IAEA
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Technical Meeting on the Implications of the International Commission on Radiation Units and Measurements Report 95 on Operational Quantities for External Radiation Exposure

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White Paper

Introduction

In radiation protection, operational quantities are utilized to measure external exposure to ionizing radiation. These quantities are designed to provide conservative estimates of protection quantities. For occupational exposure, the personal dose equivalent, $H_p(10)$, can be used as an approximation of the effective dose from external exposure to penetrating radiation, as stated in Radiation Protection and Safety of Radiation Sources: International Basic Safety Standards, IAEA Safety Standards Series No. GSR Part 3. To address the known shortcomings in the current definitions, the International Commission on Radiation Units and Measurements (ICRU) Report 95, jointly published with the International Commission on Radiological Protection (ICRP) in 2020, recommends an alternative approach to these definitions, related to the same phantoms used to calculate protection quantities.

Recognizing the potential benefits of this alternative approach, it is essential to address important questions and concerns related to its implementation and implications to facilitate a decision on adoption and ensure continuous trust in the radiation protection system. Evidence of sufficient benefit for workers in general, and specifically for real workplaces, has not been proven. Open questions remain regarding a critical analysis of financial implications in Member States, practical application, and the impact of the new definitions of operational quantities on radiation protection practices.

Objectives of the Technical Meeting

The Technical Meeting aimed to discuss current knowledge and identify gaps regarding the impact of adopting the new operational quantities on radiation protection practices across various occupational fields. The meeting sought to raise awareness among relevant stakeholders, encouraging them to consider, present, and document the potential implications of these new operational quantities for occupational radiation protection. This includes aspects such as monitoring system redesign, calibration, standardization, regulation, radiation protection practices, and training needs. The meeting was held as part of the development of a dedicated IAEA Technical Document (IAEA-TECDOC).

Target Audience and Participation

All Member States and International Organizations, including labour organizations, legislators, licensees, qualified experts, manufacturers of monitoring systems, ionizing radiation metrology laboratories, individual and workplace monitoring services, standardization bodies, health authorities, and regulators, were represented at the meeting.

A total of 54 participants from 28 IAEA Member States and five International Organizations attended. Prior to the meeting, all participants were strongly encouraged to familiarize themselves with the content of ICRU Report 95 and related background information, such as:

- Inter-Agency Committee on Radiation Safety (IACRS) Information Overview,
- Bureau International des Poids et Mesures (BIPM) – Consultative Committee for Ionizing Radiation (CCRI) Webinar,
- European Radiation Dosimetry Group (EURADOS) Report 2022-02,
- EURADOS Webinar.

Abstracts submitted for presentation elaborated on the stakeholders' views regarding the potential implications of the operational quantities defined in ICRU Report 95, considering the following guiding questions:

- Are you aware of the possible impact of adopting the operational quantities defined in ICRU Report 95?
- Where do you see clear benefits from introducing these quantities?
- What do you consider the biggest challenge associated with implementation?
- Is the expected financial effort feasible?
- What might be the consequences of changed dose indications on work practices in your field?
- From your perspective, what are the main research needs?
- What is the required timeframe for potential implementation of these quantities in your field?
- How could professional networks assist the decision-making process?
- How do you see the role of the IAEA in that process?

This guidance for participants proved very effective, leading to more concise and clear presentations and discussions on relevant topics. All stakeholders were given the opportunity to present their opinions and discuss their questions for consideration in the TECDOC under development.

Structure of the Technical Meeting

Keynote lectures from International Organizations set the scene and emphasized the anticipated implications. Stakeholder presentations from the target audience were delivered to foster discussion and collect participants' input.

The topics discussed focused on the practical consequences of potentially implementing the new operational quantities defined in ICRU Report 95 in the following areas:

- **Monitoring Systems:** Dosimeter redesign and type testing, management of dose registries, and customer communication.
- **Calibration and Reference Fields:** Adaptation of relevant standards, radiation beam qualities, calibration procedures, and metrological traceability.
- **Radiation Protection Practices:** Perception and consequences of changed dose values and units, and the impact on dose assessment in inhomogeneous radiation fields.
- **Education and Training:** Provision of training for stakeholders, measures to avoid confusion among workers, qualified experts, and regulators.

Summary of Discussions

1 Limitations of ICRU Report 39/51 Operational Quantities

Inconsistencies arise between protection quantities and operational quantities due to their respective definitions:

1.1. The ambient dose equivalent, $H^*(10)$, was defined in the ICRU sphere, which does not resemble the reference anthropomorphic phantoms used to define the protection quantity effective dose, E. Similarly, the personal dose equivalent, $H_p(d)$, was defined at a specific depth in the human body, but the conversion coefficients are calculated using simple geometrical bodies such as slabs, cylinders, and rods.

