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European Radiation Dosimetry Group e. V.

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Overview of passive area dosimetry systems used in European countries

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Content:

Abstract

EURADOS Working Group 3 (WG3) aims at providing information about the correct measurement of the ambient dose equivalent, short $H^*(10)$, in the environment and has a specific subgroup (WG3-SG2) that focuses on passive environmental dosimetry. One of the initial tasks of the subgroup was to gather information on passive area dosimetry for workplace and environmental radiation monitoring. This information has been obtained from dosimetry services using passive $H^*(10)$ photon or neutron dosemeters.

On the basis of surveys performed in 2012 and 2016 this report summarizes the situation of passive environmental dosimetry in European countries. The results were treated confidentially. Therefore, the present document shows anonymous statistical evaluations. The gathered facts helped, in particular, to prepare related intercomparisons. Some open questions have been identified, especially concerning the harmonization of environmental dosimetry since many different protocols, dosimetry systems, calibration procedures, regulations and laws exist.

1. Introduction and outline

EURADOS (www.eurados.org) is a network of more than 50 European institutions and 500 members working within the field of dosimetry and radiation monitoring. Working Group 3 (WG3-Environmental Dosimetry) carries out research projects and coordinated activities to advance the scientific understanding of environmental dosimetry. In Europe, different measuring networks provide radiological monitoring data, most of them based on active monitors that provide ambient dose equivalent rate values as well as nuclide specific data on contamination levels almost in real time.

Complementary to the use of active dosimetry or spectrometry systems, passive area dosimetry systems (e.g. using thermoluminescent dosemeters, short TLD, or optically stimulated luminescence, short OSL) are also widely used for different area monitoring applications. The routine use of such systems comprises workplace monitoring, which is often performed indoor, e.g. to supervise a controlled area, and environmental monitoring, e.g. to control doses at the border of a nuclear facility.

In 2012 EURADOS WG3 discussed two major aspects of its future work:

- the planning of an international intercomparison of passive dosimetry systems;
- the possible implementation of a WG3 subgroup addressing dosimetrical aspects related to environmental radiation monitoring using passive dosimetry.

For both, information on the practices of passive dosimetry was required, and a first questionnaire was electronically disseminated in 2012 by e-mail.

Subsequently, a specific WG3 subgroup (WG3-SG2), which works on passive dosimetry in environmental radiation monitoring (ERM), was inaugurated in 2014. The first task of the subgroup was to gain an overview of passive dosimetry systems and related measurement practices in Europe by analysing the questionnaires. Some of the results gathered from this survey were published (Duch *et al.*, 2016). Later, an updated questionnaire was disseminated in 2016.

2. Description of the surveys

2.1 Questionnaire in 2012

The first questionnaire included 20 questions addressing the following topics:

2.1.1 Dosimetry system

Six questions addressed the main radiological characteristics of the dosimetry systems:

- Measuring quantity ($H^*(10)$ or other).
- Radiation type (photons, neutrons).
- Dosemeter properties: detector type (TLD, RPL, OSL, other) and number of detectors within a dosemeter.
- Number of issued dosemeters per measuring period.
- Rated ranges (dose and energy range).
- Preferred term for the dosimetry system (area dosemeter, ambient dosemeter, environmental dosemeter, other).

2.1.2 Dose calculation methods

A dose measurement can be influenced by different reasons. Key elements of the dose assessment methodology are the subtraction of the background dose and transport dose. The transport dose can account for a considerable part of the measured dose, if the transit period is long compared with the monitoring period (Duch *et al.*, 2008; Ranogajec *et al.*, 1996).

In addition, detector readings are usually multiplied by several correction factors. For instance, thermoluminescent detectors can suffer from an unintentional loss of the latent information, known as fading effect. Consequently, several questions addressed these topics:

- Net dose calculation and applied methodology to measure/estimate the background dose:
    - Subtracting a background dose measured at a comparable location.
    - Subtracting a background dose measured earlier at the same location.
    - Subtracting an estimated or calculated natural background dose.
- Transport dose correction and applied methodology to measure/estimate the dose contributions not related to the exposure at the measuring location:
    - Subtracting a dose measured with additional active dosemeters.
    - Subtracting a dose measured with additional passive dosemeters.
    - Subtracting an estimated or calculated transport dose.
- Fading or climate correction methods: using additional irradiated passive dosemeters or by applying an estimated or calculated fading correction factor.
- Other applied corrections.
- Whether the overall measurement uncertainty is calculated and reported or not.

2.1.3 Quality assurance

Participants were asked about different aspects of quality assurance, especially if they hold a formal certification or accreditation. Some national authorities recommend the adoption of a quality management system, in particular in accordance to the international standard ISO/IEC 17025 (ISO, 2017) on general requirements for the competence of testing and calibration laboratories. The national authorities may also require a technical conformity test or type approval of the dosimetry system.

A key element of quality assurance is the regular participation in intercomparisons. In particular, the standard ISO 17025 requires such independent validation activities. Subsequently, some questions were asked to gain an overview on this area:

- Participation in past intercomparisons:
    - International intercomparison(s).
    - National intercomparison(s).
    - Comparison(s) with another institute.
- Traceability to national standards.
- National type approval of the dosimetry system.
- Compatibility with IEC 62387 (IEC, 2020) and ISO 17025.

2.1.4 Customers and interest in intercomparisons

The dosimetry services were asked to supply information on other services they provide and on their fields of application. Finally, the participants were asked about their interest in attending an international intercomparison organized by EURADOS in this area.

2.2 Questionnaire in 2016

In 2016 an updated questionnaire was circulated, it also included 20 questions, but some of them were further devised to gather more information on some aspects related to the system's characteristics and uncertainty assessment.

2.2.1 Dosimetry system

Six questions addressed the main radiological characteristics of the dosimetry systems, some of them very similar to the questions asked in Questionnaire 2012:

- Measuring quantity ($H^*(10)$ or other).
- Radiation type (photons, neutrons).
- Dosemeter properties: detector type (TLD, RPL, OSL, other), number of detectors within a dosemeter, materials and activators for each TLD detector type used in the dosemeter.
- Number of issued dosemeters per measuring period.
- Rated ranges:
    - Dose and energy range.
    - Lower limit of detection.
- Type of monitoring applications:
    - Workplace monitoring, i.e. mostly indoor, within or at the border of radiation protection areas.
    - Environmental monitoring, i.e. outdoor, outside or at the border of a facility.
    - Workplace and environmental monitoring.

2.2.2 Dose calculation methods

- Net dose calculation and applied methodology to measure/estimate the background dose.
- Transport dose correction and applied methodology to measure/estimate the dose contributions not related to the exposure at the measuring location.
- Fading or climate correction methods.
- Other applied corrections.
- Whether the overall measurement uncertainty is estimated or not.

- Total measurement uncertainty at a 68% confidence interval (k=1). The services could indicate the uncertainty contributions taken into account to calculate it:
  - Statistical/coefficient of variation uncertainty contribution at typical dose values.
  - Calibration uncertainty contribution using the calibration quality.
  - Dose non-linearity uncertainty contribution.
  - Energy and angular response uncertainty contribution.
  - Fading or environmental uncertainty contribution.
  - Transport dose subtraction.
  - Other uncertainty contributions.

2.2.3 Quality assurance

- Participation in past intercomparisons.
- Traceability. Description of the calibration procedure and how often it is performed.
- Conformity to national or international standards.
- Conformity to national or international quality standards.

2.2.4 Customers, sources of error and interest in intercomparisons

- Application fields (workplace or environmental monitoring).
- Other services provided.
- Ranked description of serious sources or causes of error:
  - Lost or unreturned dosemeters.
  - Damaged dosemeters.
  - Contaminated dosemeters.
  - Irradiation during transport.
  - Ambient conditions outside specifications.
  - Exposure conditions outside specifications.
  - Reader malfunction / operator error.
  - Loss of data / false assignment.
  - Other.
- Interests in future intercomparisons:
  - Angular response.
  - Natural radiation response at a free-field site.
  - Cosmic radiation response.
  - High dose response.
  - Low dose response.
  - High energy response.
  - Low energy response.
  - Neutron radiation response.
  - Other.

3. Questionnaire 2012 results

3.1 Participants

By the end of 2014, 60 questionnaires had been received from 47 different institutions and 24 different countries. The response representation per country is shown in Figure 1. Although we did not receive a response from all European countries, the sample covered 21 of the 28 EU member states and some candidate countries, thus there is a good representation of the European dosimetry services. The response per country was very similar in previous surveys carried out under the roof of EURADOS on individual monitoring systems (Carinou *et al.*, 2014; Gilvin *et al.*, 2014).

