Preparedness intercomparison of passive $H^*(10)$ area photon dosemeters in 2017/2018 (IC2017prep)

H. Dombrowski

Physikalisch-Technische Bundesanstalt (PTB),
Bundesallee 100, 38116 Braunschweig, Germany
E-mail: harald.dombrowski@ptb.de

Abstract: This intercomparison serves to investigate the long-term behaviour of passive $H^*(10)$ dosemeters which may be used in the aftermath of a radiological or nuclear event. In routine operation, such dosemeters are generally used to monitor installations like nuclear power plants and accelerators. Such dosemeters are used in the radiation field of the natural ambient radiation, including terrestrial and secondary cosmic radiation. From October 2017 to April 2018, photon dosemeters of 38 dosimetry systems were exposed to ionising radiation at three dosimetric reference sites which are operated by the Physikalisch-Technische Bundesanstalt (PTB). In addition to measurements which were carried out under natural conditions, a number of dosemeters was also irradiated artificially under two angles in PTB’s photon fields. 34 measuring bodies and institutions which are mainly involved in ambient radiation monitoring in Europe took part in this intercomparison in which the response of the dosemeters to terrestrial and also to secondary cosmic radiation was determined. As a result of this intercomparison, some sources of uncertainty and some errors were found. The intercomparison revealed the typical precision that has to be expected when long-term dose measurements are carried out in the natural environment. The successful participation in this intercomparison was documented by certificates that were issued to the participants. The short designation of this intercomparison is “IC2017prep”.

Keywords: Dosimetry concepts and apparatus; Solid state detectors; Detector design and construction technologies and materials
1 Introduction

For the long-term monitoring of ionising radiation (typically in the surroundings of nuclear facilities and accelerators), passive solid-state dosemeters such as thermo-luminescence dosemeters or optically stimulated luminescence dosemeters are commonly used as gamma or neutron detectors for radiation-protection purposes. Such simple and cheap dosemeters could also be used to monitor contaminated areas. When passive dosemeters are exposed to ionising radiation for many months at one specific location, the following problem arises: the dose contribution of the natural radiation must be subtracted from the total measured dose value in order to obtain the fraction of the dose that was caused by artificial radiation. However, natural radiation is subject to strong spatial and temporal variations [1]. Furthermore, in the course of long-term measurements, the dosemeter itself can have an influence on the measured value (which could lead, for example, to an increase in the indicated value due to the inherent activity of the detector material, or to a decrease due to losses of the dose information by de-excitation of metastable energy levels). This intercomparison will give an overview of the status of European passive photon dosimetry by testing the measured results of dosemeters which had all been deployed under identical conditions. At the end of this
paper, some conclusions will be drawn which are relevant to radiation monitoring by means of passive area detectors.

The whole intercomparison described in this article (short: IC2017prep) took place under the umbrella of the Preparedness project [2]. The general objective of this project is the establishment of a metrological basis to support adequate protective measures in the aftermath of nuclear and radiological emergencies on a European scale. To achieve this a central objective of this project is to develop unmanned aerial detection systems installed on aerial vehicles and helicopters for the remote measurement of dose rates and radioactivity concentrations. Because long-term measurements may be required in the aftermath of a radiological or nuclear event, as well, a work package of the project is dedicated to the aim to establish stable and reproducible procedures to measure ambient dose equivalent rates using passive dosimetry in order to harmonise passive dosimetry for environmental radiation monitoring across Europe [3].

