EURADOS intercomparison of passive *H**(10) area dosemeters 2014

Harald Dombrowski[a], *Maria A. Duch*[b], *Christian Hranitzky*[c], *Philip Kleinau*[d], *Stefan Neumaier*[a], *Maria Ranogajec-Komor*[e], *Rafael Rodriguez*[f]

[a] *Physikalisch-Technische Bundesanstalt (PTB), Bundesallee 100, 38116 Braunschweig, Germany*
[b] *Universitat Polit'ecnica de Catalunya, Diagonal 647, 08028 Barcelona, Spain*
[c] *Seibersdorf Labor GmbH, 2444 Seibersdorf, Austria*
[d] *Helmholtz Zentrum München, Otto-Hahn-Ring 6, 81739 Munich, Germany*
[e] *Ruder Boskovic Institute, Bijenicka 54, 10000 Zagreb, Croatia*
[f] *CIEMAT, Avenida Complutense 40, 28040 Madrid, Spain*

Highlights

- In an intercomparison, the performance of 32 passive area dosimetry systems was tested under real environmental conditions.
- The dosemeters were exposed at dosimetry reference sites of PTB, while independent *H**(10) reference values were established.
- The response of the systems to terrestrial as well as to secondary cosmic radiation was measured.
- The results provide information on the accuracy of typical passive area dose measurements in Europe.
- Deviations of the absolute dose values of different systems from each other are partly caused by the dissimilar response to cosmic radiation.

Keywords

Solid state area dosemeters, Intercomparison, Response to terrestrial radiation, Response to secondary cosmic radiation

Abstract

Under the umbrella of the European Radiation Dosimetry Group (EURADOS), different working groups have responded to the requests of monitoring services in Europe for independent tests of dosimetry systems for harmonization and quality assurance. After having performed regular intercomparisons of personal dosemeters, EURADOS Working Group 3, “Environmental Dosimetry”, performed the first EURADOS intercomparison for passive ambient dose equivalent, abbreviated *H**(10), area dosemeters used for environmental monitoring in 2014 (IC2014env). Such dosimetry systems are generally used to monitor nuclear installations, besides other applications. The results of this intercomparison with a total of more than 500 dosemeters help to better understand influence parameters and the possible accuracy of typical dosimetric measurements using passive dosemeters.

1. Introduction

The aim of this intercomparison was to study the long-term behaviour of passive dosemeters, which are typically used for the monitoring of nuclear facilities in the natural environment or for workplace monitoring. Especially the precision of measurements using passive dosemeters, which last over several months, is studied. In addition, some sources of flawed data were uncovered. The EURADOS Intercomparison 2014 for passive area dosemeters (IC2014env) was managed and coordinated on behalf of EURADOS by the WG3-SG2 Intercomparison Organization Group. This group decided on the irradiation plan and on details of the realization of the intercomparison. The participants, 30 European dosimetry services and official measuring bodies, supplied dosemeters to the coordinator, PTB, and provided diverse information including data on the route cards. The coordinator was responsible for commu- nication between the IC2014env project and the participants, su- pervised the implementation of the measurements, supplied forms and route cards, collected the results and evaluated the data. PTB established the reference values for all measured data traceable to the primary PTB standards.

The motivation to conduct such an intercomparison was the broad use of solid state ambient dose equivalent meters for the monitoring of nuclear facilities and accelerators all over Europe, which serves the purpose to observe the compliance with the límits of the effective dose of the population defined by the European Basic Safety Standards (Council of the European Union, 2013). The problem of all these measurements is the deduction of the natural dose from the measured total dose to possibly determine an additional dose caused by artificial, man-made radiation. Infor- mation can be derived from the intercomparison described in this article on the typical precision of environmental monitoring if solid state detectors are applied.

The following measuring sites were used to expose dosemeters during the intercomparison: The PTB reference measuring site for cosmic radiation (a floating platform on a lake) to measure the response of the dosemeters to secondary cosmic radiation, the reference measuring site for environmental radiation (a free-field installation) to measure the response to terrestrial radiation, and a gamma irradiation facility to check the home calibration in a ^{137}Cs photon field. The transport dose was measured very precisely by storing transport dosemeters in the PTB underground laboratory (UDO II) in parallel to the other irradiations, because at this place, the dose accumulated in some months can be neglected.

