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SUPPORT FOR A EUROPEAN METROLOGY NETWORK ON RELIABLE RADIATION PROTECTION: GAPS IN RADIATION PROTECTION AND RELATED METROLOGY

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Abstract. *In this work, the results of a virtual workshop on gaps in radiation protection and related metrology, which was carried out as part of the EMPIR project 19NET03 supportBSS, are reported. The topics, considered most important in terms of radiation protection metrology, were presented and discussed in 8 main areas: 1. Activity standards, 2. Reference fields, 3. New operational quantities in radiation protection, 4. Measuring devices for radiation protection in medical or industrial applications of ionizing radiation, 5. Measuring devices for environmental monitoring, 6. Type testing, 7. Harmonized handling, transmission, storage and availability of measurement data, 8. Education and training needs. The corresponding research needs and metrological challenges related to the metrology services and the relevant stakeholders are presented.*

Key words: *Activity standards, new operational quantities in radiation protection, type testing, calibration, radon, reference field, pulsed radiation, dosimetry, standards, radiological emergency response*

1. INTRODUCTION

The European regulation on ionizing radiation is mainly laid down in the COUNCIL DIRECTIVE 2013/59/EURATOM (EU-BSS) [1]. This Directive implements the basic safety standards for the protection of the health of workers and the general public against the dangers arising from the exposure to ionizing radiation.

However, the practical implementation of the regulations has become more complex due to technological developments and a lack of detail on the implications for metrology. It is therefore necessary to provide access to identified problems and solutions on a European level. A European metrology network (EMN) underpinning radiation protection regulation is required as a single point of contact to cover all metrological gaps and to address further research needs for radiation protection metrology. The development of such a joint and sustainable metrology network was planned by the consortium of the EMPIR project 19NET03 supportBSS [2]. The plan was successfully re-evaluated by EURAMET and the EMN for Radiation Protection was approved by the General Assembly of EURAMET in June 2021 [3].

The supportBSS project aims at preparing an EMN for radiation protection to provide new metrological solutions for the future. As part of this project, a scientific virtual workshop on gaps in radiation protection metrology was carried out on September 11, 2020 [4]. It was organized by the consortium of supportBSS and held by Physikalisch-Technische Bundesanstalt (PTB) and was intended to open a continuous and constructive dialogue on the identified stakeholders' needs and gaps in metrology.

In this document the results of this workshop are summarized. The topics considered most important in terms of radiation protection metrology are classified in 8 main areas. The creation of a mapping model to prioritize the identified and other relevant gaps is the subject of the various ongoing work packages within the supportBSS project. A Strategic Research Agenda (SRA) and roadmaps will be published as well as part of the project [2].

2. OBSERVED AND DISCUSSED GAPS IN RADIATION PROTECTION METROLOGY

This section reports on issues related to metrological aspects of radiation protection from ionizing radiation that are given the most urgent

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priority by the relevant stakeholders and the metrological communities involved. The following topics were presented and discussed in various focus groups during the workshop.

2.1. Activity standards

In the area of activity standards, the following gaps in radiation protection were identified with regard to the lower limit values and reference values, both resulting from the legislative tasks according to EU-BSS, as well as new radioactive sources in nuclear medicine. They result in special requirements for calibration and activity standards.

2.1.1. Lower limit values

The determination of the activity of ^{137}Cs, ^{134}Cs, ^{144}Ce, ^{106}Ru, ^{125}Sb, ^{152}Eu, ^{154}Eu, ^{95}Zr, ^{60}Co, ^{241}Am, ^{239}Pu, ^{238}Pu, ^{90}Sr, ^{222}Rn starting at a few Bq up to higher activities requires activity standards for calibration in the same small order of magnitude to derive the characteristic limits (decision threshold, detection limit). This is followed by the assessment of characteristic limits for nuclide mixtures.