1.2. Evaluating personal and ambient dose equivalents at a single, defined depth of 10 mm does not account for the geometrical complexity of the human body, with organs located at different depths. This complexity is explicitly considered in the definition and calculation of effective dose. For neutrons, this led to an overestimation of E below 1 MeV and a progressive underestimation of E at energies above 10 MeV.

1.3. At low photon energies ($E_p < 70$ keV), the choice of a 10 mm depth for ambient and personal dose equivalents resulted in a significant overestimation of effective dose. Additionally, constructing personal dosimeters and area monitoring instruments adapted to this energy range was challenging due to the high sensitivity required at low photon energies to represent the operational quantities.

1.4. For electrons with energy lower than 1 MeV, the quantities $H'(3)$ and $H_p(3)$ underestimated the equivalent dose to the lens of the eye, particularly when considering the radiation-sensitive part of the lens. The underestimation increased for oblique radiation incidences and lower energies.

1.5. The quality factor, $Q(L)$, and the radiation weighting factor, w_R, aim to provide a relative weight to different types of radiation, but they are based on different concepts of defining and measuring radiation effectiveness.

1.6. ICRU Reports 39 and 51 recommend replacing the system of operational quantities with a simpler scheme in which the ICRP/ICRU reference phantoms of the human body are used as the basis for calculations of both operational and protection quantities. This ensures that operational quantities provide measures of the protection quantities across all energy ranges.

1.7. There are now more sources of high-energy radiation than 30 years ago when the present operational quantities were developed. Examples of radiation fields considered in the new proposal include the use of high-energy proton, electron, and heavy-ion accelerators for radiotherapy, cyclotrons to produce radiopharmaceuticals, radiation fields near high-energy particle accelerators for research, and natural sources of high-energy radiation at aviation altitudes and in space.

The consequence of these inconsistencies has been poor or inaccurate estimations of the protection quantities for certain types of radiation and energies, and general differences between the conversion coefficients for protection and operational quantities.

2 Operational Quantities Recommended in ICRU Report 95

2.1. To address the need for an extended range of radiation types and energies over which operational quantities are defined, while maintaining a good approximation to protection quantities, a paradigm shift in the definition of operational quantities is necessary. ICRU Report 95 recommends redefining operational quantities as the products of radiometric or dosimetric quantities at a point in space or on the surface of the body, along with conversion coefficients related to protection quantity values.

2.2. The practical application of these operational quantities is feasible if conversion coefficients to an internationally agreed phantom exist. The ICRP and ICRU have now defined adult reference phantoms in ICRP Publication 110. These phantoms are used to define reference values of conversion coefficients to protection quantities and can be used to define the operational quantities. The recommended operational quantities aim to provide better estimations and assist in understanding radiological protection quantities.

2.3. ICRU Report 95 serves two main purposes: to introduce the general definitions of operational quantities for external radiation exposure, overcoming the limitations of the operational quantities defined in ICRU Report 39/51, and to publish specific sets of conversion coefficients that allow the calculation of operational quantities from physical quantities characterizing the radiation.

3 Technical and Regulatory Implications

General Implications

3.1. The new operational quantities represent a significant philosophical shift, as they are now tied to the definition of effective dose. This means that any revisions to the radiation weighting factor, tissue weighting factors, or phantoms could lead to new operational quantities or a loss of agreement between the new operational quantities and effective dose, potentially reducing conservatism.

3.2. The unification proposed by the ICRU may be compromised in the future if there is a change in phantoms. The current operational quantities are based on voxel phantoms, but if protection quantities were based on mesh phantoms in the future, this would result in a system based on two different phantoms. Although the numerical differences could be relatively small, this has not been proven yet.

3.3. There is currently no practical or theoretical demonstration that the new operational quantities are measurable, and they are not based on new scientific developments since the introduction of the current operational quantities.

3.4. The new operational quantities will necessitate dosimeter and instrument redesign, along with associated costs for research and development, testing, accreditation, and approval. Simple one-element dosimetry may become impossible, requiring more complex dosimeter and instrument designs and algorithms. Algorithms for estimating effective and eye-lens doses based on whole-body personal dosimeter readings will need to be re-evaluated.

3.5. The new operational quantities require a complete revision of standardization documents, inter alia published by the International Organization for Standardization (ISO) or the International Electrotechnical Commission (IEC).

3.6. Air crew dosimetry and patient dosimetry are outside the scope of ICRU Report 95, raising questions about how $Q(L)$ will be maintained for aircrew and the applicability of the new operational quantities to patient dosimetry.

