradiating laboratory			Step I			Final step		
Radiation quality	Dosemeter code	$H_p(10)$ Reference value (mSv)	$H_p(10)$ Participant's value (mSv)	*R*	Remark	$H_p(10)$ Participant's value (mSv)	*R*	Remark
Cf-252; 0°	1	0.3	0.26	0.87		0.26	0.87	
	13	0.3	0.28	0.93		0.28	0.93	
	17	0.3	0.26	0.87		0.26	0.87	
	28	0.3	0.32	1.07		0.32	1.07	
	4	3	3.18	1.06		3.18	1.06	
	12	3	3.37	1.12		3.37	1.12	
	22	3	3.43	1.14		3.43	1.14	
	36	3	3.05	1.02		3.05	1.02	
	19	15	15.01	1.00		15.01	1.00	
	25	15	14.94	1.00		14.94	1.00	
	26	15	15.94	1.06		15.94	1.06	
	31	15	16.08	1.07		16.08	1.07	
Cf-252; 45°	29	2	1.34	0.67		1.34	0.67	
	34	2	1.51	0.76		1.51	0.76	
Cf-252 (D_2O); 0°	8	3	2.93	0.98		2.93	0.98	
	9	3	2.98	0.99		2.98	0.99	
	15	3	2.77	0.92		2.77	0.92	
	24	3	3.29	1.10		3.29	1.10	
Cf-252 + cone; 0°	7	2	1.29	0.65		1.29	0.65	
	14	2	1.29	0.65		1.29	0.65	
250 keV; 0°	10	1.03	0.73	0.71		0.73	0.71	
	18	1.03	0.70	0.68		0.70	0.68	
	23	1.03	0.62	0.60		0.62	0.60	
	33	1.03	0.66	0.64		0.66	0.64	

"out by factor >2"

Radiation quality	Number of values	Median of *R*	Mean of *R*
Cf-252; 0°	12	1.04	1.02
Cf-252; 45°	2	0.71	0.71
Cf-252 (D_2O); 0°	4	0.99	1.00
Cf-252 + cone; 0°	2	0.65	0.65
250 keV; 0°	4	0.66	0.66
All	24	0.96	0.90

Number of "out by factor >2": 0 of 24

Fraction of "out by factor >2": 0%



S25, dosemeter type: Etched track

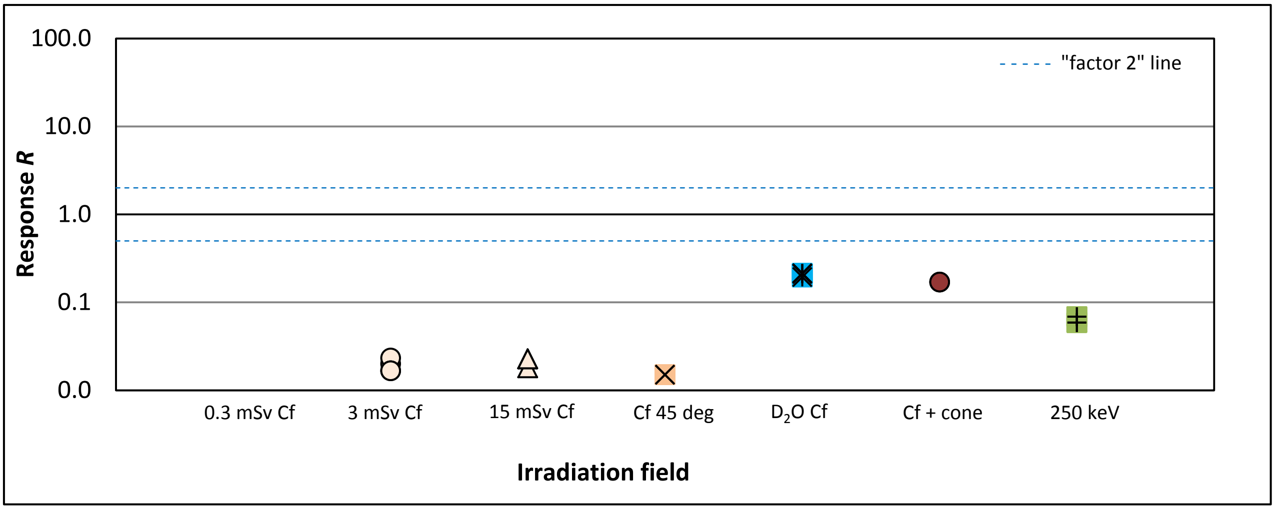
Reference values reported by the irradiating laboratory			Step I			Final step		
Radiation quality	Dosemeter code	$H_p(10)$ Reference value (mSv)	$H_p(10)$ Participant's value (mSv)	*R*	Remark	$H_p(10)$ Participant's value (mSv)	*R*	Remark
Cf-252; 0°	14	0.3	0.00	0.00	refers only to the thermal component	0.00	0.00	refers only to the thermal component
	22	0.3	0.00	0.00		0.00	0.00	
	28	0.3	0.00	0.00		0.00	0.00	
	36	0.3	0.00	0.00		0.00	0.00	
	1	3	0.06	0.02	refers only to the thermal component	0.06	0.02	refers only to the thermal component
	4	3	0.07	0.02		0.07	0.02	
	29	3	0.05	0.02		0.05	0.02	
	34	3	0.05	0.02		0.05	0.02	
	5	15	0.34	0.02	refers only to the thermal component	0.34	0.02	refers only to the thermal component
	15	15	0.27	0.02		0.27	0.02	
	18	15	0.34	0.02		0.34	0.02	
	27	15	0.34	0.02		0.34	0.02	
Cf-252; 45°	8	2	0.03	0.02	refers only to the thermal component	0.03	0.02	refers only to the thermal component
	19	2	0.03	0.02		0.03	0.02	
Cf-252 (D_2O); 0°	13	3	0.64	0.21	refers only to the thermal component	0.64	0.21	refers only to the thermal component
	16	3	0.63	0.21		0.63	0.21	
	20	3	0.64	0.21		0.64	0.21	
	24	3	0.58	0.19		0.58	0.19	
Cf-252 + cone; 0°	7	2	0.34	0.17	refers only to the thermal component	0.34	0.17	refers only to the thermal component
	26	2	0.34	0.17		0.34	0.17	
250 keV; 0°	12	1.02	0.07	0.07	refers only to the thermal component	0.07	0.07	refers only to the thermal component
	21	1.02	0.06	0.06		0.06	0.06	
	33	1.02	0.07	0.07		0.07	0.07	
	35	1.02	0.06	0.06		0.06	0.06	

"out by factor >2"