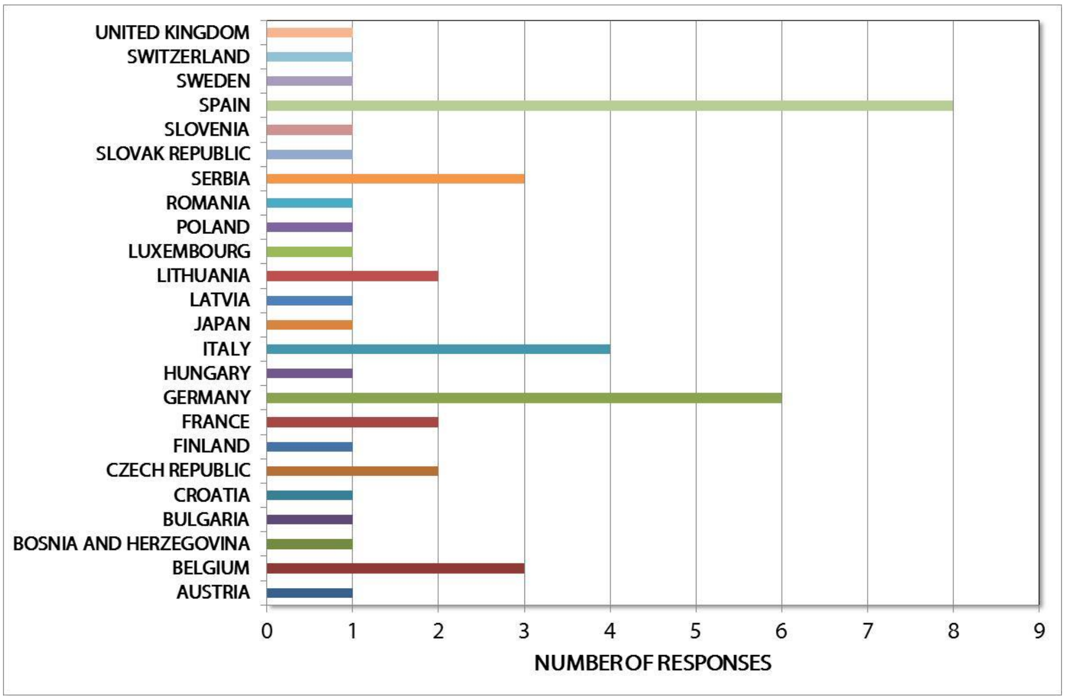

Figure 1: Number of responses received from various countries.

3.2 Dosimetry system

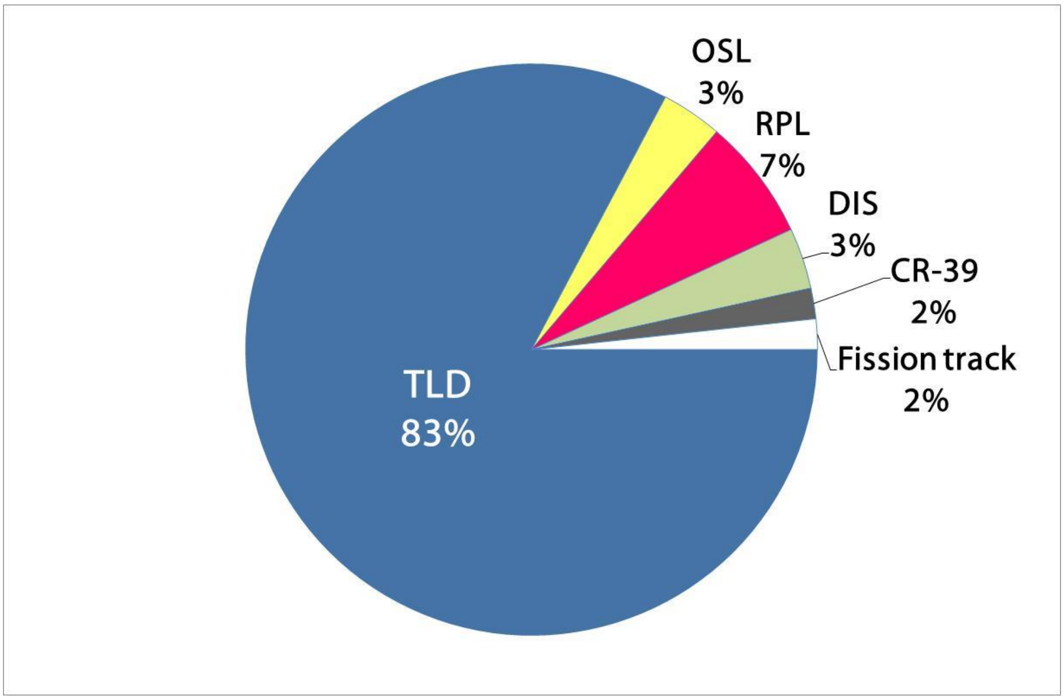

Figure 2: Types of radiation detectors used in passive environmental dosimetry.

The majority of the dosimetry systems (86%) used for environmental monitoring was utilized to detect photons, while only a few systems were built for the detection of neutrons or a combination of both, neutrons and photons. As regards the measuring quantity almost all of them (> 90%) indicated $H^*(10)$ as the measuring quantity, and very few services used $H_p(10)$, though this is not the correct quantity for area monitoring, as $H_p(10)$ is defined for a personal dosemeter to be worn on the body.

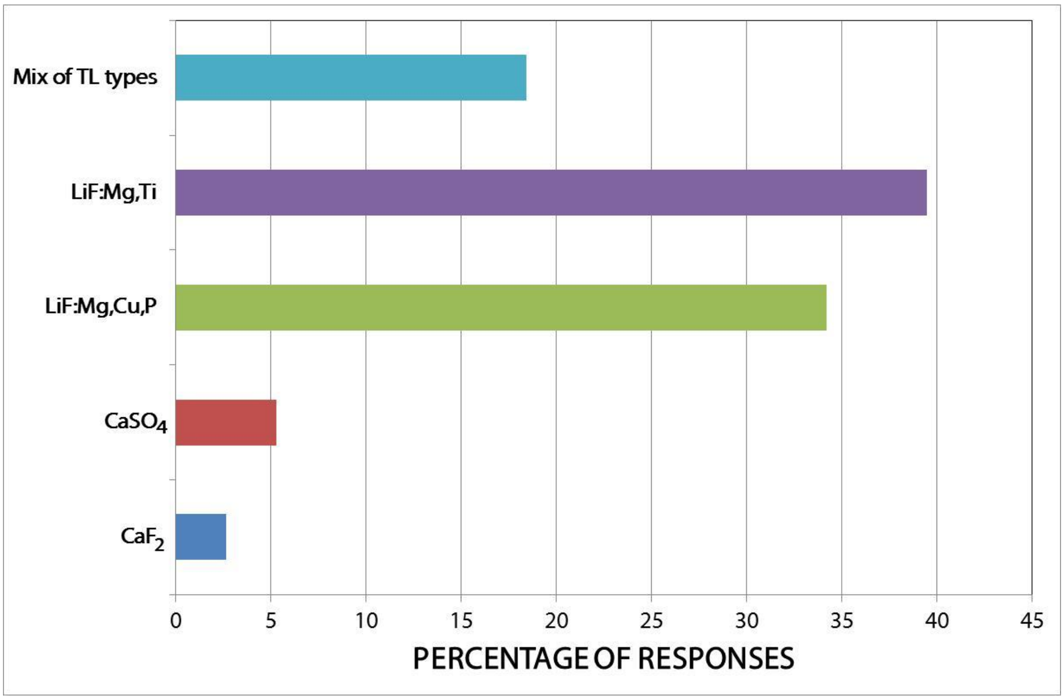

Figure 3: Types of thermoluminescent detectors used in passive environmental dosimetry.

In Figure 2, the frequency distribution of common detector types is displayed graphically. The vast majority of the services use TL-based dosimetry systems. Several TLD materials with different properties exist. LiF:Mg,Cu,P emerged in the 80's as a material with significant advantages over LiF:Mg,Ti for environmental dosimetry applications, mainly due to its higher sensitivity, which is up to 30 times higher than that of LiF:Mg,Ti (Ginjaume *et al.*, 1999). However, according to Figure 3, LiF:Mg,Ti is still the most commonly used material among the TL systems (40%), followed by LiF:Mg,Cu,P (34%) (Figure 3). Both are popular because of their relatively low fading.

The last large-scale international intercomparison of environmental dosemeters organized by the Environmental Measurements Laboratory of the USA (Klemic *et al.*, 1999), where calcium sulphate and LiF:Mg,Ti were the most commonly used TL detector materials, can be regarded as a reference. The obtained results show that the use of sensitive materials is growing.

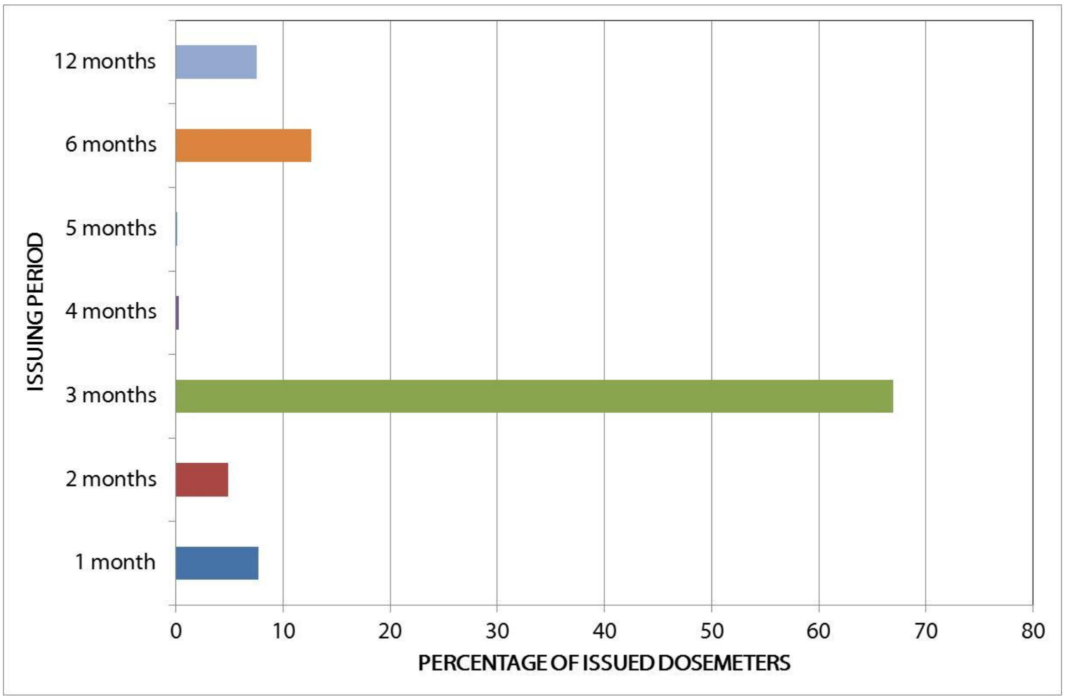

Figure 4: Relative number of issued dosemeters per issuing period.