A special regard should be paid to ^{222}Rn calibration standards due to the low activity level allowed by legislation. For ^{222}Rn in indoor air the legally permissible activity limit values are in the range 100 Bq/m^3 to 300 Bq/m^3. This is too low for decaying primary gas standards. During the first intercomparison in the EMPIR project MetroRADON, there have been many unresolved differences in the results so far [5]. Further studies and comparisons are still needed. For the activity range 1 Bq/m^3 to 100 Bq/m^3 of ^{222}Rn in outdoor air, a standard is needed for the radon trace method in climate change observation (greenhouse gases). This is a new challenge for the ongoing EMPIR project traceRadon [6-7]. The metrological gap in traceability chain for the radon concentration and radon flux measurement results to missing radon and radon flux maps for radiation protection in line with EU-BSS [7].

2.1.2. Reference values

For the activity determination of ^{222}Rn, ^{238}U, ^{234}U, ^{228}Ra, ^{226}Ra, ^{210}Pb, ^{210}Po and ^{3}H in drinking water, the validation of the radiochemical procedure is needed. There is a distinct lack of Certified Reference Materials (CRM) for a wide variety of environmental samples. Traceability for real chemical compositions and matrix-specific procedures is required. The corresponding metrological needs are:

- Gross α and β activity concentration (Bq/l)
- Specific radiochemical procedures, e.g., for nuclide-specific determination
- Activity concentration of ^{222}Rn in water (Bq/l)
- Covering chemical influences by non-radioactive components.

These are new challenges for a project in the upcoming EPM (European Partnership on Metrology) programme [8] or EURAMET Partnership Call [9].

2.1.3. New radionuclides

In nuclear medicine, more and more new complex radionuclides such as ^{223}Ra, ^{211}At, ^{213}Bi, ^{225}Ac, ^{224}Ra are used today. They lead to new metrological requirements for calibration as well as to the availability of activity standards for new radionuclides, accompanied by radiation protection issues. The most important metrological challenges in this area are:

- Short half-life down to less than 1 hour that causes a rapid change in activity during calibration measurements and the transport to a customer
- Impurities
- Large dynamic range Bq to GBq
- Nuclear decay data (half-lives, emission probabilities) have high uncertainties

2.2. Reference fields

In the area of reference fields, the complexity results from extended radiation practices and new technological developments, for example pulsed radiation fields in medical, industrial and technical applications. The increased use of pulsed radiation fields is enormous: counting only the therapy units, there are 12,309 linacs in 151 countries (data from Ref. [10] on 9/3/2020). In the following, the resulting gaps in radiation protection metrology in photon and neutron reference fields are shown.

2.2.1. Photon reference field

The main metrological gaps related to photon reference fields are summarized in the following topics:

2.2.1.1. Pulsed radiation with pulse durations in µs or shorter and with high dose rate during the radiation pulse

For several applications, the difference between real fields in radiation protection, pulsed fields, and available continuous reference fields at National Metrology Institutes (NMIs)/ Designated Institutes (DIs) aiming at the calibration and characterization of measuring devices creates problems not only for practical individual monitoring, but also for a dosimeter development, for the authorities and regulatory bodies.

2.2.1.2. Limitation of calibration fields that represent realistic conditions (pulsed fields, mixed fields, high energy, high dose rate)

In addition to classic, continuous reference fields, applications with a need for new types of reference radiation fields are increasing. Therefore, the availability of reference fields with realistic conditions, such as pulsed radiation, high energies, high dose rates and mixed particles is crucial.

2.2.1.3. Traceable measurements and characterized dosemeters for radiation protection at accelerator facilities (linacs)

The shielding of accelerators facilities (e.g., clinical linacs with energies up to 20 MeV or higher) must be approved by the relevant authority. The corresponding metrological needs are:

- The suitability of area dosemeters for this purpose, e.g., measuring in presence of high energy and pulsed radiation fields needs to be approved.
- Corresponding reference fields are needed.

These are challenges for the ongoing project at PTB department radiation protection dosimetry to set up such a reference field [11].