Radiation quality	Number of values	Median of *R*	Mean of *R*
Cf-252; 0°	12	0.02	0.01
Cf-252; 45°	2	0.02	0.02
Cf-252 (D_2O); 0°	4	0.21	0.21
Cf-252 + cone; 0°	2	0.17	0.17
250 keV; 0°	4	0.06	0.06
All	24	0.02	0.07

Number of "out by factor >2": 24 of 24

Fraction of "out by factor >2": 100%



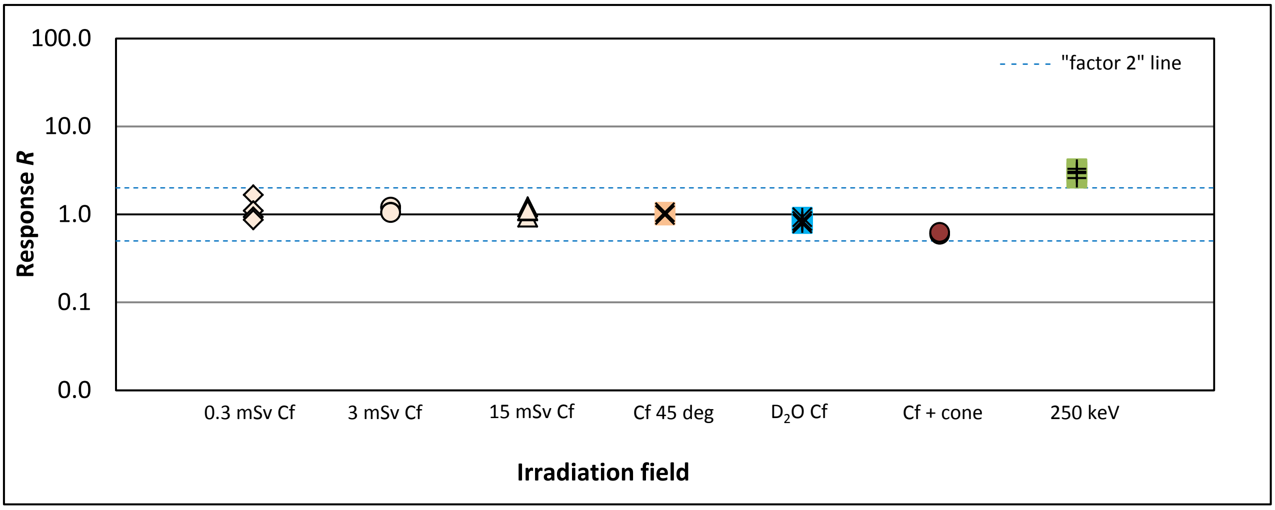
S26, dosemeter type: Albedo

Reference values reported by the irradiating laboratory			Step I			Final step		
Radiation quality	Dosemeter code	$H_p(10)$ Reference value (mSv)	$H_p(10)$ Participant's value (mSv)	*R*	Remark	$H_p(10)$ Participant's value (mSv)	*R*	Remark
Cf-252; 0°	1	0.3	0.53	1.77		0.50	1.67	
	17	0.3	0.46	1.53		0.33	1.10	
	25	0.3	0.28	0.93		0.28	0.93	
	31	0.3	0.22	0.73		0.26	0.87	
	6	3	4.10	1.37		3.59	1.20	
	9	3	4.87	1.62		3.63	1.21	
	11	3	3.45	1.15		3.17	1.06	
	14	3	3.10	1.03		3.15	1.05	
	3	15	11.08	0.74		13.95	0.93	
	4	15	18.21	1.21		16.39	1.09	
	10	15	22.17	1.48		18.25	1.22	
	26	15	16.69	1.11		16.72	1.11	
Cf-252; 45°	16	2	2.26	1.13		2.11	1.06	
	23	2	2.13	1.07		1.96	0.98	
Cf-252 (D_2O); 0°	12	3	27.02	9.01		2.51	0.84	
	21	3	33.80	11.27		2.78	0.93	
	24	3	28.45	9.48		2.52	0.84	
	35	3	27.09	9.03		2.36	0.79	
Cf-252 + cone; 0°	30	2	7.89	3.95		1.19	0.60	
	13	2	7.88	3.94		1.25	0.63	
250 keV; 0°	28	1.02	3.35	3.28		3.35	3.28	
	32	1.02	2.63	2.58		2.63	2.58	
	34	1.02	3.00	2.94		3.00	2.94	
	36	1.02	3.11	3.05		3.11	3.05	

"out by factor >2"

Radiation quality	Number of values	Median of *R*	Mean of *R*
Cf-252; 0°	12	1.10	1.12
Cf-252; 45°	2	1.02	1.02
Cf-252 (D_2O); 0°	4	0.84	0.85
Cf-252 + cone; 0°	2	0.61	0.61
250 keV; 0°	4	3.00	2.96
All	24	1.06	1.33