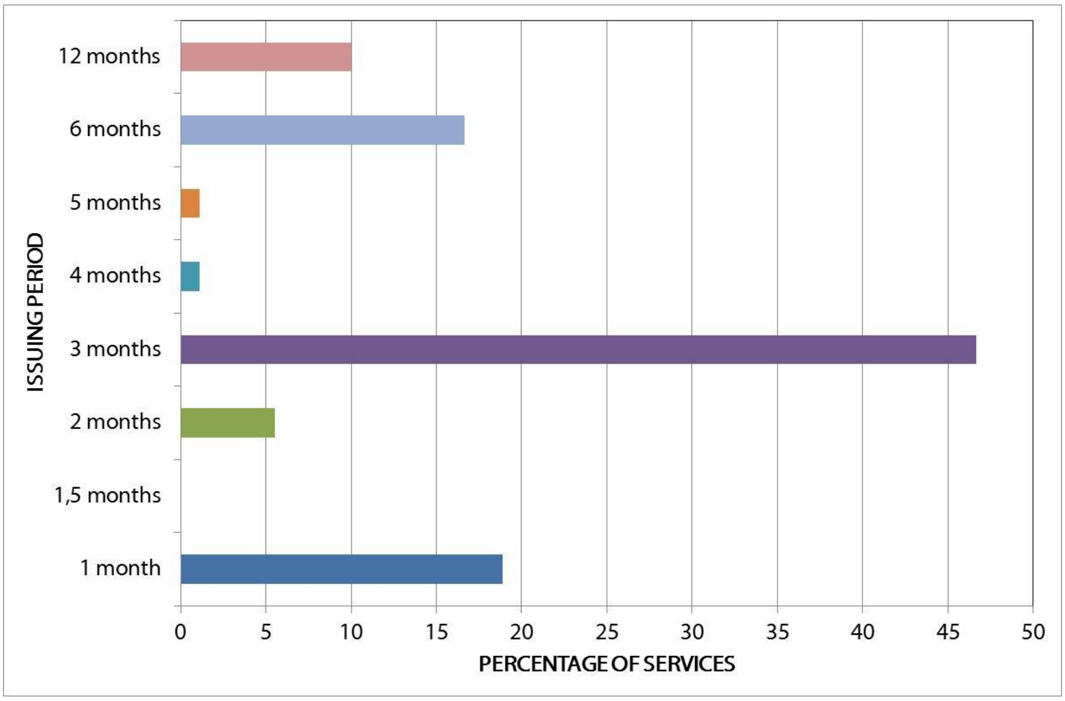

Figure 5: Relative number of services per issuing period.

The size of the services ranged from very small (fewer than 100 dosemeters issued per measuring period) to very large (more than 4000 dosemeters issued per measuring period). Figure 4 shows the percentage of issued dosemeters for each issuing period. Three months is the most common monitoring period (67% of the cases), followed by six months (12%). Other monitoring periods were one, two and also twelve months.

However, it is worth mentioning that the results using the total number of issued dosemeters as a reference is highly influenced by the monitoring period used by large services. If the analysis is carried out in terms of monitoring periods used by the services (Figure 5), the percentages are slightly different. Three months is also identified as the most common monitoring period (47% of services), but followed by 1 month (19%) and six months (17%).

The lower limit of the stated dose range varied considerably, from some µSv to more than 100 µSv (Figure 6). The stated values do not provide a unimodal distribution for deriving a meaningful average value. Lower dose range limits around 50 µSv, but also around 10 µSv were quite often stated.

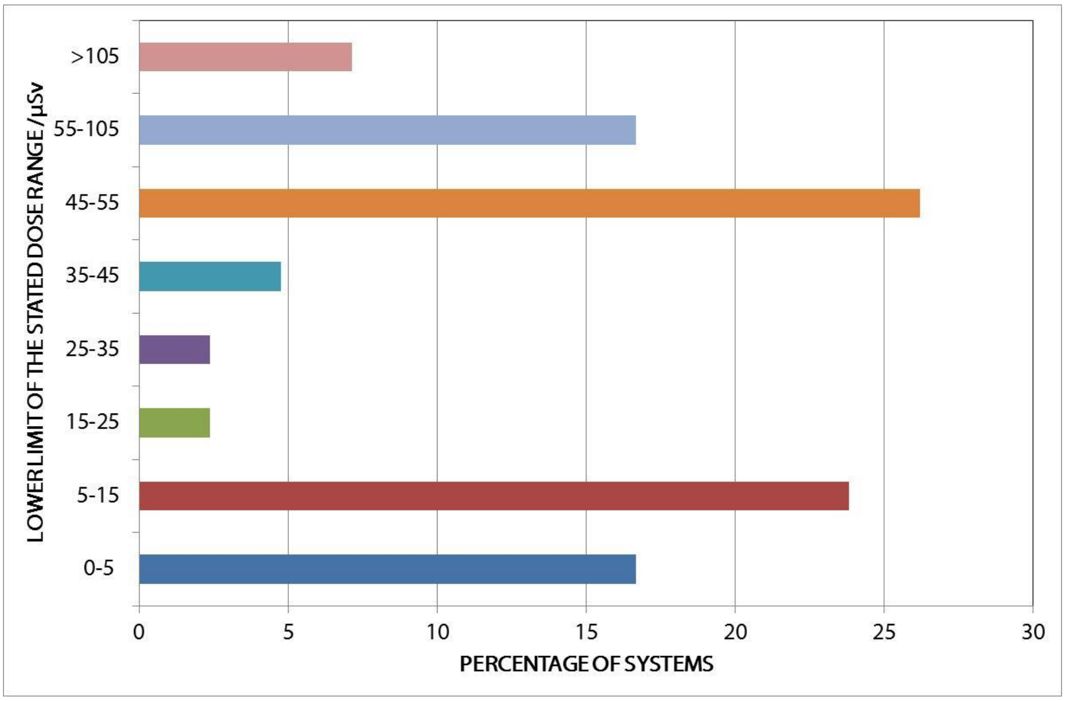

Figure 6: Stated lower limit of the dose range.

As regards the energy range, the average lower limit of the energy range was 29 keV. The minimum stated lower energy value was 5 keV (which is not credible if a dedicated $H^*(10)$ dosemeter is used), and the maximum stated lower energy value was 100 keV.

3.3 Dose calculation methods

Regarding dose calculation procedures (Figure 7), half of the dosimetry services apply transport dose corrections. Among these, the correction is based on a dose measured with additional passive transport dosemeters in 69% of the cases (Figure 8).

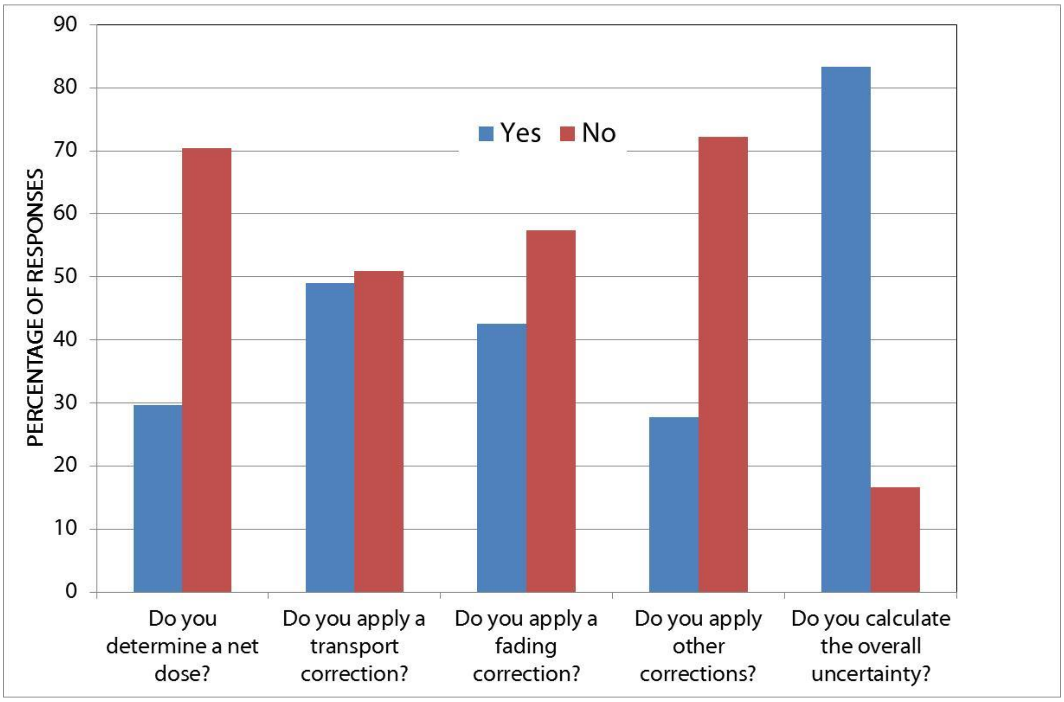

Figure 7: Dose calculation methods.