The basic physical background of all types of passive solid state dosemeters is identical. Some materials, which are chemically salts or oxides in most cases, have several metastable electron energy levels, which can be excited by ionising radiation. As long as a saturation of excited states is not observed, the response to dose is linear over many decades. This is true for common materials used in dosimetry like LiF or AlO$_3$. Non-linear effects are only observed after extreme irradiation, which normally does not occur in technical or medical applications. After the exposure to ionising radiation, the excited states can be de-excited by supplying energy in defined way, so that the characteristic radiation is released. The released energy is well-defined by the energy of the excited states. In a technical application, this is the read-out process. The basic dosemeter types are characterised by the technical read-out procedure, which is realised by heating up the detection materials (TLD = thermoluminescence dosemeters), by optically stimulating them (OSL = optically stimulated luminescence) or by de-exciting them by using electromagnetic radiation in the range of radio frequencies (RPL = radio photoluminescence). Up to now, the general technical properties of solid state dosemeters cannot be understood by the analyses of the basic physical processes. A detailed overview over the history and the current state of the art concerning this topic is found in [4]. This fact is even more underlined by the observation that the details of the read-out process, e.g. the shape of glow curve in the case of TLD dosimetry, have a profound influence on the final measured dose results. The technical procedure governs the results, not only the construction of the dosemeters! Therefore, measured results of passive dosemeters are only investigated phenomenologically in this paper.

2 Methods

The following European measuring bodies and companies (in the following listed by name and country) participated in the IC2017prep intercomparison: Belgoprocess, Belgium; Berkeley ADS Cavendish Nuclear Limited, Great Britain; Centro centro dosimetría, s.l., Spain; CIEMAT, Spain; CLOR, Poland; Dosilab, Switzerland; ENEA-Radiation Protection Institute Italy; Helmholtz Center Munich, Germany; Jožef Stefan Institute, Slovenia; IRSN / LDI, France; Karlsruher Institut für Technologie, Germany; Laboratories Protecta, Bulgaria; Laboratorio de Dosimetría/Instituto de Salud “Carlos III”, Spain; Landauer, France; LPS Berlin, Germany; Materialprüfungsamt Nordrhein-Westfalen, Germany; Mirion Technologies, Inc., U.S.A.; MTA EK, Hungary; NLWKN,
Germany; Personal Dosimetry Service Public Health England, Great Britain; Paul Scherrer Institute, Switzerland; RBI, Croatia; SCK-CEN Dosimetry laboratory Belgium; S. Maria della Misericordia Hospital, Italy; Seibersdorf Labor GmbH, Austria; Servizio di dosimetria — Polimi, Italy; Servizio di Monitoraggio Dosimetrico dei Lavoratori, Italy; National Radiation Protection Institute, Czech Republic; IST — CTN, Portugal; Tecnorad s.u.r.l., Italy; TL Dosimetry Laboratory, Institute of Energy Technologies-Universitat Politècnica de Catalunya, Spain; Vinca Institute of Nuclear Sciences, Serbia; VKTA, Germany; X-Gammaguard, Italy. The intercomparison was performed at reference measuring sites of PTB, the national metrology institute of Germany providing scientific and technical services.

At each of PTB’s three measuring sites for environmental monitoring, four dosemeters of each dosimetry system were deployed for six months. The measuring sites used were: a) the free-field reference dosimetry site for environmental radiation, b) the dosimetry site for cosmic radiation,¹ and c) the low-level underground laboratory for dosimetry (UDO II). In addition, eight of the dosemeters of each system were irradiated artificially, i.e. in d) PTB’s primary photon fields (four dosemeters under an incident angle of 0°, and four dosemeters under an incident angle of 90°).

All measured data as well as the reference values were provided in terms of ambient dose equivalent, \( H^* (10) \). This is the appropriate quantity for area dosimetry according to EU Directive 2013/59/EURATOM [5]. This quantity was introduced in 1985 by ICRU in the framework of the introduction of new concept of radiation protection quantities [6]. The idea behind \( H^* (10) \) is that measured values shall be an estimate of the effective dose to the human body. Therefore, \( H^* (10) \) was defined in a way that measured data are proportional to the biological (harmful) effects in a human body. To achieve this goal, the rated energy deposition in a depth of 10 mm in standard tissue quantified. The rating includes weighing factors, which describe the biological effectiveness of different types of ionising radiation.