3.7. There are unresolved technical issues for specific exposure situations, such as PA geometry and inhomogeneous exposures with or without protective garments.

3.8. The implementation timeline and roadmap are unclear, causing confusion among stakeholders.

3.9. There is likely to be a significant impact on harmonization, with three sets of quantities being used simultaneously for an extended period. Possible confusion may arise from the simultaneous use of different operational quantities, particularly given that they have the same units and similar names, H_p and $H_p(10)$. Explaining a change based on a concept that users already find difficult to understand, without a clear new scientific finding, practical improvement, or demonstrated technical feasibility, will be challenging.

3.10. The improvement to public health and safety has not been clearly demonstrated to offset the expected costs of implementing the new operational quantities. While costs are estimated to be high, no cost-benefit analysis has been conducted, which is necessary for a decision on the implementation of the new operational quantities. Communicating the motivation and justification for the change in operational quantities is challenging, and the impact on trust in the entire radiation protection system is controversial, with the benefits of the stability of the current system being overlooked.

Implications for Individual and Workplace Monitoring Services

3.11. If feasible, dosimeter designs or algorithms should be adapted to accurately assess the new operational quantities. If adaptation is not possible, new dosimetry systems should be purchased or developed. Additionally, uncertainties must be re-evaluated based on the new operational quantities.

3.12. To align with the new operational quantities, it is essential to type test and evaluate the performance of monitoring systems, considering the implications for the scope of accreditation.

3.13. Access to calibration laboratories capable of carrying out performance tests within the necessary energy range must be ensured.

3.14. A transition period, as defined by national regulatory authorities in Member States, should be planned for. This period may involve handling multiple operational quantities simultaneously, which could necessitate adapting databases to clearly record the operational quantities being estimated and managing different types of dosimeters concurrently. Consequently, this will likely increase the processing time and cost of services.

3.15. Increased support for users should be planned, including dissemination and outreach to customers. All Quality Management System (QMS) documents must be revised to reflect the new operational quantities. Furthermore, access to calibration laboratories capable of carrying out performance tests within the necessary energy range must be ensured.

3.16. Financial and human resources required to implement the new operational quantities must be considered. This includes costs for testing and adapting current systems, evaluating and/or replacing dosimetry systems, developing software and databases, additional irradiations, calibration, covering accreditation and approval costs, participating in additional intercomparison exercises, and providing additional customer support and training.

Gaps:

- It is not clear which dosimeter design will be able to satisfy the new OQs.
- It is not clear how the new ISO/IEC standards will be structured for the new OQs.
- Current intercomparison are insufficient to properly test the systems for the new OQs.

Implications for Manufacturers

3.17. If feasible, dosimeter or detector designs and algorithms should be adapted to accurately assess the new operational quantities. If adaptation is not possible, new dosimetry systems should be developed. Additionally, uncertainties must be re-evaluated based on the new operational quantities.

3.18. To align with the new operational quantities, it is essential to type test and evaluate the performance of monitoring systems, considering the implications for the scope of accreditation.

3.19. Access to calibration laboratories capable of type testing within the required energy range must be ensured.

3.20. Enhanced customer support should be planned, along with preparations for transition periods. This includes maintenance and support for existing systems, as well as the introduction and support of new systems. Dissemination and outreach to customers should be conducted to ensure a smooth transition.

3.21. Financial and human resources necessary to implement the new operational quantities must be considered. This includes costs for testing, adapting and/or redesigning dosimetry systems or instruments, software development, type testing, calibration, approval costs, and increased customer support and training. Finally,

Gaps:

- Manufacturers may not develop new solutions until a regulatory framework, well-defined timeline, and customer demand are established.

Implications for Metrology Laboratories

3.22. The realization of the new operational quantities might be easily adopted. The implications of adopting the new operational quantities may be more significant for laboratories using secondary standards.

3.23. If traceability is provided in terms of air kerma, there is likely to be no change in the calibration procedure. The calibration procedure is based on standard dosimetry phantoms defined by ISO and conversion coefficients from air kerma to operational quantities. It is important to note that ICRU Report 95 provides two sets of conversion coefficients, but only one set is applicable to the calibration of dosimeters.

3.24. It is important to consider a possible increase in demand for low-energy photon radiation beam qualities, as new systems will need to be tested.

3.25. Applicable quality management system documents should be revised accordingly.

3.26. A transition phase should be planned, during which there may be a demand for calibration in both the new and current operational quantities. This may require updating software to accommodate the new operational quantities.