Only 30% of the services subtract the natural background from the dosemeter results. Only 43% of the dosimetry services apply fading corrections. This can be explained by taking into account that the correction factors related to the fading effect are highly dependent on the measurement procedure, the TL material, the exposure time and the ambient temperature. Some materials show a low influence of fading after three months of exposure even at relatively high ambient temperatures, such as LiF:Mg,Cu,P, while other TL materials show significant fading effects (Ginjaume *et al.*, 1999).

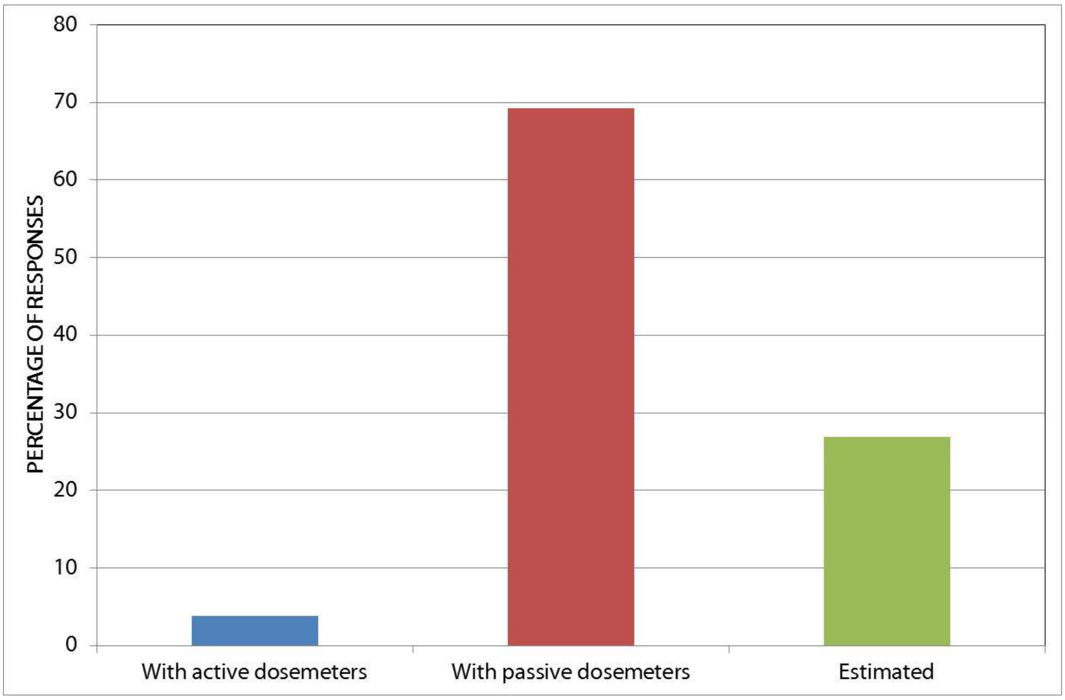

Figure 8: Methods of transport correction.

Among services which apply methods for fading corrections, about half of them (52%) apply a fading or climate correction based on estimated values, while additional irradiated dosemeters ("fading dosemeters") are used in 39% of cases (Figure 9). Other corrections are applied only in 28% of the cases, specifically individual correction factors for single detectors in 17% of the cases and other corrections in 11% of the cases (energy dependence and linearity were the most frequently cited additional corrections). Most dosimetry services (83%) state that they calculate the overall measurement uncertainty.

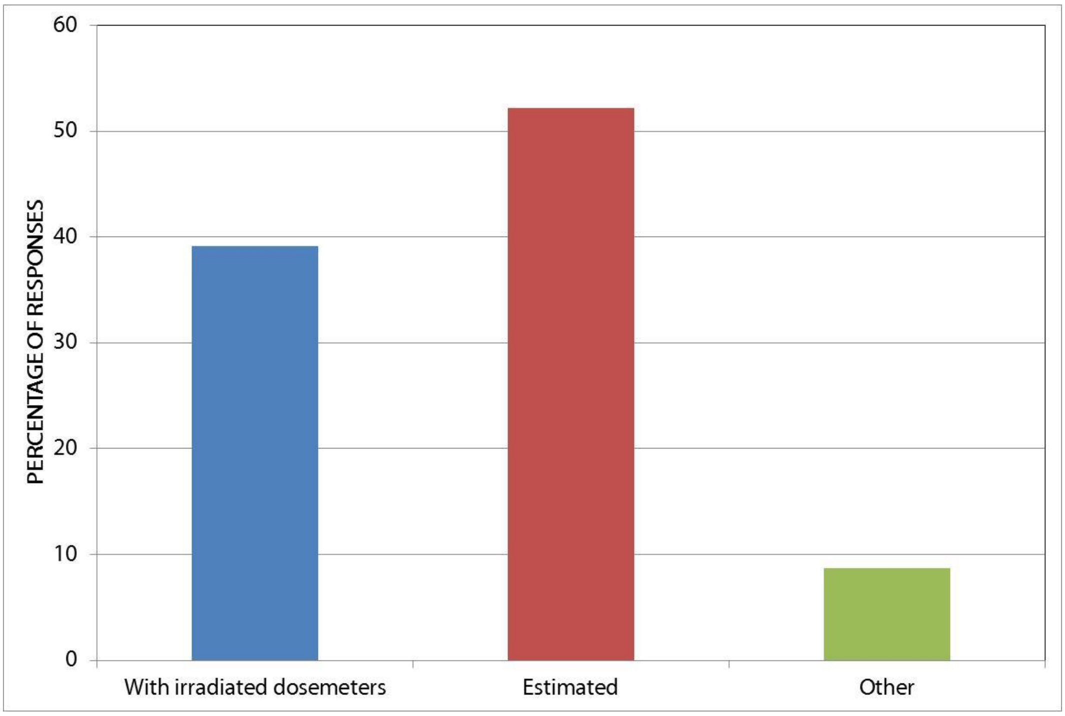

Figure 9: Methods of fading correction.

3.4 Quality assurance

As regards the quality assurance (Figure 10), most of the services participated in area/ environmental dosimetry intercomparisons in the past. The majority of the services stated that their systems are traceable, and 66% of the systems had previously been accredited in compliance with ISO 17025, underlining that there is a wide recognition of the added value and importance of such quality systems. Therefore, a clear interest was expressed to take part in further international intercomparisons in this field.

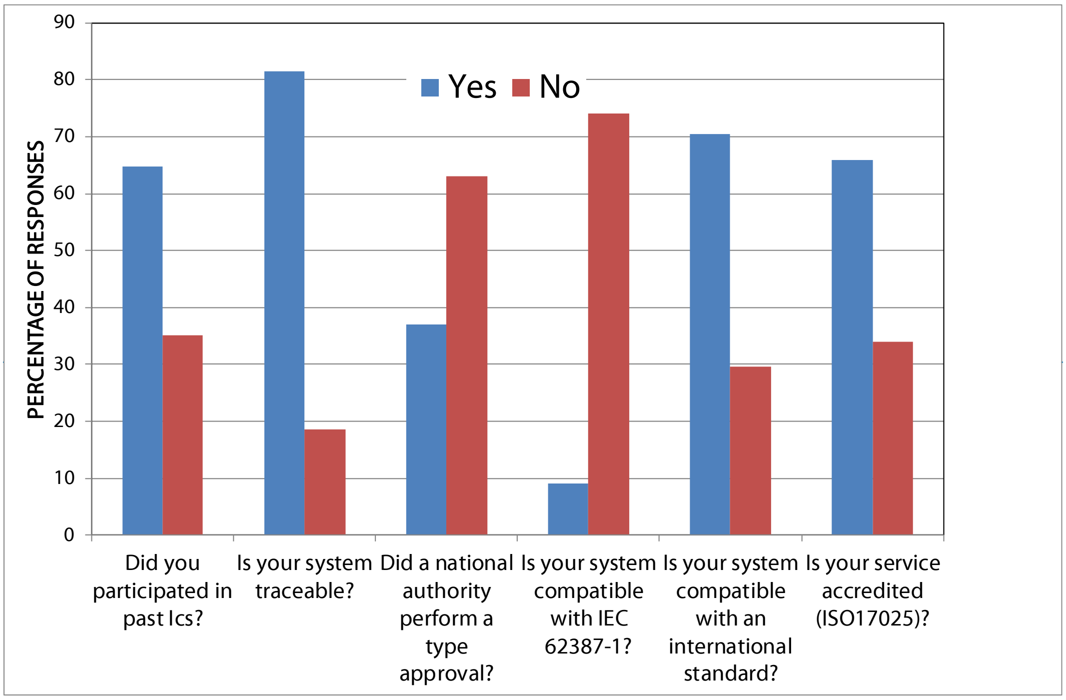

Figure 10: Quality assurance aspects.