Independent of the measurements carried out by the participants, PTB determined reference dose values. These reference values were calculated for each single dosemeter (the period of time they were deployed differed slightly between the dosemeters if they arrived late because their shipping took too much time). This was done by taking dose rate values of active detectors as a basis which had been collected over a time period of 10 minutes. These detectors are routinely operated around the clock at the free-field measuring site. The response of the dosemeters, i.e. the measured dose divided by the reference dose, both for the cosmic and for the terrestrial component of the natural radiation, is determined by combining the results obtained at the measuring sites for environmental and for (secondary) cosmic radiation [7]. The dose to which the dosemeters were exposed during their transport was measured directly by storing four dosemeters so-called transport dosemeters inside the underground laboratory UDO II. In the following, the reference measuring sites will be described in more detail.

2.1 Environmental radiation dosimetry (on a free field)

A reference site for the dosimetry of environmental radiation was established by PTB. At this site, dosemeters are characterised with respect to environmental ionising radiation (figure 1) which comprises both terrestrial radiation and secondary cosmic radiation (SCR, also). This measuring

¹At the height of 85 m above sea level, more precisely, secondary cosmic radiation is observed.
Figure 1. PTB’s reference measuring site for environmental radiation (free-field measuring site). The passive dosemeters are hung on exchangeable aluminium rods.

The site is located on PTB’s premises in Braunschweig at an altitude of 85 m above sea level. The measuring site consists of a flat lawn (approx. 35 m × 55 m) and is equipped with two air-conditioned wooden cabins, in which detectors and electronics, which are not weather-proof, are operated safely. Several detectors of different types are installed at this measuring site. They permanently record the different components of the dose rate of the natural environmental radiation (which are caused by photons, electrons, muons and neutrons): Photon detectors quantify the total of the terrestrial gamma radiation including the charged component of the SCR. The latter radiation consists of muons (which make up approx. 2/3 of the dose rate) and high-energy electrons (approx. 1/3 of the dose rate). These are detected by the particle detectors DECOS and MUDOS, which are not sensitive to gamma radiation (see section 3.1).

The calibration of all the reference detectors that exist for terrestrial radiation and for SCR is traceable to the primary standards of PTB. Long-term measurements allow the investigation of the influence of changing weather and solar conditions on the exposed detectors, as the natural dose rate is subject to precipitation, atmospheric temperature and air pressure. This installation was used to characterise the passive area dosemeters of the participants in the natural environment.

2.2 Secondary cosmic radiation dosimetry (on a floating platform)

PTB has installed a floating platform (figure 2) on a lake close to Braunschweig. This platform consists of air-filled rubber pontoons. Three containers are mounted on this platform. They are made of plastic and the detectors accommodated in them are thus weather-proof. To keep the level of gamma radiation low, the rubber and the plastic of the containers have a very low content of
radionuclides. Furthermore, the terrestrial component of the gamma radiation of the surroundings is strongly reduced because a) the platform is floating on water, which is 2.5 m to 3.5 m deep, b) it is more than 100 m away from the shore and c) the area around the lake is flat. Therefore, the dosemeters on the platform are almost exclusively exposed to secondary cosmic radiation. This measuring site on the lake was erected in particular to characterise the response of dosemeters with regard to the $H^*(10)$ rate of the secondary cosmic radiation at ground level. In contrast to this, the reference values are measured inside a cabin on the free-field site (as described in the last section) by using particle detectors that are insensitive to photons.

2.3 Low-level underground laboratory

PTB’s underground laboratory for dosimetry (UDO II) is located in the esco salt mine “Bergwerk Braunschweig-Lüneburg” near Helmstedt, at a depth of 430 m below ground level. Because of the shielding effect of the rock overburden, the muon component is suppressed in this depth — compared to the muon flux at the ground surface — by about four orders of magnitude. All materials inside the UDO II laboratory were selected under the aspect of ensuring a low activity concentration of radionuclides. Thus, the floor, for example, is made of stainless steel. The very low activity of the rock salt walls, combined with a very low radon level ($< 10$ Bq/m$^3$), leads to an $H^*(10)$ rate of only $(1.4 \pm 0.2)$ nSv/h inside the laboratory room. This is, therefore, the laboratory with the lowest documented radiation level worldwide. If dosemeters are stored in a lead castle inside UDO II, it is possible to reduce the dose rate even further, to about 0.1 nSv/h. Consequently, the passive transport dosemeters of the participants were stored in a lead castle in UDO II, while the
other dosemeters were exposed to ionising radiation above ground at the different measuring and irradiation sites.