Gaps:

- Possible need for metrology laboratories to develop new secondary standards to ensure traceability for the new OQs and for measurements in unknow radiation fields.
- Adoption of the new OQs will require additional training for radiation metrologists, including their capability to train users of the calibration services.

Implication for International Standardization Bodies

3.27. ISO and IEC will need to revise and adapt numerous standards to accommodate the new operational quantities. This task is challenging due to the large number of standards that need revision and the limited resources available.

3.28. There is limited knowledge on the technical feasibility of the new operational quantities, which complicates decision-making for ISO and IEC.

3.29. The performance of dosimeters and algorithms in complex mixed and realistic fields remains unknown, adding another layer of uncertainty to the implementation process.

3.30. There may be a need to relax acceptance limits in the standards until optimized dosimeters are developed. However, this relaxation could result in unacceptably increased uncertainty in dosimeter reports, potentially up to 500%.

Implications for International Organizations, Technical and Scientific Support Organizations

3.31. To facilitate the introduction of the new operational quantities, it is crucial to promote discussions on their benefits, costs, and impact, while raising awareness among stakeholders.

3.32. Assessing the dosimetry systems and detectors potentially affected by the adoption of new operational quantities is necessary to understand the implications. Organizing tailored intercomparison exercises before the transition period will help identify and address any issues.

3.33. Identifying research needs and promoting scientific research related to the potential adoption of new operational quantities will contribute to the development of effective solutions. Raising awareness about financial support for the preparation and implementation of the new operational quantities is also important. Finally, promoting coordinated actions and securing funding will support the activities required for the successful implementation of the new operational quantities.

3.34. Engaging with legislators, regulators, and government officials is essential to ensure a smooth transition.

3.35. Contributing to education through courses, publications, and the development of training and guidelines will help disseminate knowledge and best practices. Providing technical and expert support, along with training, will ensure that all parties are well-prepared.

Implications for Legislators and Regulators

3.36. To introduce the new operational quantities effectively, it is essential to assess the benefits, costs, and impacts at both national and regional levels.

3.37. Supporting and initiating intercomparison exercises tailored for the transition to the new operational quantities will help identify and address any potential issues.

3.38. Revising legislation and regulations is necessary to align with the new standards. Additionally, adapting national dose registries and planning for a transition period will ensure a smooth changeover.

3.39. Promoting and funding research on the topic will contribute to the development of effective solutions and best practices. Guaranteeing funding to support the transition, including for training programs on the new operational quantities, will ensure that all parties are well prepared, and that the implementation process is successful.

3.40. Developing a comprehensive roadmap and timeline for implementation will provide clear guidance for all stakeholders.

3.41. Preparing detailed guidelines for the implementation of the new operational quantities will further support this transition.

Implications for Licensees, Qualified Experts and Radiation Protection Officers

3.42. Ensuring that the dosimetry systems and instruments are adequate for specific exposure situations and fields will help maintain accuracy and reliability.

3.43. Planning for possible higher costs and investments associated with dosimetry, including the update or acquisition of instruments, software, and additional training, is also important.

3.44. Organizing targeted training for specific audiences will instil trust in the radiation protection system. Managing the transition to the new operational quantities involves informing staff, preparing instrumentation, and communicating the impact effectively.

3.45. It is important to continue promoting the optimization of protection principles and maintaining a strong safety culture throughout the transition process.

Implication for Occupationally Exposed Workers

3.46. Assessing the impact on work organization and practices is crucial. Based on this assessment, the Radiation Protection Programme should be adapted accordingly to maintain its effectiveness and relevance.

3.47. It is essential to adhere to the optimization of protection principles and not reduce any protection measures solely because dosimeter readings have decreased. Maintaining stringent protection measures ensures continued safety and compliance with regulatory standards.

3.48. To effectively implement the new operational quantities, it is important to engage in training opportunities to raise questions and address concerns. This proactive approach ensures that all stakeholders are well-informed and prepared for the changes.

3.49. International and national authorities, along with other professional bodies, continue to recognize the need for a gradual and prudent evaluation period to assess the impact and adoption of the new operational quantities. This approach aims to balance the costs of implementation with the benefits of a more coherent system of operational quantities that accurately represent protection quantities in measurements.

4 IAEA Technical Document

The proposed TECDOC aims to document identified gaps in current knowledge and discuss the implications of adopting the new operational quantities on radiation protection practices across various occupational fields. It will serve as a framework to promote discussion and encourage relevant stakeholders to consider and document the potential implications of these new operational quantities on the current radiation protection system. The TECDOC will provide recommendations on actions needed to collect essential information to support the decision-making process regarding the adoption of the new operational quantities.

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