4. Questionnaire 2016 results

4.1 Participants

In the end of 2017, 29 questionnaires had been received from 24 different institutions and 12 different countries after submitting the second questionnaire. In Figure 11, the results from the first and the second survey are compared.

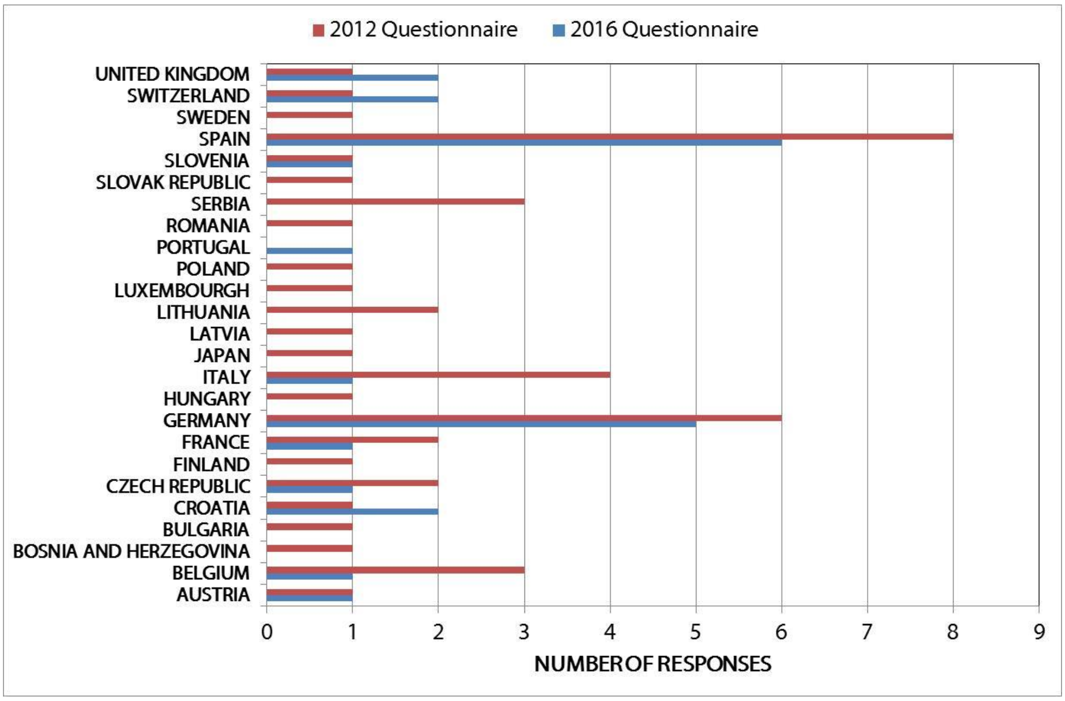

Figure 11: Number of responses received from various countries.

4.2 Dosimetry system

The results regarding the measuring quantity and the radiation type were similar to that of the questionnaire in 2012. 83% of the dosimetry systems are based on thermoluminescent detectors. The most widely used TL detector materials are LiF:Mg,Ti and LiF:Mg,Cu,P (Figure 12).

In addition, questionnaire 2016 asked detailed information about the characteristics of the system. Therefore, systems described as "Mix of TL materials" or without details in the analysis of Questionnaire 2012 results were better categorized. When a mix of thermoluminescent materials is used, a mix of LiF:Mg,Ti and LiF:Mg,Cu,P is most popular, followed by a mix of $Li_2B_4O_7$ and $CaSO_4$. LiF:Mg,Ti and LiF:Mg,Cu,P are very similar, but their relative response to photons below 100 keV is significantly different (Duggan *et al.*, 2004). The use of different materials (e.g. $CaSO_4$ with LiF or $Li_2B_4O_7$), or materials with different isotopic compositions of Li isotopes (enriched with ^{6}Li or ^{7}Li) allows the separate measurement of the photon dose and the neutron dose, if a dosemeter has been exposed to a mixed neutron-gamma radiation field (Lee, 2008).

Figure 13 illustrates that three months is the most common monitoring period. A measuring period of one month is clearly used more frequently compared to the first questionnaire.

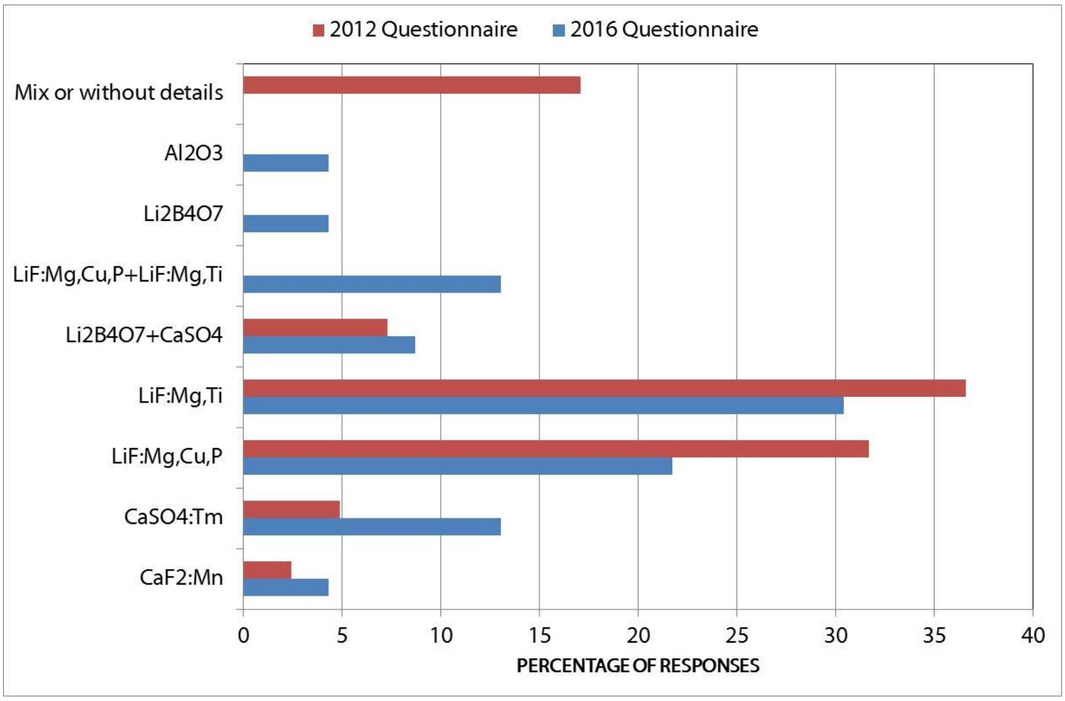

Figure 12: Types of thermoluminescent detectors used in passive environmental dosimetry.

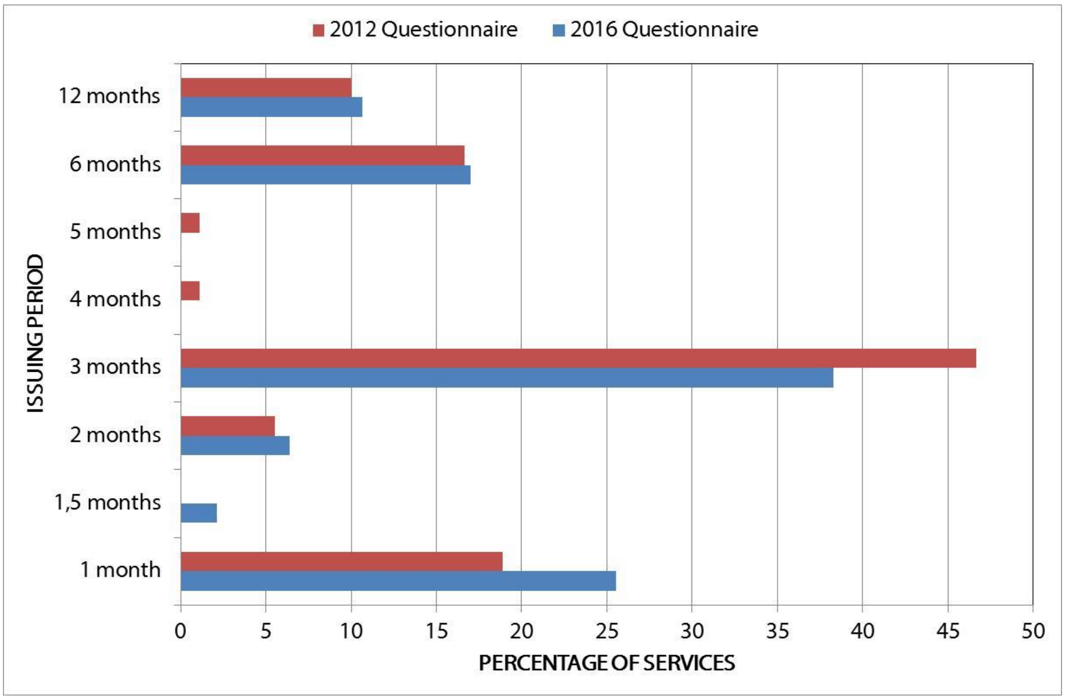

Figure 13: Relative number of services by issuing period.

Similar to the questionnaire in 2012, the lower limit of the stated dose range is between some µSv and 100 µSv (Figure 14).