Number of "out by factor >2":	4 of 24
Fraction of "out by factor >2":	17%



S27, dosemeter type: Etched track

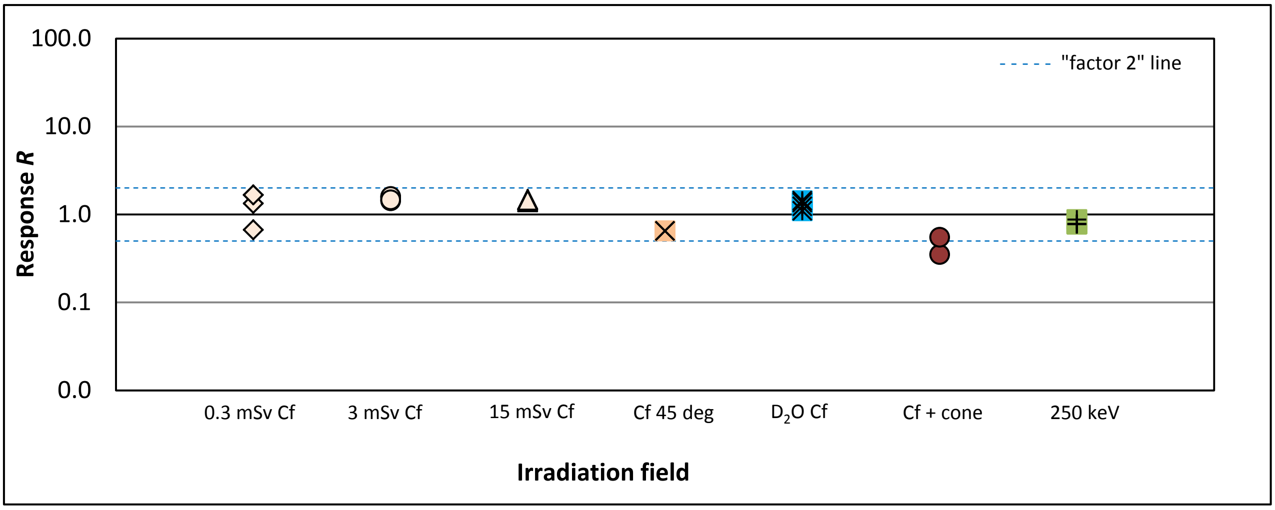
Reference values reported by the irradiating laboratory			Step I			Final step		
Radiation quality	Dosemeter code	$H_p(10)$ Reference value (mSv)	$H_p(10)$ Participant's value (mSv)	*R*	Remark	$H_p(10)$ Participant's value (mSv)	*R*	Remark
Cf-252; 0°	1	0.3	0.70	2.33		0.50	1.67	
	5	0.3	0.30	1.00		0.20	0.67	
	21	0.3	0.60	2.00		0.40	1.33	
	31	0.3	0.80	2.67		0.50	1.67	
	11	3	6.40	2.13		4.30	1.43	
	17	3	7.10	2.37		4.70	1.57	
	22	3	7.20	2.40		4.80	1.60	
	33	3	6.60	2.20		4.40	1.47	
	3	15	31.20	2.08		20.80	1.39	
	8	15	33.40	2.23		22.30	1.49	
	23	15	32.40	2.16		21.60	1.44	
	28	15	32.60	2.17		21.70	1.45	
Cf-252; 45°	25	2	2.00	1.00		1.30	0.65	
	30	2	1.90	0.95		1.30	0.65	
Cf-252 (D_2O); 0°	6	3	5.50	1.83		3.70	1.23	
	13	3	6.20	2.07		4.10	1.37	
	19	3	6.50	2.17		4.30	1.43	
	27	3	4.90	1.63		3.30	1.10	
Cf-252 + cone; 0°	7	2	1.10	0.55		0.70	0.35	
	24	2	1.60	0.80		1.10	0.55	
250 keV; 0°	16	1.03	0.00	0.00		0.90	0.87	non routine evaluation procedure
	18	1.03	0.00	0.00		0.80	0.78	
	20	1.03	0.00	0.00		0.80	0.78	
	35	1.03	0.00	0.00		0.80	0.78	

"out by factor >2"

Radiation quality	Number of values	Median of *R*	Mean of *R*
Cf-252; 0°	12	1.46	1.43
Cf-252; 45°	2	0.65	0.65
Cf-252 (D_2O); 0°	4	1.30	1.28
Cf-252 + cone; 0°	2	0.45	0.45
250 keV; 0°	4	0.78	0.80
All	24	1.35	1.15

Number of "out by factor >2": 1 of 24

Fraction of "out by factor >2": 4%



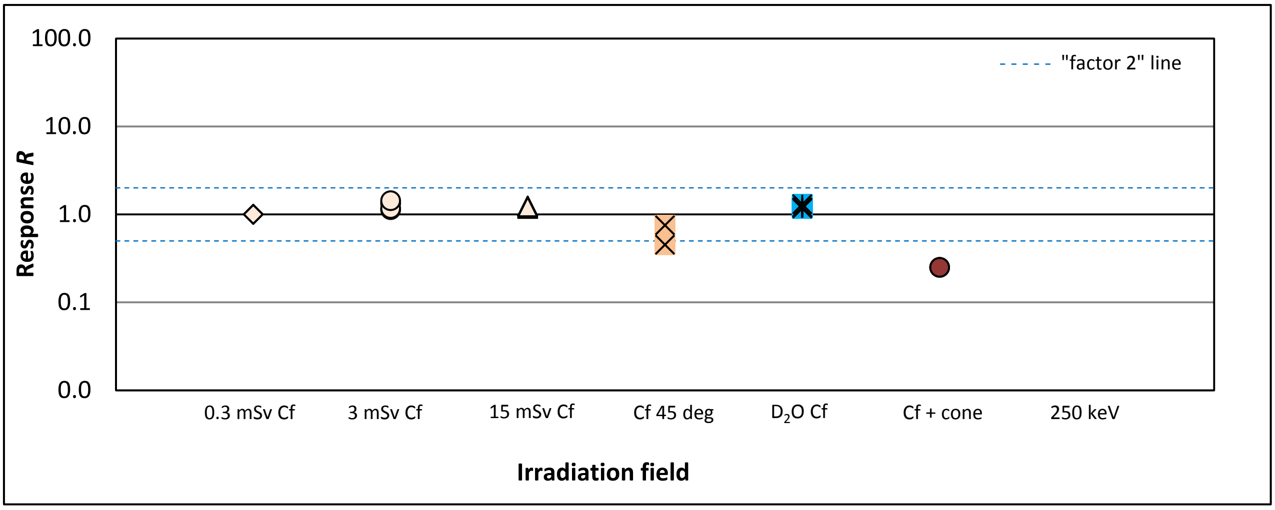
S28, dosemeter type: Etched track

Reference values reported by the irradiating laboratory			Step I			Final step		
Radiation quality	Dosemeter code	$H_p(10)$ Reference value (mSv)	$H_p(10)$ Participant's value (mSv)	*R*	Remark	$H_p(10)$ Participant's value (mSv)	*R*	Remark
Cf-252; 0°	8	0.3	0.50	1.67		0.30	1.00	
	11	0.3	0.40	1.33		0.30	1.00	
	22	0.3	0.50	1.67		0.30	1.00	
	34	0.3	0.40	1.33		0.30	1.00	
	12	3	5.10	1.70		3.40	1.13	
	15	3	6.00	2.00		4.00	1.33	
	25	3	5.20	1.73		3.50	1.17	
	31	3	6.50	2.17		4.30	1.43	
	2	15	27.80	1.85		18.50	1.23	
	16	15	26.30	1.75		17.50	1.17	
	20	15	27.90	1.86		18.60	1.24	
	28	15	27.30	1.82		18.20	1.21	
Cf-252; 45°	21	2	1.40	0.70		0.90	0.45	
	24	2	2.20	1.10		1.50	0.75	
Cf-252 (D_2O); 0°	4	3	5.30	1.77		3.50	1.17	
	26	3	5.40	1.80		3.60	1.20	
	29	3	5.40	1.80		3.60	1.20	
	33	3	5.80	1.93		3.90	1.30	
Cf-252 + cone; 0°	14	2	0.80	0.40		0.50	0.25	
	27	2	0.80	0.40		0.50	0.25	
250 keV; 0°	3	1.03	0.00	0.00		0.00	0.00	
	9	1.04	0.00	0.00		0.00	0.00	
	17	1.04	0.00	0.00		0.00	0.00	
	36	1.03	0.00	0.00		0.00	0.00	

"out by factor >2"

Radiation quality	Number of values	Median of *R*	Mean of *R*
Cf-252; 0°	12	1.17	1.16
Cf-252; 45°	2	0.60	0.60
Cf-252 (D_2O); 0°	4	1.20	1.22
Cf-252 + cone; 0°	2	0.25	0.25
250 keV; 0°	4	0.00	0.00
All	24	1.07	0.85