### 2.4 Handling of the dosemeters

The participants were asked to preferably ship their dosemeters to PTB simultaneously. Dosemeters which, nevertheless, arrived early were stored inside UDO II so that they were not irradiated until the official beginning of the planned exposition period. The history of every dosemeter (regeneration date, departure, arrival date, etc.) was recorded on a route card. As all goods that are sent by air freight are X-rayed at the airport, air transportation of the dosemeters was avoided to keep the transport dose low. Some German participants arranged a direct express transport of the dosemeters to PTB and back to keep the transport doses as low as possible. The total dose accumulated by the dosemeters that were stored in UDO II is — in very good approximation — identical with the transport dose. The transport dose had to be minimized because a high transport dose would affect the results negatively by causing higher uncertainties, because the transport dose had to be subtracted from all other measured data.

On the free-field site, the dosemeters were exposed to environmental radiation at a height of 1 m above ground level. They were fixed on aluminium rods which were positioned around PTB’s active photon reference detectors. To make sure that the dosemeters were all exposed to radiation equally, the rods, including the dosemeters, were rotated weekly. On the floating platform, the dosemeters were stored inside the containers in a hanging position. As far as SCR is concerned

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**Figure 3.** PTB’s underground laboratory UDO II, located in the *esco* salt mine “Bergwerk Braunschweig-Lüneburg”.

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(which consists of minimum ionising particles), the positioning height does not matter. The dose rate caused by SCR will be identical to that on the free-field. At UDO II, the dosemeters were stored in a lead castle. The dose which resulted after six months of storage is so low (roughly 0.5 µSv) that it is not measurable with passive dosemeters. The total number of dosemeters used in this intercomparison was 760 (20 dosemeters of each of the 38 dosimetry systems).

3 Reference values

3.1 Free-field

All reference dose values were measured and calculated independently of the data of the participants by evaluating the data of the active instruments that were operated simultaneously on PTB’s free-field. The dose rate caused by SCR cannot be measured directly because the charged component of this radiation, which consists of high-energy muons and electrons, was detected by using the instruments DECOS and MUDOS, whose count rate is proportional to the dose rate of the charged component of the SCR. The influence of the cosmic neutron radiation was considered as negligible in this intercomparison.

MUDOS (the abbreviation of “MUon DOSemeter”) contains two multi-wire proportional chambers which are separated by a lead layer of 25 mm thickness [8], while the newer — and more sensitive — DECOS (the abbreviation of “DEtector for COSmic radiation”) incorporates two plastic scintillator plates, each one 80 cm ×80 cm ×4 cm in size, which are read out by photomultipliers. Both detectors of each system are identical and they are operated in coincidence. In contrast to MUDOS, DECOS is equipped with a pulse-height discrimination, which is based on the fact that the cosmic muons and the high-energy electrons cause such intensive light pulses in the scintillators that they can be discriminated from photon events. Thus, a double discrimination of photons is realised. Furthermore, DECOS — mainly due to its larger active area — has a much higher count rate than MUDOS (more than 30 times higher), which allows measurements that are more precise.

The calibration procedure for MUDOS is described by Wissmann [8]. DECOS is calibrated analogously. The calculation of the reference values is based on the assumption that the incoming SCR on the free-field and the incoming SCR on the floating platform (which is located about 14 km away from the free-field) are identical and that the shape of the spectrum of muons is temporally constant in good approximation, whereas the total particle rates change with time.