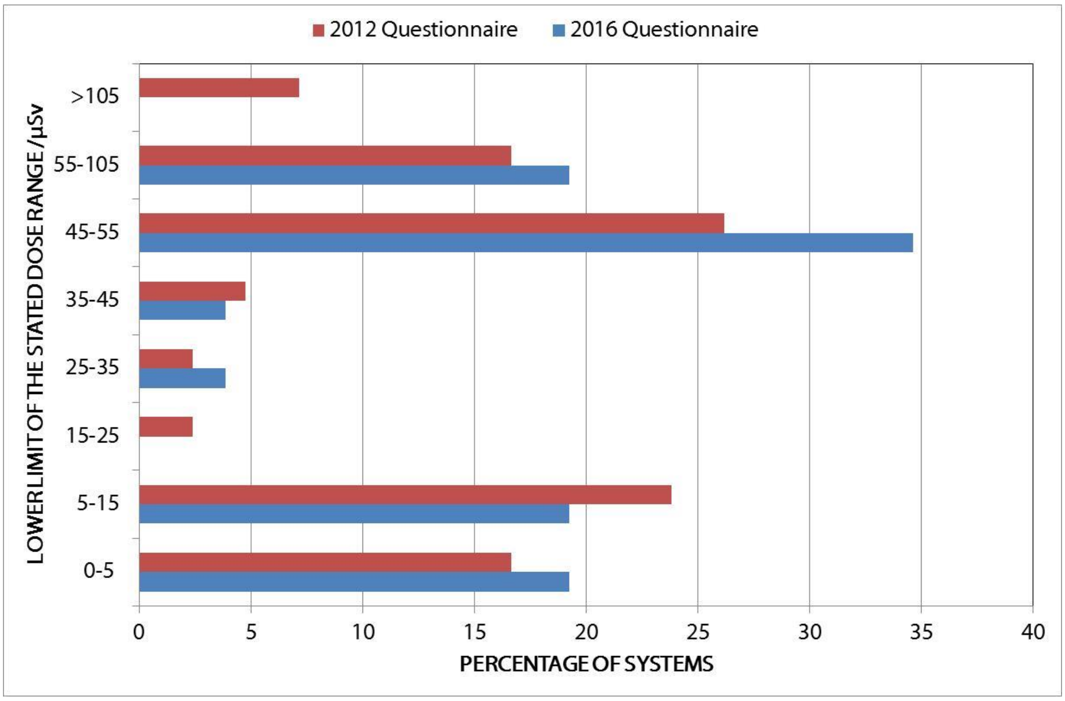

Figure 14: Lower limit of the stated dose range.

The survey in 2016 included a question on the stated lower limit of detection for the first time. According to the answers, the lower detection limit is smaller than the lower limit of the rated dose range, in many cases (Figure 15).

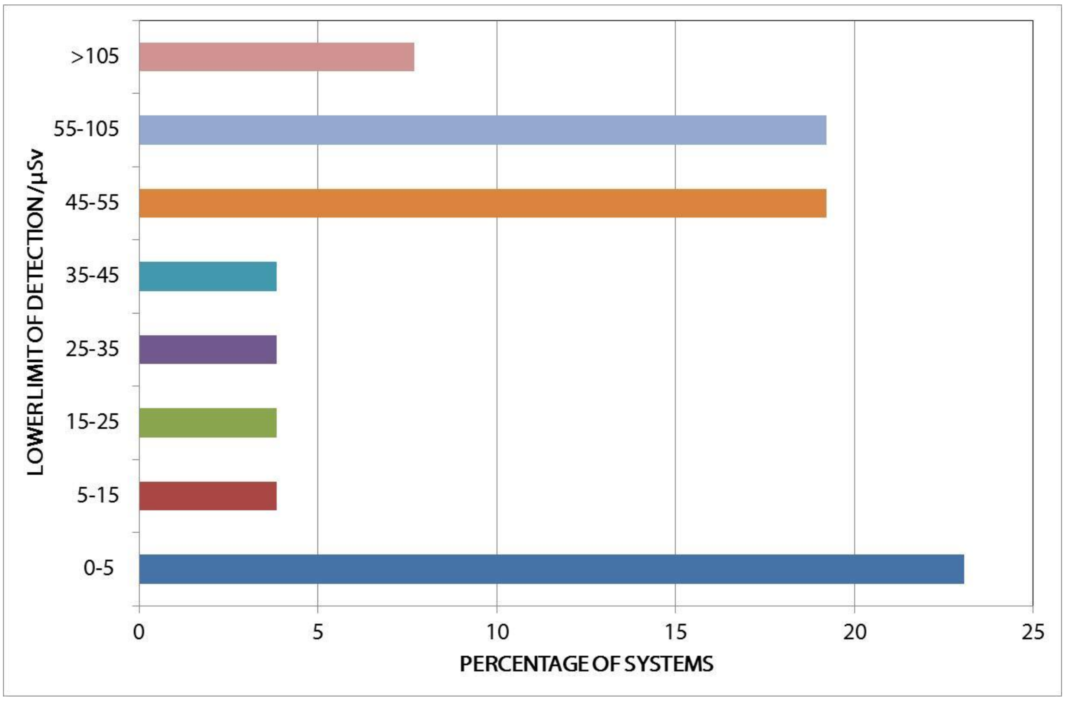

Figure 15: Lower limit of detection.

As regards the energy range, the minimum stated lower energy value was 10 keV and the maximum stated lower energy value was 70 keV. The average lower energy value was 29 keV.

Regarding the type of application, the vast majority of services do workplace and environmental monitoring (63%), only environmental monitoring (i.e. dosemeters are used outdoor, outside or at the border of nuclear facilities or any other facilities which have to be supervised) (29%), and very few are specialized in workplace monitoring, i.e. mostly indoor measurements, within or at the border of radiation protection areas (8%).

4.3 Dose calculation methods

Regarding dose calculation procedures, half of the dosimetry services calculate net doses by performing a background subtraction, and 75% of them apply transport corrections in (Figure 16). Among these, the correction is mainly based on a dose measured with additional passive dosemeters, similar to the results from 2012.

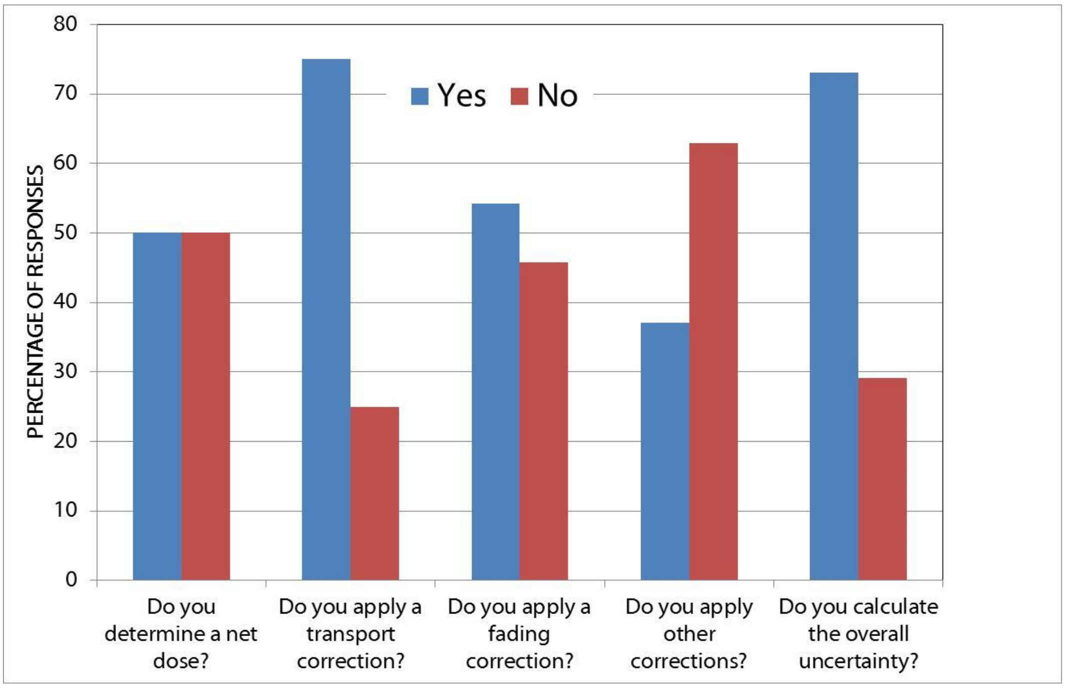

Figure 16: Dose calculation methods.

About half of the services apply a fading or climate correction based on estimated values, while additional irradiated dosemeters are used in about 40% of cases for the tracking of the calibration factor, very similar to the results in 2012.

Other corrections are applied by 36% of the services, specifically individual correction factors are used by 14% of the services and other corrections (concerning the linearity, energy response, etc.) are applied by 22% of them, which is a higher percentage than that in the first survey.

The stated total uncertainty (*k*=1) differs between a few percent, which is unrealistic if the results of former intercomparisons are taken into account, and 30% (Figure 17). The different possible uncertainty contributions (Figure 18) taken into account are:

- Statistical (coefficient of variation) uncertainty at typical dose values.
- Calibration uncertainty.
- Dose non-linearity uncertainty.
- Energy and angular response uncertainty.

- Fading or environmental uncertainty.
- Transport dose.
- Other uncertainties.