30 measuring services and institutions from 16 countries took part in this intercomparison using 33 dosimetry systems of different types (mostly TLD). In total, about 510 dosemeters were exposed at the different PTB reference measuring sites. PTB deter- mined all reference dose values independently from the data of the participants by using active dosemeters and detectors, which are traceable to PTB's primary standards.

2. Methodical procedure

Each participant dispatched 16 passive dosemeters of one type to PTB, including 12 dosemeters for the irradiation in three different ways and 4 transport dosemeters. One dosemeter means one physical holder, which actually may contain several “internal” detectors (e.g. TLD or RPL). In this case, the participant calculates a mean value of all “internal” detectors, so that only one result per holder is reported. Two different measuring periods were possible: The participant had the choice between 3 months or 6 months. The participants had to fill in route cards (including serial numbers) so that all relevant dates in the measuring cycle are documented.

The intercomparison took place in 2014, starting in April and ending in July (3-month irradiation) or October (6-month irradiation). A list of the used dosemeter types of the participants is found in Table 1 and Table 2. The following measurements were performed:

1. 8 dosemeters of each participant were exposed at the reference site for environmental radiation (Fig. 1), i.e. to the terrestrial and the cosmic component of the environmental radiation, for the complete measuring period. This extended free-field site is equipped with a number of active detectors which are operated permanently around the clock, like photon detectors and particle detectors (more details can be found in Dombrowski and Neumaier, 2012). The latter are used to measure the dose (rate) produced by the secondary cosmic radiation. All reference instruments are calibrated in terms of $H^*(10)$ traceable to the primary PTB standards. The dosemeters of the participants were fixed on rods at the height of 1 m above ground. The rods were exchanged weekly to exclude local effects.
2. 4 dosemeters of each participant were exposed at the reference site for cosmic radiation for the complete measuring period, where they were only exposed to the cosmic component of the environmental radiation. This site is realized as a floating platform on a lake. The border of the lake is rather flat and the minimal distance from the platform to the shore is 100 m.
3. 4 dosemeters of the 8 dosemeters of each participant from 1) were irradiated additionally in a primary ^{137}Cs photon field of PTB with a dose of about 5.5 mSv. The additional dose dominates the total dose because it is more than 10 times larger than the accumulated environmental dose.
4. 4 dosemeters of each participant served as transport dosemeters. They were stored in a lead castle in the underground laboratory of PTB, UDO II, while the other dosemeters were exposed above ground. They had to be of the same type as the other dosemeters. The accumulated dose in UDO II, less than 0.5 mSv, is negligible, so that the transport dosemeters display only the transport dose in a good approximation. Only two participants used active dosemeters to detect an unusual irradiation during transport (the respective reading cannot be used for quantitative data evaluation).

After the dosemeters were sent back to their owners, the latter read out the dose values and PTB provided reference values and finally certificates. A more detailed description of the PTB reference measuring sites for environmental radiation is found in Dombrowski and Neumaier (2012). In this reference, the calculation of the reference values for all measurements is explained in addition. PTB made sure that all dosemeters were exactly irradiated for the same time by storing dosemeters which arrived earlier in a lead castle the underground laboratory where the dose rate is negligible (< 0.1 nSv/h). All reference values of this intercomparison are listed in Table 3.

Fig. 1. Dosemeters exposed at the PTB reference site for environmental radiation.

Table 1
Information on dosimeters exposed for 3 months.

Code	Det. principle	Type
A	TLD	TLD-100 in four element in holder by Seibersdorf Labor GmbH
B	TLD + TLD	LiF:Mg,Cu,P. GR-200A by Conqueror Electronics Technology + LiF:Mg,Ti. TLD-100 by Thermo
C	TLD	Panasonic UD-804AS
D	TLD	TLD-UD802A
E	RPL	GBF-JO1, environmental dosemeter, Technol
F	TLD	LPS-TLD-DU 02 (Gamma7777); 4-element TLD-700 card in Seibersdorf holder
G	TLD	TLD-100H, HARSHAW
H	OSL	Inlight model 2 case type GN by Landauer
I	OSL	Inlight model 2 case type GN by Landauer
J	OSL	InLight EX9
K	TLD	Harshaw TLD type 8855
L	TLD	TLD-100
M	TLD	OD-A1203-J92
N	TLD	LiF:Mg,Cu,P TLD in self-constructed badge
O	TLD	Photon Neutron Area Dosemeter Seibersdorf TLD-2K-V4
P	TLD	LiF: Mg,Cu,P (MCP-N)
Q	TLD	LiF:Mg,Cu,P; TLD-700H Harshaw
R	Film badge + TLD	Film AGFA - 22MUO Personal monitoring + TLD-100 Harshaw

Table 2
Information on dosemeters exposed for 6 months.