The environmental photon radiation was measured using high-pressure ionisation chambers (HPICs) of the type Reuter-Stokes RSS131ER. These detectors do not quantify the total dose rate of the secondary cosmic and of the terrestrial radiation correctly, because the response to SCR is much higher than that to photon radiation. Any calibration in a photon field is only valid as far as photon radiation is concerned. Therefore, first of all, the independently measured cosmic component is subtracted from the instrument reading of the photon detectors by taking into account the response to SCR, combined with the reference measurements of the SCR. From this, the terrestrial component of the environmental radiation is obtained. The traceability to the primary standards of PTB is realised by calibrating the HPICs in the low-dose calibration facility at UDO II. In the energy region of most interest (300 keV < E < 2.8 MeV), the energy response of the HPICs is almost flat with respect to \( H^*(10) \), with deviations of ±3% at maximum.
Finally, the terrestrial dose rate and the cosmic dose rate are integrated to dose values according to the measuring period and are added up, which then yields the total ambient dose equivalent. At the free-field site, three HPICs were in permanent operation: Two in midst of the passive test specimen and one inside a cabin. The results of all three HPICs are in agreement within 2%, which proves that these instruments work correctly as the uncertainty limits are actually higher (about 3%, \( k = 2 \)).

3.2 Underground laboratory

The dose accumulated inside the lead castle at UDO II over six months is in the order of 0.5 µSv. This is so low — compared to the total transport dose, which is in the order of some 10 µSv, at minimum — that it can be neglected. The mean dose value of the transport dosemeters’ values is subtracted from all other dose values that have been measured in this intercomparison.

3.3 Irradiation in a \(^{137}\text{Cs}\) photon field

8 photon dosemeters of each system were irradiated at two angles with the — comparably high — dose of 30 mSv, which corresponds to a dose that is 100 times higher than a typical half-year dose. The storage dose of the dosemeters, which were irradiated once in a \(^{137}\text{Cs}\) photon field, was determined to be 2.4 µSv (this value is based on measurements which were recorded with active dosemeters). This means that the natural dose of these dosemeters, which was accumulated while the dosemeters were stored in a PTB building, is less than 2% of the artificial irradiation dose. Thus, the gamma irradiations, carried out free in air at PTB’s Hartlep facility using a collimated \(^{137}\text{Cs}\) beam, dominate the total dose of the dosemeters by far, which reduces the measurement uncertainties. To gain basic information about the dependence of the dosemeter response on the angle of irradiation, 4 dosemeters were irradiated in the reference direction and 4 were irradiated at an angle of 90° from the reference direction (rotation in a horizontal plane).

4 General remarks

The periods of time during which the dosemeters of the participants were deployed at the measuring sites were not completely identical, as some dosemeters arrived very early and some arrived very late with regard to the scheduled starting date. For this reason, reference values were calculated for every set of dosemeters (a set of dosemeters consists of dosemeters with the same history).

Some measuring bodies routinely correct for the transport doses, whereas other bodies neglect them. When the transport dose was not calculated correctly (either because it could not be measured correctly or because the period of time was not determined correctly), corrections were made by the organiser. If necessary, a mean transport dose of 2 µSv per day was assumed. Due to this standardised procedure, some deviations in the results were excluded, which had merely been caused because different procedures were applied for the correction of the transport dose.

4.1 Data evaluation

The data of the passive dosemeters of the participants were evaluated by the participants themselves. Thereby, they applied their own standard routine procedures. As a consequence, some of the
participants made fading corrections. Such corrections are only used for some TLD-based systems. They may depend on the exposure conditions according to the procedures of the participant. The results of the dose measurements are also influenced by other factors such as the readout methods and the methods of data evaluation. The calculated uncertainties shown in the diagrams below only include statistical uncertainties, which were obtained by calculating the standard deviation of all detectors of one set by means of Student’s $t$-distribution with a coverage factor of 95%.

5 Results and discussion

In figure 5 and figure 6, the detector responses — i.e. the measured dose values, divided by the corresponding PTB reference values — are shown, grouped according to measuring sites and irradiation types. The expression “cosmic radiation” denotes radiation measured at the floating platform, i.e. SCR. The measured dose values are the mean values of a set of four detectors of one dosimetry system (exposed under identical conditions). Most of the passive dosimetry systems showed results that are in agreement with the reference values within a range of 0.77 to 1.43 (the inverse of a correction factor of $\pm 30\%$). In many cases, even better agreement was found. However, some systems clearly failed. If two measured values of a participant were outside these limits, no certificate was issued. In addition, statistical variances higher than 30% were not accepted. The accepted range of the values of the response is derived analogously from standard IEC EN
60846 [9], according to which the combined deviation of the inverse angular and energy response has to differ by less than ±40% from a defined reference value.