Number of "out by factor >2":	7 of 24
Fraction of "out by factor >2":	29%



S29, dosemeter type: Etched track

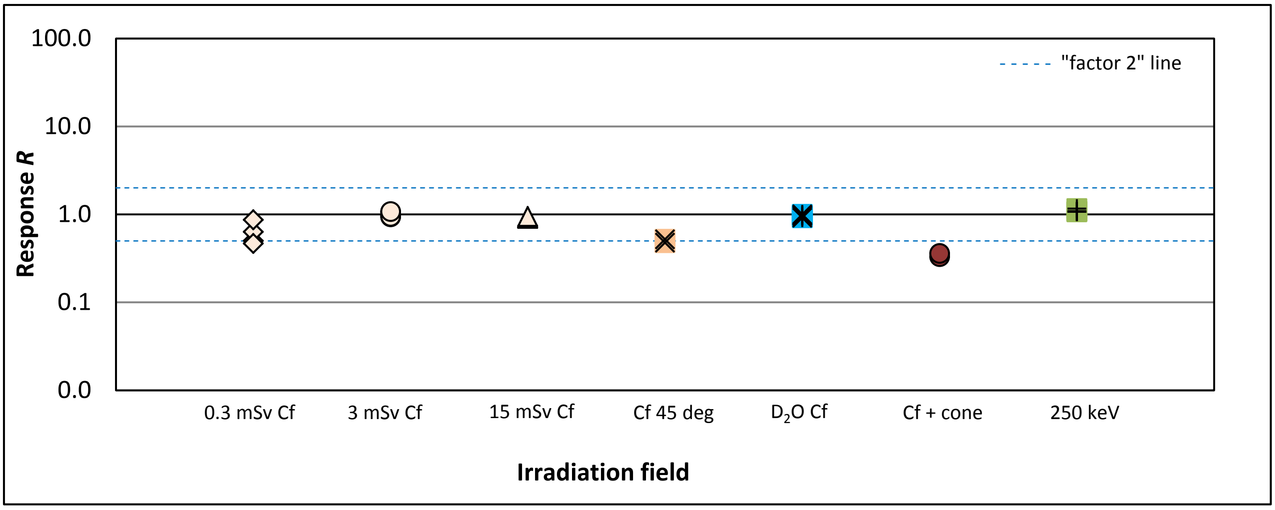
Reference values reported by the irradiating laboratory			Step I			Final step		
Radiation quality	Dosemeter code	$H_p(10)$ Reference value (mSv)	$H_p(10)$ Participant's value (mSv)	*R*	Remark	$H_p(10)$ Participant's value (mSv)	*R*	Remark
Cf-252; 0°	2	0.3	0.15	0.50		0.15	0.50	
	7	0.3	0.19	0.63		0.19	0.63	
	27	0.3	0.26	0.87		0.26	0.87	
	33	0.3	0.14	0.47		0.14	0.47	
	15	3	2.81	0.94		2.81	0.94	
	22	3	3.19	1.06		3.19	1.06	
	25	3	2.85	0.95		2.85	0.95	
	35	3	3.23	1.08		3.23	1.08	
	3	15	13.53	0.90		13.53	0.90	
	13	15	13.51	0.90		13.51	0.90	
	18	15	13.80	0.92		13.80	0.92	
	28	15	14.20	0.95		14.20	0.95	
Cf-252; 45°	34	2	1.04	0.52		1.04	0.52	
	36	2	0.95	0.48		0.95	0.48	
Cf-252 (D_2O); 0°	1	3	2.86	0.95		2.86	0.95	
	9	3	2.74	0.91		2.74	0.91	
	23	3	3.00	1.00		3.00	1.00	
	32	3	2.91	0.97		2.91	0.97	
Cf-252 + cone; 0°	8	2	0.66	0.33		0.66	0.33	
	16	2	0.72	0.36		0.72	0.36	
250 keV; 0°	12	1.04	0.18	0.17		1.12	1.08	
	17	1.04	0.09	0.09		1.11	1.07	
	20	1.05	0.19	0.18		1.22	1.16	
	26	1.05	0.09	0.09		1.14	1.09	

"out by factor >2"

Radiation quality	Number of values	Median of *R*	Mean of *R*
Cf-252; 0°	12	0.91	0.85
Cf-252; 45°	2	0.50	0.50
Cf-252 (D_2O); 0°	4	0.96	0.96
Cf-252 + cone; 0°	2	0.35	0.35
250 keV; 0°	4	1.08	1.10
All	24	0.93	0.84

Number of "out by factor >2": 4 of 24

Fraction of "out by factor >2": 17%



S30, dosemeter type: Etched track

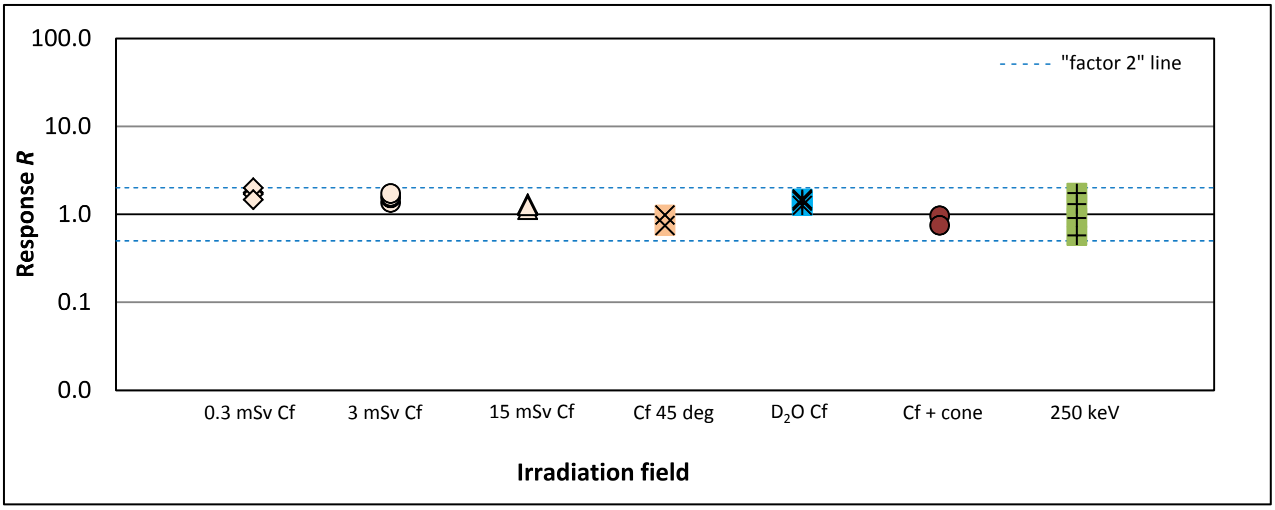
Reference values reported by the irradiating laboratory			Step I			Final step		
Radiation quality	Dosemeter code	$H_p(10)$ Reference value (mSv)	$H_p(10)$ Participant's value (mSv)	*R*	Remark	$H_p(10)$ Participant's value (mSv)	*R*	Remark
Cf-252; 0°	6	0.3	0.53	1.77		0.53	1.77	
	15	0.3	0.51	1.70		0.51	1.70	
	21	0.3	0.60	2.00		0.60	2.00	
	30	0.3	0.44	1.47		0.44	1.47	
	2	3	4.10	1.37		4.10	1.37	
	5	3	4.60	1.53		4.60	1.53	
	17	3	4.81	1.60		4.81	1.60	
	22	3	5.18	1.73		5.18	1.73	
	1	15	16.96	1.13		16.96	1.13	
	9	15	19.42	1.29		19.42	1.29	
	13	15	19.72	1.31		19.72	1.31	
	28	15	18.69	1.25		18.69	1.25	
Cf-252; 45°	23	2	1.96	0.98		1.96	0.98	
	35	2	1.49	0.75		1.49	0.75	
Cf-252 (D_2O); 0°	7	3	4.34	1.45		4.34	1.45	
	11	3	4.47	1.49		4.47	1.49	
	20	3	4.23	1.41		4.23	1.41	
	34	3	3.79	1.26		3.79	1.26	
Cf-252 + cone; 0°	25	2	1.93	0.97		1.93	0.97	
	33	2	1.50	0.75		1.50	0.75	
250 keV; 0°	16	1.01	0.58	0.57		0.58	0.57	
	27	1.01	0.92	0.91		0.92	0.91	
	29	1.01	1.76	1.74		1.76	1.74	
	36	1.01	1.31	1.30		1.31	1.30	