2.2.2. Neutron reference field

The most important metrological gaps corresponding to neutron reference fields, are dealt with in the following topics:

2.2.2.1. Difficulties in neutron dosimetry due to lack of resources to characterize dosemeters in realistic fields

There is a need for new high-energy neutron reference fields for characterizing measuring devices for medicine, flight dosimetry and space applications.

2.2.2.2. Simulated workplace neutron fields satisfying the requirements of ISO 12789

Because the strong energy dependence of the response of neutron dosemeters, simulated workplace fields with broad realistic energy distributions are needed, complying the requirements of ISO 12789:2008 *Simulated Workplace Neutron Fields*. The qualified individual monitoring is also dependent on a good infrastructure for characterizing these measuring instruments in realistic conditions.

2.2.2.3. Lack of operating neutron reference fields in epithermal (0.5 eV - 1 keV) energy region

There is currently no reference field available for epithermal neutrons while radiation protection measuring devices show strong discrepancies in this energy range [12]. Epithermal neutron reference fields are required for the quantification and development of new devices.

2.3. New operational quantities in radiation protection

In the area of new operating quantities in radiation protection according to ICRU Report 95, the following metrological gaps were identified when they become legal quantities [13].

2.3.1. Characterisation of scattered radiation

There is a need for the characterisation of scattered radiation fields at typical workplaces for photon energies below 60 keV, as many workplaces in medicine will have lower mean energies and many instruments could not respond correctly in this angular and energy range. This is already the case for the current phantom based radiation protection quantities. For many workplaces, the spectra of scattered radiation are unknown. The directional distribution of the radiation incident on the dosemeter is even less well known. These characteristics of the radiation field could play a crucial role in deciding the suitability of dosemeters. Fortunately, there are already some devices for accomplishing this task [14, 15]. One of them is based on scintillation crystals in connection with a Geiger-Mode avalanche photodiode array. It was developed at PTB especially for this purpose [15].

2.3.2. Modification of standard

Before the new quantities are legally enacted, all relevant standards must be adapted to the new quantities. This is more relevant at the international level, i.e., especially at ISO and IEC but at the European and national level, too.

2.3.3. Modification of dosemeters for new quantities

In general, it is expected that the necessary modification of dosemeters required for the proposed new quantities will be possible but not trivial and, therefore, requiring a significant amount of time, resources and budget. A need for research, especially for personal and area dosemeters for low energies and for low cost dosemeters, is identified. The market for dosemeters is small, so a strong need for supporting projects is expected to ensure the availability of dosemeters fulfilling the requirements at the time of the introduction of the new quantities.

2.3.4. Instruments for beta radiation

There is a need for research on survey instruments for beta radiation. Especially in the field of brachytherapy beta sources, but also in other fields of medicine, industry, and research.

2.3.5. Testing under Non-Charged Particle Equilibrium (Non-CPE)

Type testing and calibration in photon reference radiation fields will still be possible under Charged Particle Equilibrium (CPE), however, in realistic situations the electron component is unknown and it can be expected that in certain situations such as rather high energy photon fields CPE is not present leading to dosemeter use at Non-CPE conditions. Therefore, there is a need for research into workplace fields for electron, photon and neutron components separately.

2.4. Measuring devices for radiation protection in medical or industrial applications of ionizing radiation

In the area of measuring devices for radiation protection in medical or industrial applications of ionizing radiation, the gaps in metrology were presented in the following topics:

2.4.1. Pulsed radiation

Developments of suitable dose measuring devices for pulsed radiation and for low energies are needed.

2.4.2. Radon metrology

- There are only a limited number of suppliers of primary Radon gas standard: in Europe recently LNHB, METAS, PTB
- In Europe, only 2 NMIs (Austria, Ukraine) realize the relevant measured ^{222}Rn activity concentration in air.
- Accredited calibration laboratories suffer from a lack of interlaboratory comparisons on a similar metrological level (see Figure 1).