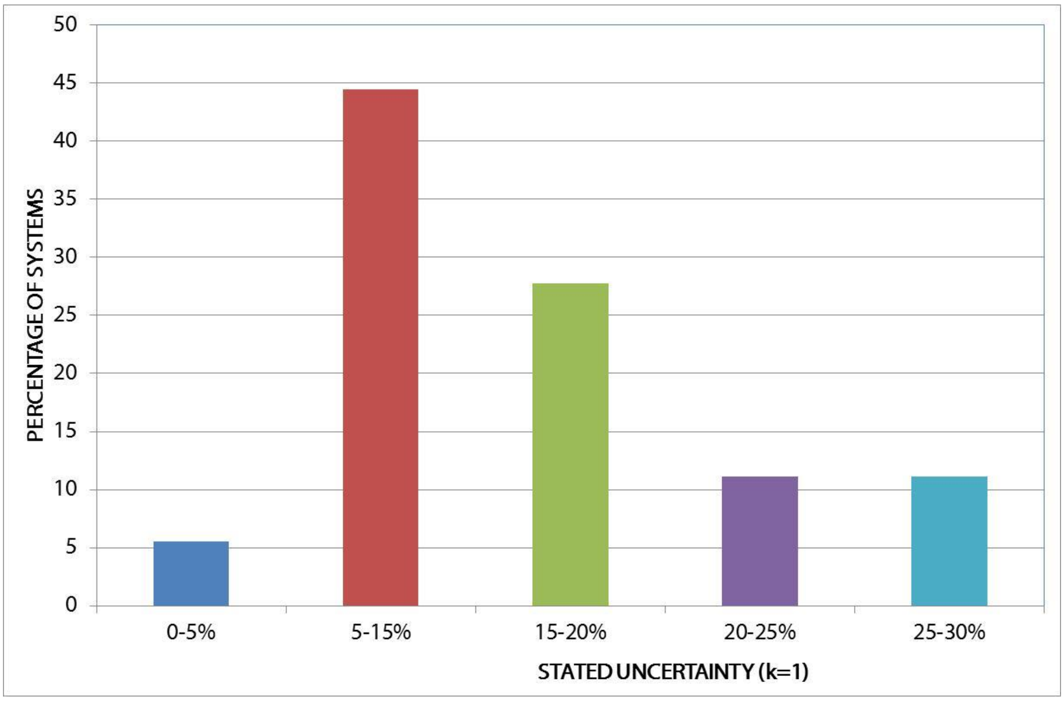

Figure 17: Frequency distribution of the total stated uncertainty in percent.

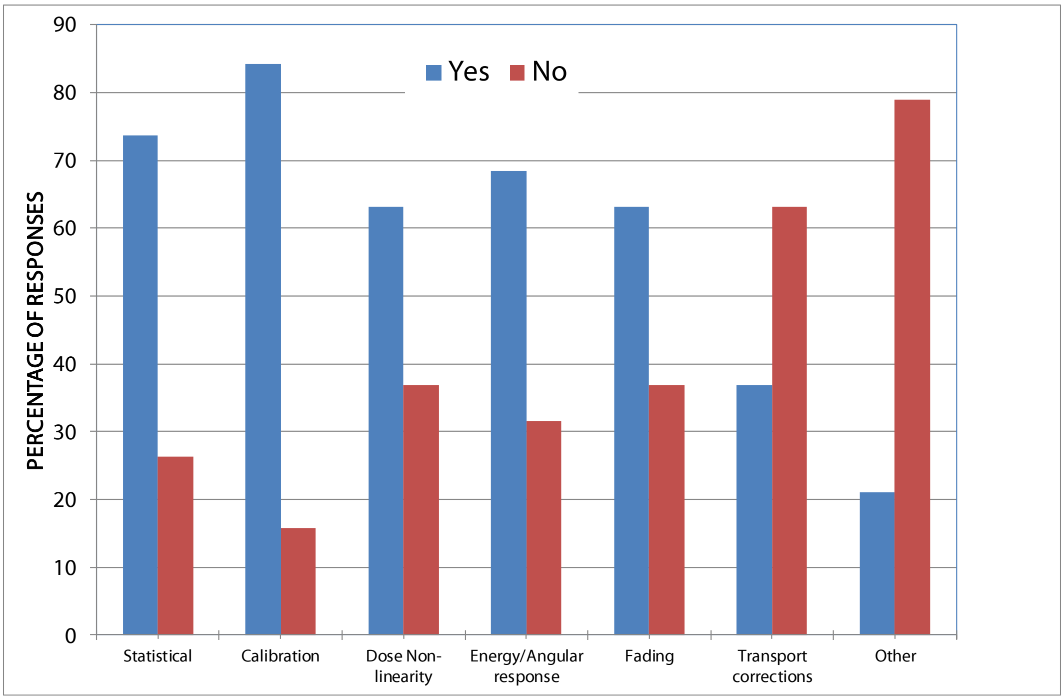

Figure 18: Uncertainty contributions.

Most services do not take the uncertainty of the transport dose into account. Only a minority of 21% of them considers other sources of uncertainty, such as the residual dose uncertainty (uncertainty derived from the residual signal after the first readout), the stability of the individual correction factors and changes in the sensitivity of the detectors.

4.4 Quality assurance

For the purpose of quality assurance, most of the services have participated in passive area dosimetry intercomparisons in the past. The majority of the systems are stated to be traceable, and 81% of the systems had previously been accredited in compliance with ISO 17025 (Figure 19).

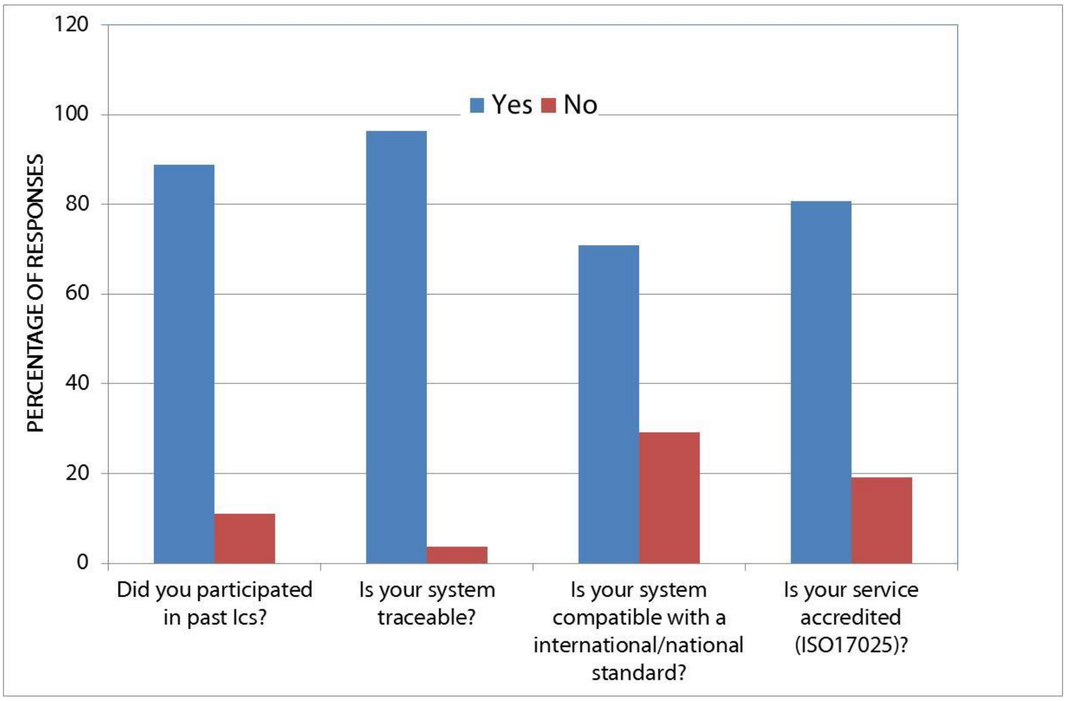

Figure 19: Quality assurance.

Regarding the traceability of the dosimetry systems, the participants could select different options:

- By regular intercomparisons / proficiency tests of a national office / authority.
- By regular calibrations of an accredited / approved body.
- Other methods.

Mostly, the traceability was established by a calibration in an accredited laboratory (76%), some participants (24%) prefer the combination of two options (regular intercomparisons and regular calibrations), and only 20% of them indicated that their traceability merely relies on regular intercomparisons / proficiency tests of a national office / authority.

When a regular calibration in a Cs-137 reference field is performed, the different calibration frequencies, up to one calibration in two years, are displayed below (Figure 20). In most cases, the calibration is performed in a laboratory accredited according to ISO 17025.