If measured dose data deviate from the reference values, the reason for this might simply be an inexact calibration, whereas the dosimetry system and its handling may be reproducible and reliable. To rule out this effect of an inexact calibration, all results were corrected for with a factor that includes the ratio of the reference value to the measured value of the irradiation in 0°, which should simply indicate the deviation of the home calibration of the participant to a calibration in PTB’s reference field (the home calibration is often done secondary or tertiary with regard to primary standards). The results are plotted in figures 7 and 8 (analogous to those in figure 5 and figure 6). Figures 7 and 8, however, reveal the fact that some corrected data deviate more from the reference data than the original data. Figure 8 directly shows the deviation between the irradiations in a 137Cs photon field under an incident angle of 0° and under an incident angle of 90°.

Most of the data of the photon detectors deviate by less than 20% from the reference value, although tolerances that are permitted by standard IEC 62387-1 (and are due to different influence factors) could lead to much larger deviations [10]. On the other hand, if detectors are exposed to secondary cosmic radiation on the floating platform, an over-response of almost all systems is observed. Relative to the irradiation at 0° data, this over-response reaches up to 54% (not taking into account data sets of flawed measurements).

This observation is in agreement with former tests carried out using active instruments [7] and can be explained by the different properties of the components of the natural radiation, as the terrestrial radiation consists of photons, whereas the detected SCR almost completely comprises minimum-ionising charged particles (high-energy muons and electrons). The latter produce a track of an almost constant energy loss inside the dosemeter, whereas due to absorption, scattering, etc. in the detector casing, only a part of the photons is detected. Thus, the response to photons is lower. However, photon dosemeters are only calibrated in photon fields, although they are also sensitive to SCR. Often, the response to SCR is undetermined. It must, however, be taken into account when the gamma-ray component of the environmental radiation has to be derived from dose rate data in order to detect artificial radiation. Therefore, it was part of this intercomparison to determine the dosemeter response to SCR.

When the response to SCR is known, the response to the terrestrial component can be extracted from the free-field measurements (terrestrial radiation plus SCR) and from the floating-platform measurements (almost pure SCR). The diagrams above show that the uncertainties of the terrestrial response data are rather high, as the values are based on the difference between two values of similar magnitude.

The photon dosemeters, which were exposed to 137Cs gamma radiation, reproduced the reference values very well when they were irradiated at an angle of incidence of 0°. Most of the data points do not deviate from the reference values by more than 20%. The 137Cs irradiation results mainly reveal information about the home calibration of the participants and about the dependence of the detector systems on the angle of incident radiation. They indirectly show how correct fading corrections were done if the participant had applied this type of correction. A tendency of some systems to underestimate the reference values is visible. Flat detector holders, which are actually constructed for personal monitoring, often strongly depend on the angle of incident radiation when they are exposed in the environment. This may lead to a high uncertainty when measurements are
performed in surroundings where the radiation field is inhomogeneous. Deviations up to a factor of 1.7 — depending on the angle of irradiation (0° or 90°) — were found (three systems showed such a high value).

The measured values of the dosemeters stored at UDO II are depicted differently to the results in the other diagrams. The absolute dose rates plotted in figure 8 give information about the transport dose. In some cases, the transport dose was considerable because the shipping from abroad lasted many days and some packed dosemeters may have even been exposed to X-raying when they were shipped via air freight.

6 Valuation

The Preparedness Intercomparison, which was dedicated to environmental radiological monitoring by means of passive area dosimetry, yielded in many cases good results of absolute dose measurements, whereas some measuring bodies clearly failed to reproduce the reference values. All participating institutions were informed about the overall results. If measured data showed significant deviations from the reference values, the institutions concerned were notified, in order to allow them to investigate the reasons for their poor results. This intercomparison contributes significantly to the quality assurance of dosimetry services that deal with passive dosimetry and will help these services to improve their performance and — ultimately — to reduce their measurement uncertainties.