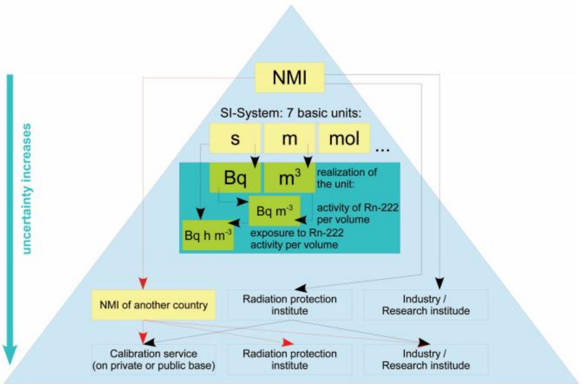

Figure 1. Traceability chain for the determination of an exposure to ^{222}Rn activity concentration. The basic units (s, m, mol) are realized by an NMI. The derived units (Bq, m^3) may be realized by an NMI but have to be at least traceable to an NMI. The length of the traceability chain influences the total uncertainty at the laboratory level [16].

2.4.3. Large variability of equipment

- At least minimum requirements (radiological, e.g., IEC and others e.g., for CE approval) with regard to the definition of "medical device" must be specified, especially in the area of activity and surface contamination measurement no IEC standards exist.
- End-user guidance is needed to assist in the use of the equipment and its calibration.

2.5. Measuring devices for environmental monitoring

In the area of measuring devices for environmental monitoring, apart from the topics investigated above and below (see 2.1 to 2.4 and 2.6 to 2.8), a special metrological gap was identified in the following topic:

2.5.1. Thoron (^{220}Rn) - underestimated in the big shadow of Radon?

The most important metrological gaps result from the legal requirement according to EU-BSS for exposure to radon and thoron in indoor areas, in workplaces, apartments and other buildings.

- No NMI realizes the activity concentration of ^{220}Rn in air or potential alpha energy-concentration of thoron progenies.
- A traceability for a thoron progeny atmosphere is yet not available (there are only some experiences of PTB, some recent activity at BfS and in the frame of the RadoNorm Project [17]).

2.6. Type testing

In the area of type testing, where the harmonization of national requirements with international standards (IEC and ISO) and radiation protection legislation is required, the metrological gaps in the following topics were identified:

2.6.1. Radon in regulation

- Harmonization of dose conversion factors is necessary in order to have a harmonized basis for the risk assessment. Furthermore, the mandatory application of ICRP 137 (Occupational Intakes of Radionuclides) is a significant step of harmonization. ICRP 137 is not a regulatory document and therefore non-mandatory for EU countries.
- Radon mitigation standards are missing, e.g., which procedures / strategies are to be used at which dose or concentration - standards only for measurements (devices / procedures).
- Different conversion coefficients for radon concentration are used for workers and the public. There is a gap for persons working from home instead of working in the office, which became more usual during the COVID-19 pandemic: Which coefficient should be applied?"
- Despite of radon being an important topic in the EU-BSS, the degree of awareness of radon, its risks, measurement methods and mitigation techniques varies tremendously in the EU member states.

2.6.2 Approval of radon instruments

Taking into account the metrological control for the approval of radon devices (type testing), the following gaps were identified:

2.6.2.1. Missing official measurement regulations

- No technical infrastructure (independent inspection bodies) exists for carrying out type tests specified in IEC 61577 *Radiation protection instrumentation - Radon and radon decay product measuring instruments*.
- In turn, no measuring instruments available on the market can pass the test to prove conformity with the requirements of IEC 61577.

2.6.2.2. Missing of standards for radon measurement and calibration

- There is no harmonised calibration procedure for radon measurements and calibration monitors (up to now: MetroRADON [5]). Related ISO standard is missing.

- ISO 11665 *Methodologies for initial and additional investigations of radon in buildings* does not take into account the latest state of the art of measurement instrumentation and the possibilities offered.
- Standards for the measurement of radon in soil activity concentration and radon exhalation rate are missing.

2.6.3. Standards for similar measuring tasks contain extremely different requirements

Harmonization is needed (see Figure 2): there are IEC standards for similar measuring tasks that contain different requirements that must be harmonized.