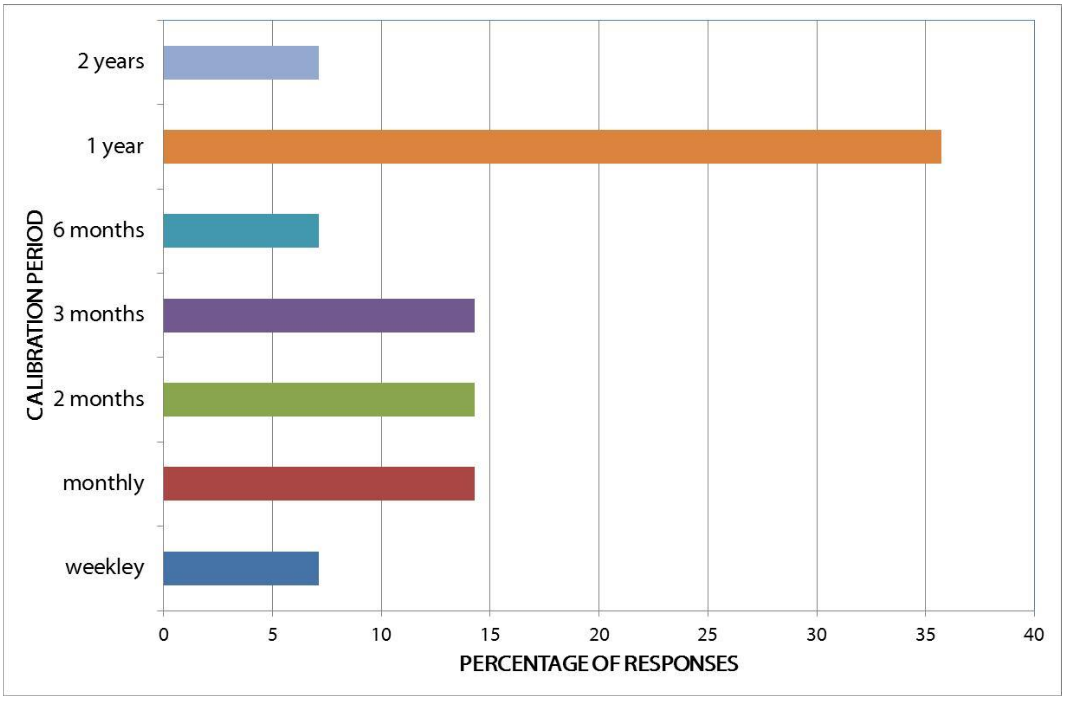

Figure 20: Calibration periods.

4.5 Customers, sources of error and interest in intercomparisons

The services indicated and ranked the most common errors in routine operation, which lead to flawed or missing results, among the following options:

- Lost or unreturned dosemeters.
- Damaged dosemeters.
- Contaminated dosemeters.
- Irradiation during transport.
- Ambient conditions outside specifications.
- Exposure conditions outside specifications.
- Reader malfunction / operator error.
- Loss of data / false assignment.
- Other.

The most frequent error was 'Lost or returned dosemeters', followed by damaged dosemeters (Figure 21).

Finally, the participants were asked about their interest in future intercomparisons (Figure 22). Figure 22 shows which measurement categories are of high or low interest. These results are specifically interesting for the organizers of future intercomparisons.

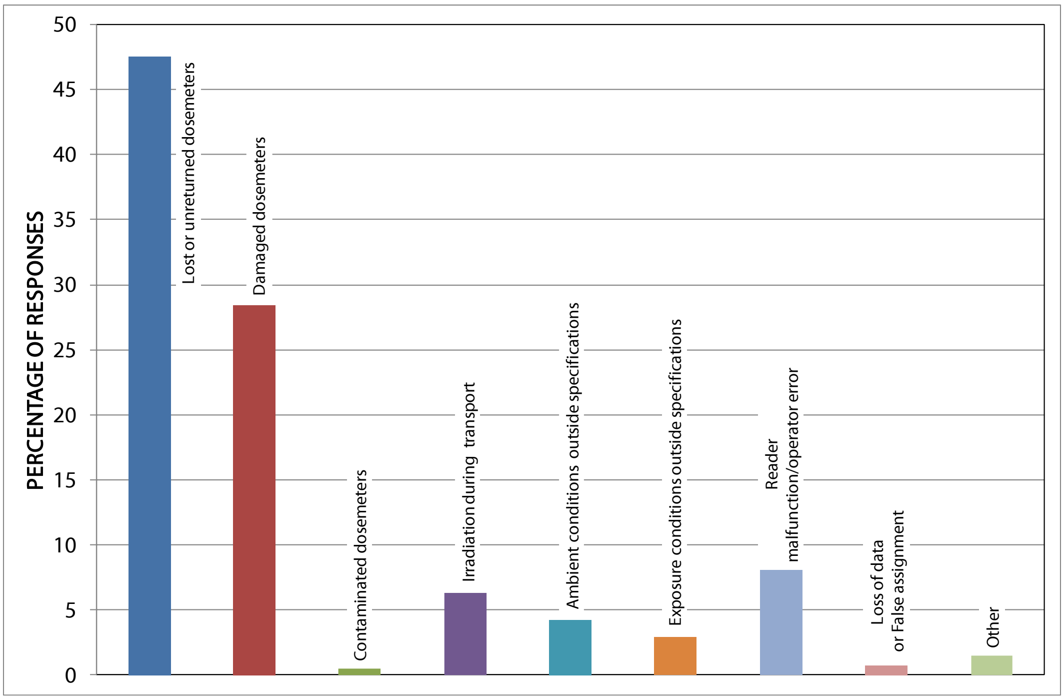

Figure 21: Ranked most frequent causes of error.

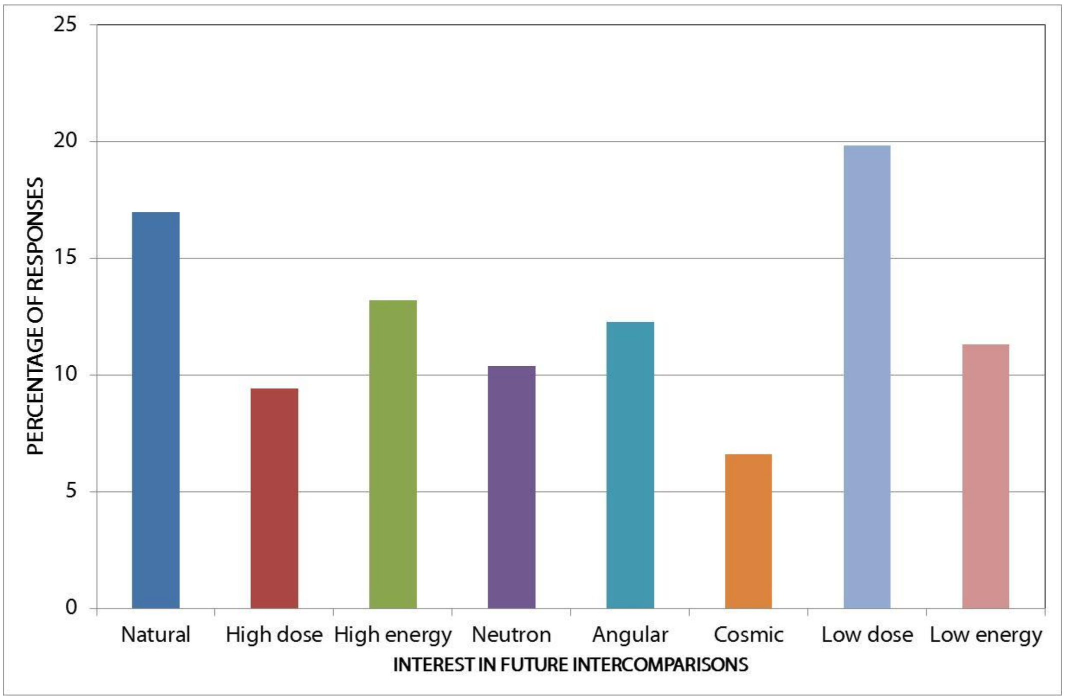

Figure 22: Further interest in future intercomparisons.

5. Discussion and Conclusions

This report provides an overview of passive dosimetry systems used for environmental radiation monitoring in Europe, covering the majority of the European countries. Compliance of measured data with technical performance requirements and legal limits can only be achieved with appropriate area dosimetry systems. The two surveys in 2012 and 2016 clearly showed that there is a potential for improvements of measurement methods and uncertainty analysis.

Environmental area dosimetry is preferably performed using thermoluminescent detectors, as more than 80% of the dosimetry services rely on this technique. In comparison with other passive detectors, TLD based measurements can suffer from fading (signal loss over time especially at higher temperatures).

Another influence quantity and source of uncertainty of passive dosemeters is the handling and transport dose accumulated before and after the on-site measurement period. Merely half of the services correct for the transport dose, though it may be considerable if the measurement period is short (shortest issuing period reported is one month).

Only about a third of the dosimetry services perform a background dose subtraction to calculate a net dose. In environmental monitoring applications, net dose values often result from the subtraction of two values of similar height. Therefore, reliable methods of radiation background determination are of key importance.

One of the main measurement uncertainty contributions is due to the energy and angular response depending on the incident radiation fields. An isotropic response is an advantage for environmental monitoring by using spherical or cylindrical dosemeter holders. Nevertheless, some services use flat dosemeter holders like personal dosemeter badges. Appropriate weather protection may be another problem of personal dosemeters used as environmental dosemeters (Dombrowski, 2017).

From previous intercomparisons it can be concluded that the accurate measurement of very low doses below 1 mSv per year in addition to the natural background may be a problem for a number of dosimetry systems (Dombrowski, 2012). The quality of the calibration method has a direct influence on the accuracy of measured results. Therefore, a series of intercomparisons for testing the performance of calibration laboratories was started (IC2017calm, IC2018calm, IC2020calm).

Differing answers and partly unrealistic statements of the participants concerning the lower detection limit, the lower measurement range limit and the lower energy range limit reveal the need for clarification on these topics. Similarly, a discussion on the relevant uncertainty contributions, evaluation methods and corresponding correction procedures would be helpful.

The conclusion can be drawn that there is a further need for harmonisation in the field of environmental dosimetry using passive detector systems. The results of the survey will help to identify focal points for future discussions, improvements and intercomparisons.

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