Code	Det. principle	Type
A	TLD	Harshaw TLD-Karte 7777 in Seibersdorf $H^*(10)$ holder
B	TLD	ENEA card 2 detector GR200; LiF(Mg,Cu,P) (SDDML-China)
C	TLD + TLD	TLD-IJS by JSI (CaF2:Mn), TLD Poland (LIF:MgCuP)
D	TLD	TLD-UD802A
E	TLD	Panasonic UD 804 AS
F	TLD	LPS-TLD-DU 02 (Gamma7777) 4 element TLD-700 card in Seibersdorf holder
G	RPL	Glass area dosemeter OD FGD-203&SC-2
H	TLD +	TLD-700 (Harshaw)
I	TLD	TLD-100 (Harshaw)
J	TLD	TLD-100 (Harshaw); replica of PTB area dosemeter
K	TLD	TLD-700 in self-constructed PMMA sphere
L	TLD	MTS-100 (LiF:Mg,Ti), Radcard
M	TLD + OSL + TLD + RPL	CaF2:Mn made by Jožef Stefan Institute + AL2O3:C − Russia + LiF:Mg,Cu,P - MCPN, Poland + SC-1, Asahi Glass Company, Japan
N	OSL + TLD + TLD	Al2O3:C, TLD-100H, CaF2:Mn

3. Results and discussion

In the following, the results of the intercomparison are pre- sented and discussed by considering response values, the quotients of the measured dose divided by the reference ambient dose equivalent. The measuring services are represented by anonymised labels. The uncertainty bars are only related to the statistical standard deviation of the mean value of 4 dosemeters exposed in the same way, using Student's t-distribution. The investigated major parameters, which have an influence on reported results, are the home calibration, the response to terrestrial radiation and the response to cosmic radiation.

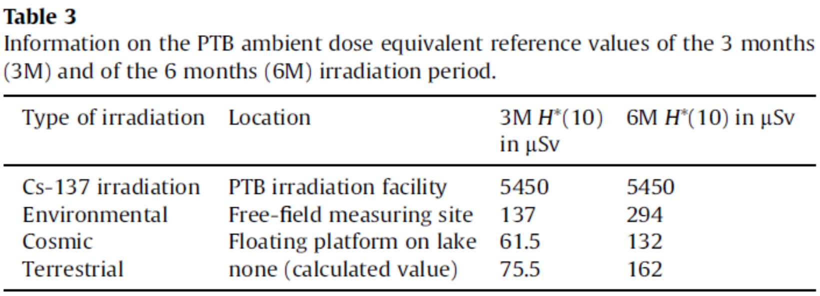

Table 3
Information on the PTB ambient dose equivalent reference values of the 3 months (3M) and of the 6 months (6M) irradiation period.

Type of irradiation	Location	3M $H^*(10)$ in µSv	6M $H^*(10)$ in µSv
Cs-137 irradiation	PTB irradiation facility	5450	5450
Environmental	Free-field measuring site	137	294
Cosmic	Floating platform on lake	61.5	132
Terrestrial	none (calculated value)	75.5	162

Fig. 2 shows the response of the dosimetry systems, which were irradiated in a ^{137}Cs photon beam (irradiation 3 in section 2). This type of measurement allows a quantative test of the home calibration of the participants, which is also related to the dosemeter response in a ^{137}Cs photon field. If the response value plotted in Fig. 2 is too high (> 1.0), the corresponding calibration factor of the participant is also too high, and vice versa. Apart from a few outliers, the calibration factors of the participants lie in a band of ±20% around the reference value, most of them even in a band of ±10% (outliers are discussed in Section 4). The mean values of the data sets of both graphs are 0.94 (after removing outliers). This means that there is a tendency to a slight under-response, which is not desirable in radiation protection.