"out by factor >2"

Radiation quality	Number of values	Median of *R*	Mean of *R*
Cf-252; 0°	12	1.50	1.51
Cf-252; 45°	2	0.86	0.86
Cf-252 (D_2O); 0°	4	1.43	1.40
Cf-252 + cone; 0°	2	0.86	0.86
250 keV; 0°	4	1.10	1.13
All	24	1.34	1.32

Number of "out by factor >2": 0 of 24

Fraction of "out by factor >2": 0%



S31, dosemeter type: Albedo

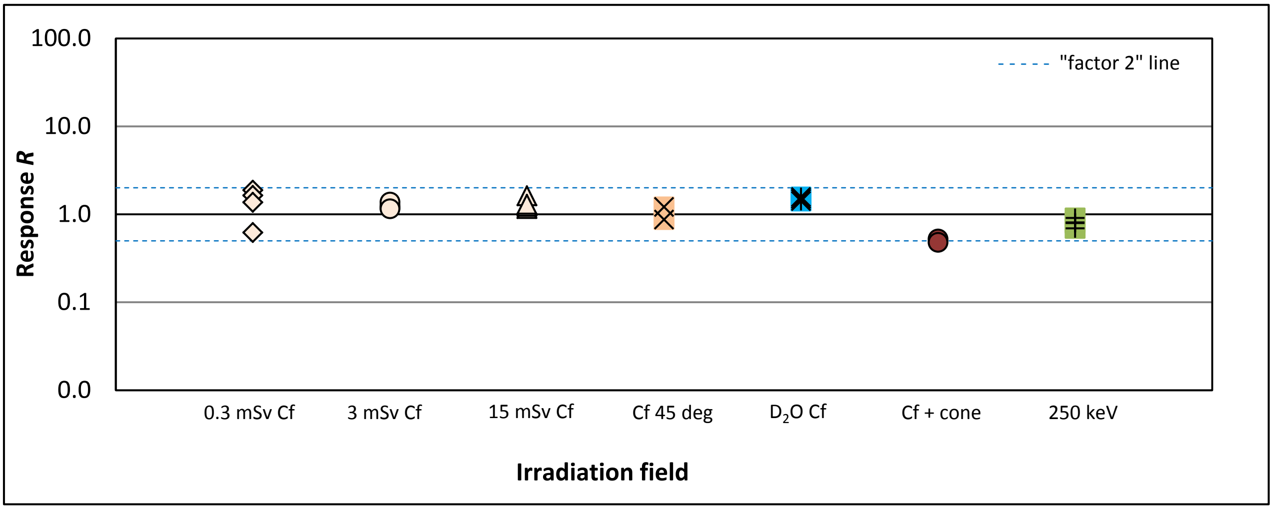
Reference values reported by the irradiating laboratory			Step I	Final step		
Radiation quality	Dosemeter code	$H_p(10)$ Reference value (mSv)	see next page	$H_p(10)$ Participant's value (mSv)	*R*	Remark
Cf-252; 0°	4	0.3		0.19	0.62	N3
	6	0.3		0.56	1.88	N3
	29	0.3		0.49	1.64	N3
	36	0.3		0.41	1.37	N3
	11	3		3.56	1.19	N3
	16	3		3.77	1.26	N3
	23	3		4.14	1.38	N3
	33	3		3.47	1.16	N3
	13	15		24.33	1.62	N3
	14	15		17.41	1.16	N3
	24	15		18.46	1.23	N3
	31	15		19.47	1.30	N3
Cf-252; 45°	21	2		2.42	1.21	N3
	30	2		1.74	0.87	N3
Cf-252 (D_2O); 0°	5	3		4.47	1.49	N1
	7	3		4.24	1.41	N1
	9	3		4.70	1.57	N1
	32	3		4.49	1.50	N1
Cf-252 + cone; 0°	26	2		1.05	0.52	N1
	27	2		0.96	0.48	N1
250 keV; 0°	12	1.03		0.71	0.69	N2
	17	1.03		0.94	0.91	N2
	19	1.03		0.83	0.81	N2
	20	1.03		0.82	0.79	N2

"out by factor >2"

Radiation quality	Number of values	Median of *R*	Mean of *R*
Cf-252; 0°	12	1.28	1.32
Cf-252; 45°	2	1.04	1.04
Cf-252 (D_2O); 0°	4	1.49	1.49
Cf-252 + cone; 0°	2	0.50	0.50
250 keV; 0°	4	0.80	0.80
All	24	1.22	1.17

Number of "out by factor >2": 1 of 24

Fraction of "out by factor >2": 4%



S31, dosemeter type: Albedo (continued)