For the most part, the home calibration of the photon dosimetry systems furnished response factors in the range between 80% and 120% of the reference value (with several outliers) when the dosemeters were irradiated in the preferred direction. A more precise calibration may remove this source of deviation. However, many dosemeters do not have an isotropic response because flat dosemeter badges — as are known from personal dosimetry — were also used in area dosimetry. Typically, the response of such flat dosemeters is about 10% lower when they are irradiated under an angle of 90°, but even a difference of 40% in the response at 0° and 90° was found. If such dosemeters are mounted in the natural environment without a defined orientation, the accuracy of the results will be inadequate.

This intercomparison can reveal general trends in the results of the investigated dosimetry systems because the reference values were derived independently of the participants’ results by measurements using active detectors. One general trend is that most of the systems investigated showed an over-response to secondary cosmic radiation, which can reach more than 40%. If measurements carried out in the natural environment are evaluated, this effect has to be taken into account. The most important aspect in monitoring radiation in the environment is the correct quantification of gamma radiation. Therefore, the dosemeters should be calibrated in photon fields, preferably in the gamma radiation of a sealed $^{226}$Ra source because it greatly resembles the wide spectrum of natural terrestrial radiation. As a consequence of a correct calibration with regard to gamma radiation, an overestimation of the total dose is very likely (depending on the design of the dosemeter). This fact is inevitable because the response to secondary cosmic radiation is different as the latter radiation consists almost only of muons and high-energy electrons. Especially dosemeters with an isotropic response often have an inherent over-response to secondary cosmic radiation due to their thick plastic casings.
Figure 5. Response of the investigated dosimetry systems to different sources of radiation (measured data including statistical uncertainties). The systems are anonymised and denoted by letters.
Figure 6. Upper two figures: Response of the investigated dosimetry systems to $^{137}$Cs radiation (measured data including statistical uncertainties). The systems are anonymised and denoted by letters. Lower figure: Absolute transport dose.
Figure 7. Response of the investigated dosimetry systems to different sources of radiation (data, however, normalised to correct for the influence of the home calibration).
Some results were so poor and/or the delivered data had such a high statistical uncertainty that certificates could not be issued and the corresponding data sets were not taken into account in the discussions above. This proves that a few European measuring services cannot ensure adequate radiation protection in environmental radiation monitoring as they would not detect increased artificial radiation levels reliably enough — even if the level was so high that human beings would receive radiation doses that lie above the limit values stipulated by the EU.

7 Summary

Monitoring radiation in the natural environment by means of passive area dosemeters is common all over Europe. Dosemeters of 38 different dosimetric systems of European measuring services and bodies were exposed to ionizing radiation and tested under different conditions. The ability of the systems to detect whether prevailing doses comply with European limits is of basic interest. After removing flawed data sets from the investigation, some deviations of measured values from reference values were still found. The reason for this may be, on the one hand, that several tolerances,
which are all permitted in IEC EC 62387-1, were combined. On the other hand, this may be due to deviations of the absolute calibration from reference values. In addition, the anisotropic angular response of many flat dosemeters (which were actually constructed for personal monitoring) leads to further uncertainties or even to distorted results. Differences between the results of dosimetric measurements which took place at the same location under the same conditions may differ absolutely by a factor of 2, which is not acceptable because it may be unclear whether the measured data comply with the legal limiting values. In environmental radiation monitoring, it would be highly desirable if the measured data of different dosimetry services agreed better with each other. The measuring procedures should be harmonised at the European level and best practices should be recommended. To date, no international standards (e.g. ISO standards) exist which harmonise the procedures in the field of passive area dosimetry.

The results of this IC2017prep intercomparison are, on the one hand, important for the quality assurance systems of the participants. On the other hand, the measured data can be used to get an idea as to whether the properties of the tested photon dosimetry systems are in agreement with the requirements of the national legislation of a country, e.g. with the German “Directive for the Surveillance of Emission and Immission from Nuclear Installations” (REI) [11].

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