In Fig. 3, the response of the dosimetry systems exposed to both components of the environmental radiation is plotted. The measured values were multiplied with the inverse response factor plotted in Fig. 2 in order to correct for the improper home calibration. The obtained values reveal the combined response to terrestrial and cosmic radiation. Almost all measured response values lie in a band of ±20%, but most of them even in a smaller band. The mean values of the data sets of both graphs are 1.04 (after removing outliers). This can be explained by looking at both components of the environmental radiation separately (see below).

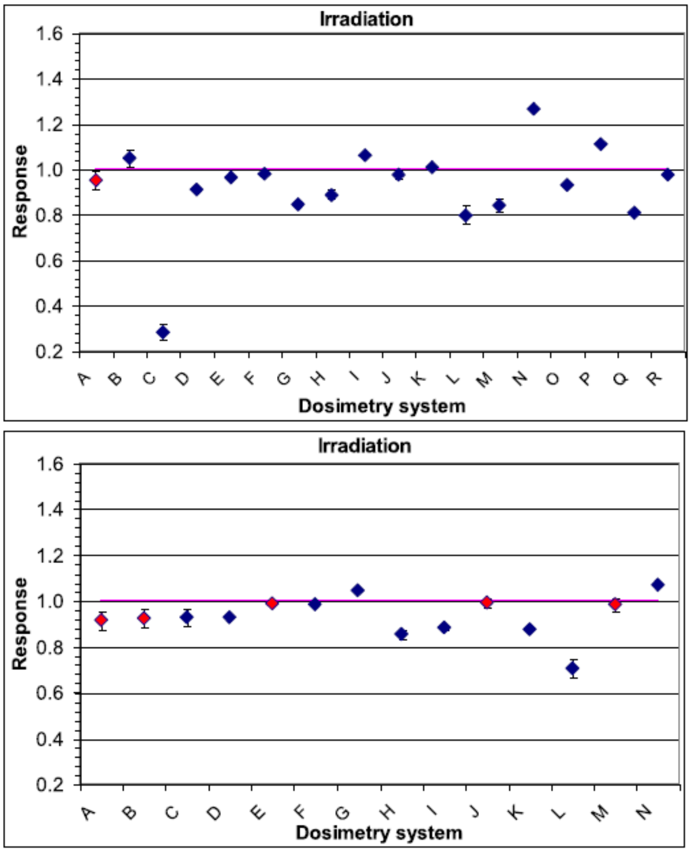

Fig. 2. Response of the dosimetry systems which were irradiated in a 137Cs photon beam in addition to their exposure on the free-field for 3 months (upper diagram) and for 6 months (lower diagram). The ideal response is 1.00 (this is also true for the following graphs). The dark symbols denote dosimetry systems which are officially traceable.

The response to cosmic radiation is depicted in Fig. 4. Again, the data are normalized to the response to ^{137}Cs radiation as explained above. An over-response to cosmic radiation of almost all systems is clearly visible: The mean values of the data sets of both graphs are 1.15 and 1.12. The uncertainty bars in the figure of the 3-month irradiation are larger due to lower a statistic and due to some higher transport doses (by coincidence).

In contrast to the data in Fig. 4, the data in Fig. 5 show a slight under-response, as the mean values of the data sets of both graphs in Fig. 5 are 0.96 and 0.96, respectively. This effect is hard to see especially in the upper graph, because the uncertainty bars are rather large. This indicates that the precision of 6-month exposures are much higher than that of 3-month exposures.