Reference values reported by the irradiating laboratory			Step I Participant's value											
Radiation quality	Dosemeter code	Hp(10) Reference value (mSv)	$H_p(10)$ (mSv)	R	Remark	$H_p(10)$ (mSv)	R	Remark	$H_p(10)$ (mSv)	R	Remark	$H_p(10)$ (mSv)	R	Remark
Cf-252; 0°	4	0.3	0.03	0.11	N1	0.05	0.17	N2	0.19	0.62	N3	0.21	0.71	N4
	6	0.3	0.07	0.22	N1	0.09	0.31	N2	0.56	1.88	N3	0.75	2.50	N4
	29	0.3	0.06	0.20	N1	0.09	0.29	N2	0.49	1.64	N3	0.69	2.29	N4
	36	0.3	0.05	0.17	N1	0.08	0.25	N2	0.41	1.37	N3	0.61	2.03	N4
	11	3	0.46	0.15	N1	0.67	0.22	N2	3.56	1.19	N3	5.35	1.78	N4
	16	3	0.47	0.16	N1	0.69	0.23	N2	3.77	1.26	N3	5.50	1.83	N4
	23	3	0.51	0.17	N1	0.75	0.25	N2	4.14	1.38	N3	5.96	1.99	N4
	33	3	0.46	0.15	N1	0.66	0.22	N2	3.47	1.16	N3	5.31	1.77	N4
	13	15	2.78	0.19	N1	4.06	0.27	N2	24.33	1.62	N3	32.44	2.16	N4
	14	15	2.25	0.15	N1	3.28	0.22	N2	17.41	1.16	N3	26.22	1.75	N4
	24	15	2.28	0.15	N1	3.33	0.22	N2	18.46	1.23	N3	26.61	1.77	N4
	31	15	2.36	0.16	N1	3.44	0.23	N2	19.47	1.30	N3	27.54	1.84	N4
Cf-252; 45°	21	2	0.31	0.16	N1	0.46	0.23	N2	2.42	1.21	N3	3.66	1.83	N4
	30	2	0.25	0.12	N1	0.36	0.18	N2	1.74	0.87	N3	2.88	1.44	N4
Cf-252 (D_2O); 0°	5	3	4.47	1.49	N1	6.52	2.17	N2	28.23	9.41	N3	40.92	13.64	N4
	7	3	4.24	1.41	N1	6.17	2.06	N2	26.13	8.71	N3	36.58	12.19	N4
	9	3	4.70	1.57	N1	6.85	2.28	N2	30.54	10.18	N3	46.25	15.42	N4
	32	3	4.49	1.50	N1	6.55	2.18	N2	28.24	9.41	N3	40.68	13.56	N4
Cf-252 + cone; 0°	26	2	1.05	0.52	N1	2.61	1.30	N2	5.21	2.60	N3	5.21	2.60	N4
	27	2	0.96	0.48	N1	2.56	1.28	N2	4.77	2.39	N3	4.77	2.39	N4
250 keV; 0°	12	1.03	0.49	0.47	N1	0.71	0.69	N2	3.85	3.74	N3	5.69	5.52	N4
	17	1.03	0.64	0.62	N1	0.94	0.91	N2	5.46	5.30	N3	7.48	7.27	N4
	19	1.03	0.57	0.55	N1	0.83	0.81	N2	4.44	4.31	N3	6.65	6.46	N4
	20	1.03	0.56	0.55	N1	0.82	0.79	N2	4.52	4.38	N3	6.55	6.35	N4

S32, dosemeter type: Etched track

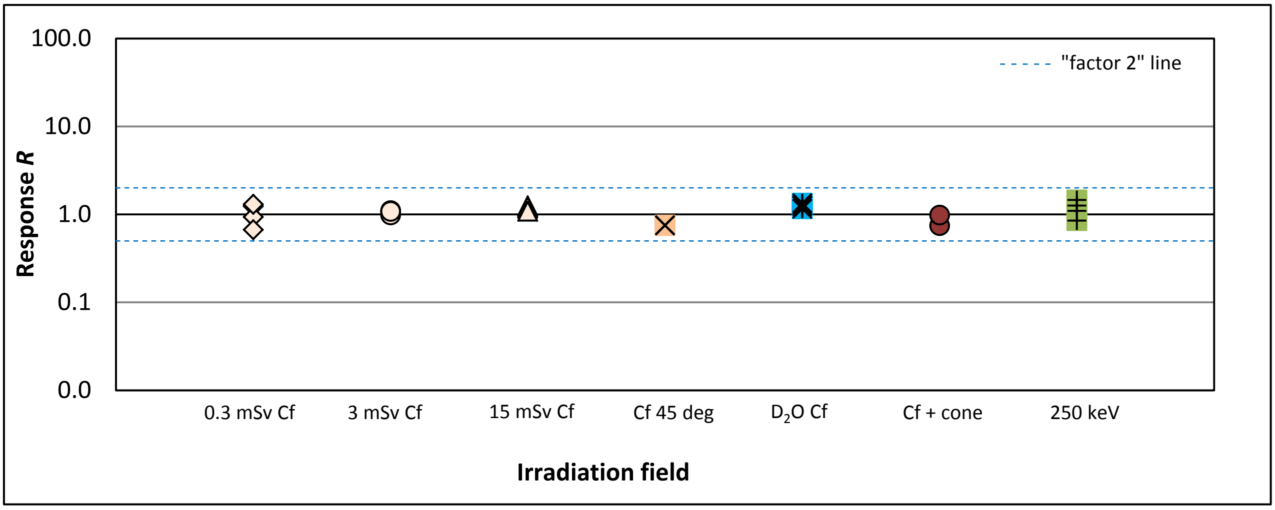
Reference values reported by the irradiating laboratory			Step I			Final step		
Radiation quality	Dosemeter code	$H_p(10)$ Reference value (mSv)	$H_p(10)$ Participant's value (mSv)	*R*	Remark	$H_p(10)$ Participant's value (mSv)	*R*	Remark
Cf-252; 0°	1	0.3	0.37	1.23		0.37	1.23	
	5	0.3	0.28	0.93		0.28	0.93	
	18	0.3	0.20	0.67		0.20	0.67	
	23	0.3	0.39	1.30		0.39	1.30	
	8	3	3.31	1.10		3.31	1.10	
	19	3	3.22	1.07		3.22	1.07	
	22	3	2.96	0.99		2.96	0.99	
	28	3	3.24	1.08		3.24	1.08	
	3	15	18.70	1.25		18.70	1.25	
	13	15	17.60	1.17		17.60	1.17	
	24	15	18.20	1.21		18.20	1.21	
	26	15	16.30	1.09		16.30	1.09	
Cf-252; 45°	12	2	1.51	0.76		1.51	0.76	
	29	2	1.49	0.75		1.49	0.75	
Cf-252 (D_2O); 0°	20	3	3.83	1.28		3.83	1.28	
	21	3	3.70	1.23		3.70	1.23	
	27	3	3.46	1.15		3.46	1.15	
	30	3	4.01	1.34		4.01	1.34	
Cf-252 + cone; 0°	17	2	1.49	0.75		1.49	0.75	
	32	2	1.96	0.98		1.96	0.98	
250 keV; 0°	2	1.05	1.96	1.87		1.53	1.46	
	11	1.05	1.18	1.12		0.89	0.85	
	15	1.05	1.50	1.43		1.15	1.10	
	31	1.05	1.70	1.62		1.32	1.26	