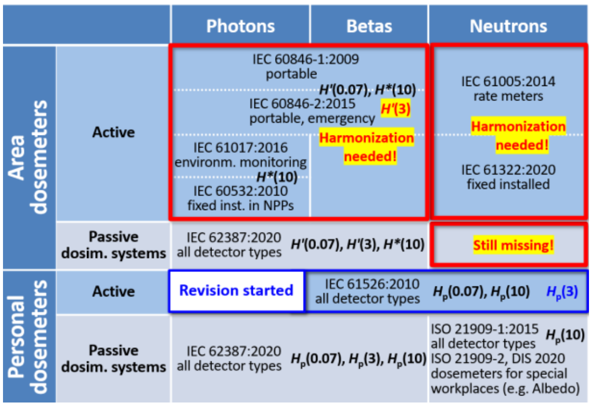

Figure 2. Standards for dosemeter and dosimetry systems [18]. Red rectangles show areas in need of harmonization.

2.7. Measurement data

In the area of harmonized handling, transmission, storage and availability of measurement data, gaps were identified in the following topics:

2.7.1. Emergency response

- Large amounts of data have to be processed in emergency situations. There are no training courses or tools for this. It should be possible to map pollution in food, the environment and water.
- Environmental transfer processes are important in emergency situations. Here is a large research need (e.g., short term exchange from earth to sea, but also long-term radioecological behavior).

2.7.2. Radon metrology

The lack of a qualified central information platform for radiation protection institutes and calibration services with their capabilities is identified as an important gap that can be remedied by the EMN.

2.8. Education and training needs

In the area of education and training needs, the metrology gaps in the subject area of metrological competence and training in radiological/nuclear emergency response were presented.

2.8.1. Metrological competence

Radiation protection metrology requires specific competences, which are, however, not well defined, and verification of the competence is not consistent. Therefore, there is a need to harmonize the qualification of radiation metrologists on a national/international level. This has posed the following challenges:

- What competences can be obtained at graduate level? How to get young people interested in radiation metrology? Are new approaches needed: video material, Youtube? How to organize practical training?
- How to get specific education/training on radiation metrology? In most countries it is not efficient to establish a national educational system specifically for radiation metrology. Therefore, European cooperation would be rational.
- It should be investigated what educational resources are already available and if they could be utilized more broadly. For example, existing educational material could be centrally collected.

2.8.2. Radiological emergency response

In this area, the following topics were brought into focus during the workshop.

- How to involve people with local knowledge e.g., farm managers, local representatives?
- Lack of competence and ability to respond to radiological and/or nuclear emergency situations, lack of staff, lack of resources (suitable equipment and suitably trained technicians and scientists to perform internationally accepted calibrations).
- The actual methods of dose assessment need to be harmonized. A combination of bioassay, biodosimetry, electron paramagnetic resonance and other retrospective dosimetry methods may be involved.
- For field monitoring during the emergency response, the detector/equipment response would need to be adjusted for reliable measurements when measuring high dose rate immersed in a radioactive plume, or when a high concentration of activity is deposited on surfaces. Normally the detector/equipment calibration does not consider those situations.
- There is a need for simulated fields for emergency environment monitoring and NORM measurements.

3. Summary and Conclusion

The most important metrological gaps in radiation protection and related areas are presented and discussed here. They were identified during the scientific stakeholders' workshop and opened a continuous and constructive dialogue on needs and gaps in radiation protection metrology. The topics were discussed in eight main areas: 1. Activity standards 2. Reference fields 3. New operational quantities in radiation protection 4. Measuring devices for radiation protection in medical or industrial applications of ionizing radiation 5. Measuring devices for environmental monitoring 6. Type testing 7. Measurement data 8. Education and training needs. The presentations are available under Ref. [4].

The European Metrology Network [3] for radiation protection interacts with innovative technological developments and has set itself the goal of being the central point of contact to cover the metrological needs in radiation protection and to find the metrological solutions to better protect European citizens against the dangers arising from exposure to ionizing radiation.

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