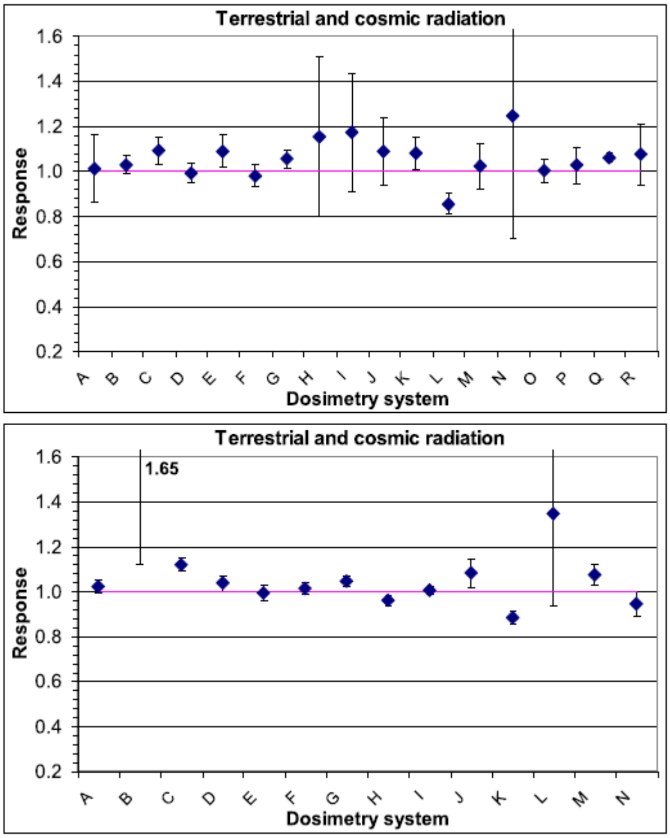

Fig. 3. Response of the dosimetry systems exposed on the free-field for 3 months (upper diagram) and for 6 months (lower diagram). The values were adjusted by division by the dosemeter response to ^{137}Cs photon radiation shown in Fig. 2, so that the response relative to a (virtual) PTB calibration in a ^{137}Cs photon field is shown (the deviations found in Fig. 2 are interpreted as inverse calibration factors).

The uncertainty of the response values to the terrestrial radiation is the highest, because these values are calculated from the difference between the doses measured on the free-field and the doses measured on the floating platform. A direct measurement is not possible. The under-response to terrestrial radiation and the over-response to cosmic radiation result in a combined small over-response to environmental radiation. The tendency to an under-response to terrestrial radiation is unwanted, because gamma-radiation should be detected conservatively, while any response to cosmic radiation can be accepted, as the latter is only a background in radiation protection which has to be subtracted in environmental monitoring, anyway.

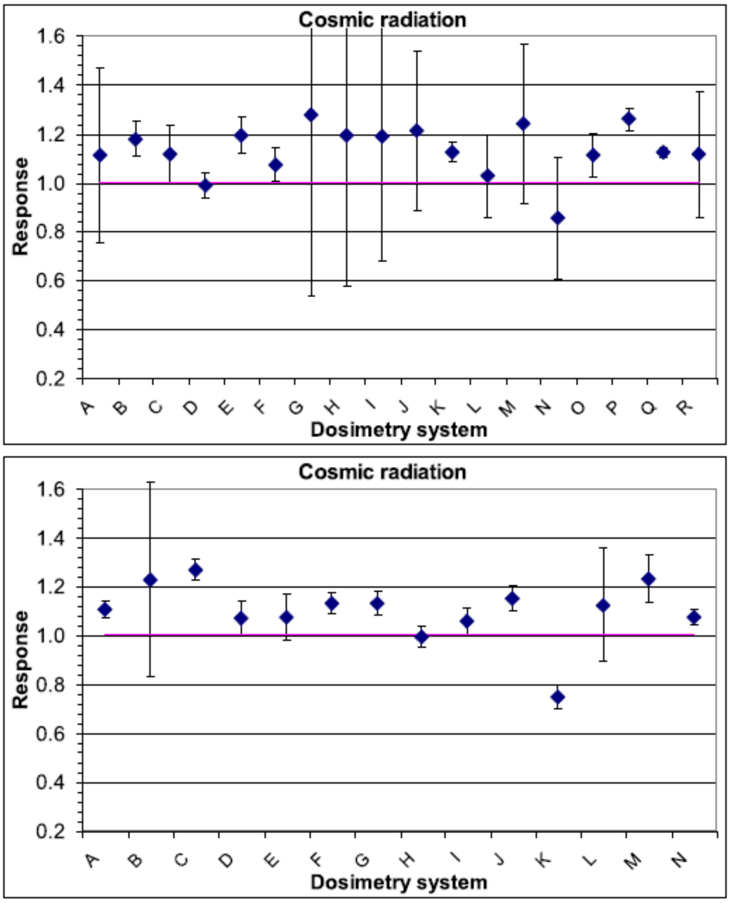

Fig. 4. Response of the dosimetry systems exposed on the floating platform for 3 months (upper diagram) and for 6 months (lower diagram). The values were adjusted by division by the dosemeter response to ^{137}Cs photon radiation shown in Fig. 2.