"out by factor >2"

Radiation quality	Number of values	Median of *R*	Mean of *R*
Cf-252; 0°	12	1.10	1.09
Cf-252; 45°	2	0.75	0.75
Cf-252 (D_2O); 0°	4	1.26	1.25
Cf-252 + cone; 0°	2	0.86	0.86
250 keV; 0°	4	1.18	1.16
All	24	1.10	1.08

Number of "out by factor >2": 0 of 24

Fraction of "out by factor >2": 0%



S33, dosemeter type: Other

Reference values reported by the irradiating laboratory			Step I			Final step		
Radiation quality	Dosemeter code	$H_p(10)$ Reference value (mSv)	$H_p(10)$ Participant's value (mSv)	*R*	Remark	$H_p(10)$ Participant's value (mSv)	*R*	Remark
Cf-252; 0°	3	0.3	0.41	1.37	^{252}Cf	0.41	1.37	^{252}Cf
	21	0.3	0.38	1.27	^{252}Cf	0.38	1.27	^{252}Cf
	27	0.3	0.44	1.47	^{252}Cf	0.44	1.47	^{252}Cf
	33	0.3	0.44	1.47	^{252}Cf	0.44	1.47	^{252}Cf
	6	3	2.48	0.83	^{252}Cf	2.48	0.83	^{252}Cf
	15	3	2.18	0.73	^{252}Cf	2.18	0.73	^{252}Cf
	18	3	2.63	0.88	^{252}Cf	2.63	0.88	^{252}Cf
	32	3	2.47	0.82	^{252}Cf	2.47	0.82	^{252}Cf
	1	15	15.24	1.02	^{252}Cf	15.24	1.02	^{252}Cf
	5	15	16.66	1.11	^{252}Cf	16.66	1.11	^{252}Cf
	19	15	15.83	1.06	^{252}Cf	15.83	1.06	^{252}Cf
	28	15	16.24	1.08	^{252}Cf	16.24	1.08	^{252}Cf
Cf-252; 45°	23	2	1.23	0.62	^{252}Cf	1.23	0.62	^{252}Cf
	25	2	1.23	0.62	^{252}Cf	1.23	0.62	^{252}Cf
Cf-252 (D_2O); 0°	14	3	4.19	1.40	^{252}Cf moderated by 15 cm D_2O	4.19	1.40	^{252}Cf moderated by 15 cm D_2O
	26	3	3.82	1.27		3.82	1.27	
	34	3	3.98	1.33		3.98	1.33	
	36	3	4.02	1.34		4.02	1.34	
Cf-252 + cone; 0°	4	2	8.89	4.45	monoenerg. neutrons with En>1.2 MeV?	2.66	1.33	*)
	17	2	5.19	2.60		2.62	1.31	En>1.2 MeV?
250 keV; 0°	9	1.04	2.52	2.42	monoenerg. neutrons with E_n>1.2 MeV?	0.96	0.92	monoenerg. neutrons with E_n>1.2 MeV?
	10	1.03	1.30	1.26		0.74	0.72	
	13	1.04	2.25	2.16		0.86	0.83	
	22	1.04	1.88	1.81		0.72	0.69	

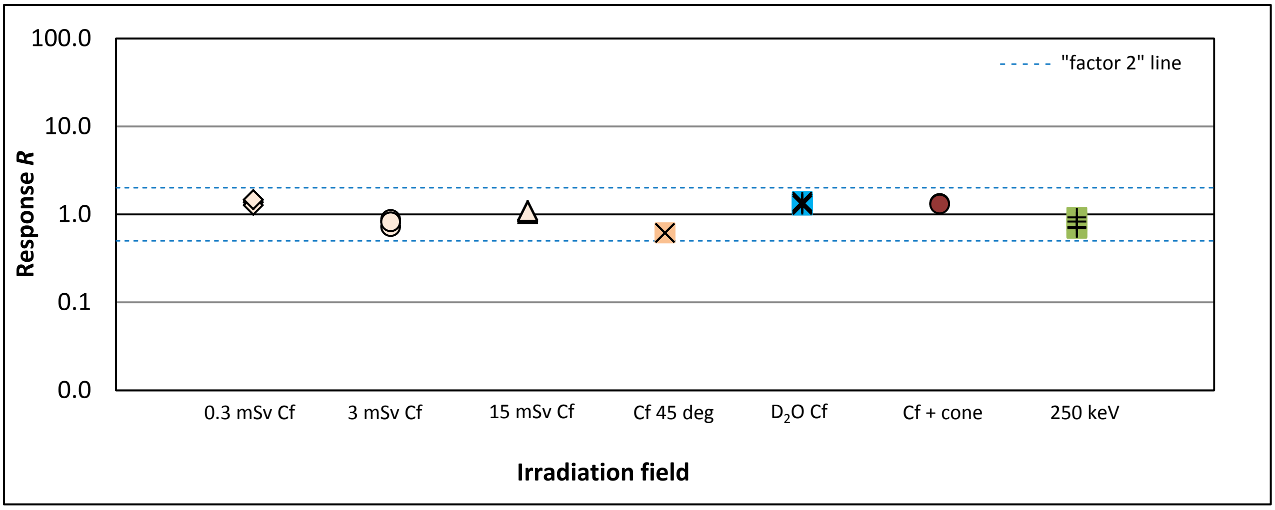
"out by factor >2"

*) n with En>1.2 MeV + strongly moderated n

Radiation quality	Number of values	Median of *R*	Mean of *R*
Cf-252; 0°	12	1.07	1.09
Cf-252; 45°	2	0.62	0.62
Cf-252 (D_2O); 0°	4	1.33	1.33
Cf-252 + cone; 0°	2	1.32	1.32
250 keV; 0°	4	0.77	0.79
All	24	1.07	1.06

Number of "out by factor >2": 0 of 24

Fraction of "out by factor >2": 0%



S34, dosemeter type: Etched track

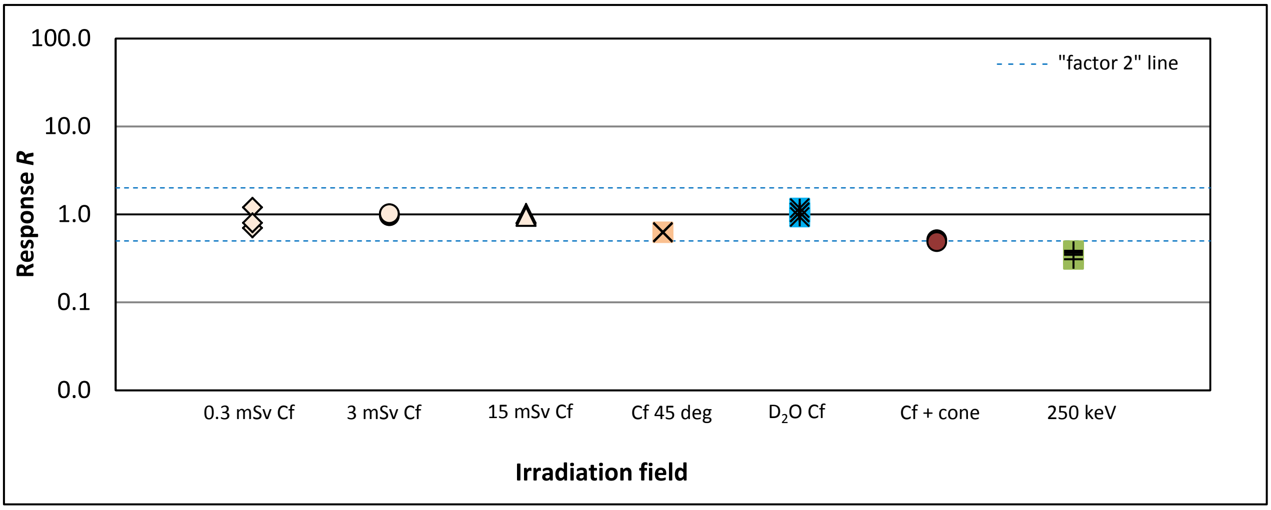
Reference values reported by the irradiating laboratory			Step I			Final step		
Radiation quality	Dosemeter code	$H_p(10)$ Reference value (mSv)	$H_p(10)$ Participant's value (mSv)	*R*	Remark	$H_p(10)$ Participant's value (mSv)	*R*	Remark
Cf-252; 0°	4	0.3	0.00	0.00		0.36	1.20	Recalc with corrected neut path using TLD
	14	0.3	0.00	0.00		0.21	0.70	
	18	0.3	0.00	0.00		0.36	1.20	Recalc with corrected neut path using CR39
	27	0.3	0.05	0.17		0.24	0.80	
	8	3	2.89	0.96		2.89	0.96	
	20	3	3.02	1.01		3.02	1.01	
	31	3	3.00	1.00		3.00	1.00	
	32	3	3.06	1.02		3.06	1.02	
	12	15	15.05	1.00		15.05	1.00	
	21	15	15.33	1.02		15.33	1.02	
	25	15	14.95	1.00		14.95	1.00	
	34	15	14.19	0.95		14.19	0.95	
Cf-252; 45°	6	2	1.24	0.62		1.24	0.62	
	33	2	1.26	0.63		1.26	0.63	
Cf-252 (D_2O); 0°	7	3	2.80	0.93		2.80	0.93	
	15	3	3.53	1.18		3.53	1.18	
	23	3	3.17	1.06		3.17	1.06	
	29	3	3.13	1.04		3.13	1.04	
Cf-252 + cone; 0°	5	2	1.03	0.52		1.03	0.52	
	35	2	0.98	0.49		0.98	0.49	
250 keV; 0°	17	1.04	0.32	0.31		0.32	0.31	
	19	1.04	0.40	0.38		0.40	0.38	
	24	1.04	0.36	0.35		0.36	0.35	
	26	1.04	0.38	0.37		0.38	0.37	

"out by factor >2"

Radiation quality	Number of values	Median of *R*	Mean of *R*
Cf-252; 0°	12	1.00	0.99
Cf-252; 45°	2	0.63	0.63
Cf-252 (D_2O); 0°	4	1.05	1.05
Cf-252 + cone; 0°	2	0.50	0.50
250 keV; 0°	4	0.36	0.35
All	24	0.95	0.82

Number of "out by factor >2": 5 of 24

Fraction of "out by factor >2": 21%



Appendix H: Comments at the Participants' meeting

At the Participants' meeting comments were received by the participants.

An overview is presented below of the comments and the answers from the organization group. The comments can be divided into three groups: on practical aspects, on the spectral influence, and on the future intercomparisons.

Practical aspects:

Q: Were any special arrangements made for the long irradiations for the radiation field behind the shadow cone? How was this done for the electronic dosemeters?

A: The irradiations behind the shadow cone took 3 days, in total about 6 weeks were used for all the irradiations. The staff at the irradiation facility monitored all the irradiations. The electronic dosemeters were treated in the same way as the passive ones; no special arrangements were made for them, also not in these long irradiations.

Spectral influence:

Q: Will the spectral information be available in tabulated form for further analyses?

A: Yes, it can be made available (see appendix F)

Q: Some services that use albedo dosemeters wanted more information on the spectral distribution so that they could have better estimated the N-correction factor to be used. Some have complained that they could have chosen a more appropriate N value for the shadow cone field

A: It was decided during the set-up of the exercise not to provide the description of the neutron field exactly according the N-factor (German DIN) description. It was not up to the organization group to judge on the correct N-factor to be used. Even though according to what their routine procedure the clients have to supply the N-factor to the services. So the best that could be done was to give a realistic description of the neutron field. In this way none of the albedo services would derive any advantage compared to other services. With the present procedure, all services had the opportunity to change their results in Step II, based on a general description. The whole procedure will be reviewed for the next intercomparison, but the intercomparison will not be made specifically for albedo dosemeters using the N-factors.

Q: It could be useful to give also information on the angular distribution of the field in Step II

A: That can be considered for next time, although the angular distribution is not always easy to determine.

Future intercomparisons:

Q: There was some disappointment that no power plant spectrum was included in the intercomparison

A: The main reason that the present fields were used was that they could come from accredited laboratories. It is indeed much more difficult to provide softer spectra or even workplace fields, it would make the exercise more complex and expensive. If workplace spectra were be used in the intercomparison it would give practical problems in organising the intercomparison, and also the determination of a reference $H_p(10)$ is much more difficult.

Q: Some participants wanted to participate only in certain fields that are applicable for their scope. Could the information be provided on the types of workplace field be provided at the outset of the intercomparison?

A: It could be done for future intercomparisons.

Q: In reality the doses of the workers are below 300 µSv, so this is different to the doses in the intercomparison

A: This can be considered in future intercomparisons.

Q: No high energies were considered in this intercomparison, which could be useful for accelerator facilities

A: This can be considered in future intercomparisons

Q: It was suggested not to mix moderated and bare sources because many services have problems with it

A: The radiation fields will still be chosen so that they are relevant for the workers, not if they are easy or not for the services.