The measured transport doses are plotted in Fig. 6. In contrast to the figures above, Fig. 6 shows absolute dose values. Some transport doses are quite high, because the referring dosemeters had to be send abroad, which lasted for several days, in some cases. But even the highest values are at least one order of magnitude smaller than the doses measured on the reference sites.

Limitations of the ability of a dosimetric measuring programme to uncover additional artificial radiation in the natural environment can be derived from the data plotted in Fig. 3. If the conclusion is drawn that in general a precision of 20% can be reached in a 3 months measurement and of 10% in a 6 months measurement, the detection limit of any dosimetry system of an additional dose per month will be about 22 mSv (3 months irradiation) and 11 mSv (6 months irradiation). This can be estimated from the absolute values listed in Table 3 and the precision stated in the sentence before. However, these results are based on the assumption that the dosemetry system including the data evaluation procedure is stable in terms of time and that the measuring service has a perfect method available to determine reference background doses (doses which would have been measured if no artificial radiation was present). As a consequence, much higher detection limits are expected in routine monitoring.

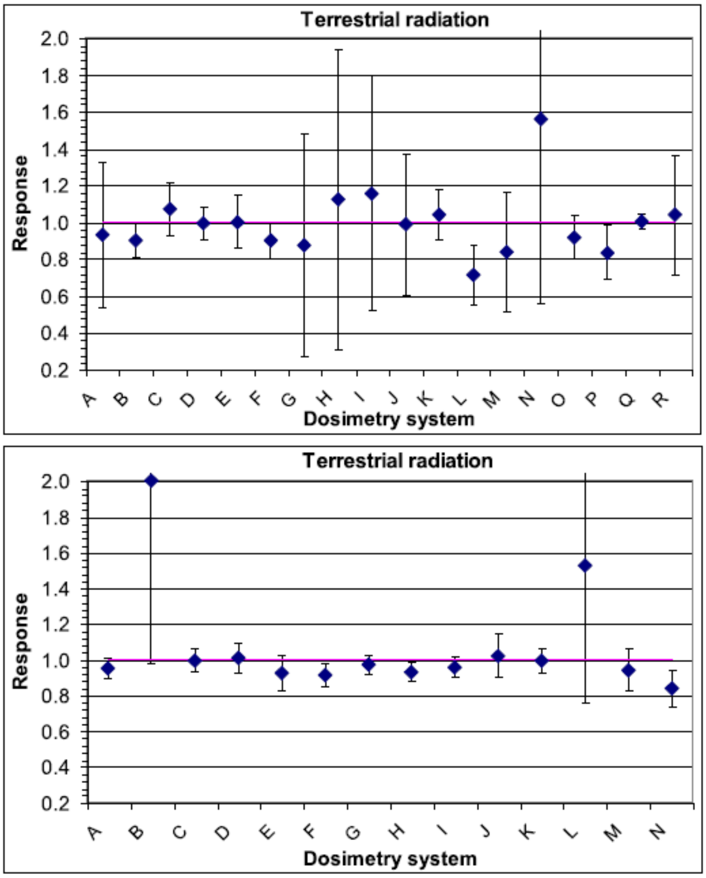

Fig. 5. Response to terrestrial radiation of the dosimetry systems exposed on the free-field for 3 months (upper diagram) and for 6 months (lower diagram). The values were adjusted by division by the dosemeter response to ^{137}Cs photon radiation shown in Fig. 2.

Even a detection limit of 11 mSv per month would lead to the conclusion that a detection limit of 0.1 mSv per year is unrealistic. Nevertheless, this detection limit is e.g. required by a German directive (see Dombrowski and Neumaier, 2012 for further details), because 0.1 mSv is 10% of the permissible effective dose limit of 1 mSv per year for a member of the public, defined in 2013/59/Euratom.

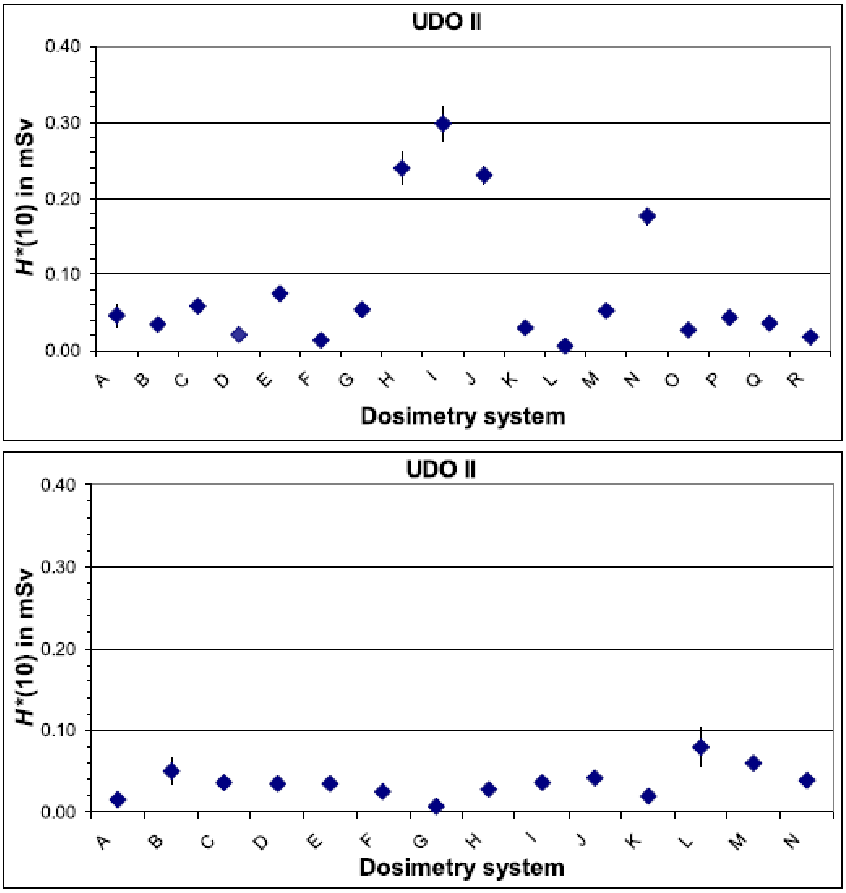

Fig. 6. Measured transport dose values of the dosimetry systems exposed for 3 months (upper diagram) and for 6 months (lower diagram).

3.1. Uncovering some sources of flawed data

The intercomparison revealed some problems in the detector hardware or in the data evaluation which flawed some results or had a disturbing influence on the reported values:

1. An error was found in the standard data evaluation processing of one participant, which only appeared at high dose rates, so that it was not discovered previously in routine operation. As a consequence of this error, the response of System C in Fig. 2, upper diagram, was low by a factor of about 4. The participant removed the error after the intercomparison.
2. Some detector holders were not watertight. Hence, the water inside some holders changed the response. Particularly the results of System N in Fig. 2, Fig. 3 and Fig. 5, upper diagram, respectively, were considerably high. The measured response of System N in Fig. 4 does not show this effect, because on the floating platform the dosemeters were stored water protected in a little plastic cabin.
3. One participant overestimated his uncertainties a great deal and rounded his results roughly, though the Guide to the Expression of Uncertainty (BIPM, 2008) does not recommend changing the expected value if the relative uncertainty is regarded as high (e.g. 50%). This led to the deviations visible in the response of System B in the lower diagram of Fig. 3, Fig. 4 and Fig. 5.

4. **Conclusions**

In general, the results of this intercomparison are very promising. Most of the measured data of the participants do not differ by more than 20% from the PTB reference values. The dosemeters showed an over-response to secondary cosmic radiation, but there was a tendency to underestimate terrestrial radiation. In spite of the positive overall picture, the intercomparison uncovered some errors or weaknesses, so that the measuring services were able to perform improvements in their detector holders or in their procedures.

The first international intercomparison of passive *H**(10) dosemeters organised by EURADOS revealed interesting results about the properties of passive dosimetry systems and about the precision of their data. The results are important for the quality assurance of measuring bodies, on the one hand, but also for a better understanding of the properties of the dosimetry systems, on the other hand.

In general, the precision of environmental monitoring of gamma radiation using passive area dosemeters is not sufficient to detect an excess dose rate of 0.1 mSv per year.

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