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**Assessment of the impact of an introduction
of the ICRU95 dosimetric quantities
on radiological protection in Germany**

Recommendation by the Commission on Radiological Protection

Adopted at the 343rd meeting of the SSK on 16/17 July 2026

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**Bewertung der Auswirkungen einer Einführung der ICRU95 Dosismessgrößen
auf den Strahlenschutz in Deutschland**

Empfehlung der Strahlenschutzkommission

This translation is for informational purposes only, and is not a substitute for the official statement. The original version of the statement, published on www.ssk.de, is the only definitive and official version.

Preface

Radiological protection protects humans and the environment from the harmful effects of ionising and non-ionising radiation, without unduly restricting justified applications. The protection quantities defined by the International Commission on Radiological Protection (ICRP), in particular the effective dose and the organ equivalent dose, refer to exposures of organs, tissues, or the whole body by ionising radiation and are not directly measurable. For this reason, in practical area and personal dosimetry, operational quantities defined by the International Commission on Radiation Units and Measurements (ICRU) are used as measurable, usually conservative, surrogate quantities for monitoring. With ICRU Report 95 (ICRU 2020), new operational quantities have been proposed, which are more closely based on anthropomorphic reference phantoms and conversion coefficients to the effective dose and are intended to approximate this dose more accurately in certain exposure situations.

The introduction of these newly proposed operational quantities would have far-reaching impacts on radiation protection dosimetry and practical radiation protection. This would affect, among other things, the calibration and type testing of area and personal dosimeters, the traceability of measurements, the interpretation of measured values, as well as the adaptation of national and international regulations. In addition, measuring devices, calibration fields, evaluation algorithms, dosimetry protocols, and existing limit or reference values would have to be checked for consistency with the new system of quantities and, if necessary, adjusted. Comprehensive information and communication measures would also be required in parallel. The effort and associated costs for the transition need to be estimated, and a cost-benefit analysis should be conducted, considering international harmonisation. The Federal Ministry for the Environment, Climate Action, Nature Conservation and Nuclear Safety (BMUKN), therefore, commissioned the Commission on Radiological Protection (SSK) with a mandate on 17 April 2025 to evaluate the consequences from a scientific, practical, technical and economic perspective.

To prepare the present recommendation, the SSK set up a working group in June 2025, comprising the following members:

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Bonn, July 2026

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1 Introduction and advisory mandate

Radiological protection aims to protect humans and the environment from the harmful effects of ionising and non-ionising radiation, without unduly restricting justified and necessary applications. In 1977, so-called protection quantities were introduced for the purpose of protection against ionising radiation. These quantities are based on recommendations of the International Commission on Radiological Protection (ICRP) and serve to assess human exposure to radiation on the basis of radiobiological and epidemiological risk models. The effective dose and organ equivalent dose refer to exposures of organs, tissues, or the whole body by ionising radiation. They serve as a basis for assessing radiation exposure, estimating health risks, and legally defining limit values and protective measures, but cannot be measured directly in practice.

In routine area and personal dosimetry, operational quantities are used that are defined at specific points and tissue-equivalent depths. They enable the monitoring of radiation fields and individual exposures. The operational quantities are recommended by the International Commission on Radiation Units and Measurements (ICRU) and serve as practical, generally conservative surrogate values for the above-mentioned protection quantities, supporting compliance with requirements in radiological protection.

With ICRU Report 95 (ICRU 2020), the operational quantities for external exposures have been more closely aligned with the protection quantities of the ICRP. Whereas previous quantities, such as the ambient dose equivalent $H^*(10)$ and the personal dose equivalent $H_p(10)$ (for calibration and tests), were defined as dose equivalents in simplified tissue phantoms, the newly proposed quantities H^* and H_p are based on conversion coefficients derived from calculations of effective dose in anthropomorphic reference phantoms. Consequently, these new operational quantities are intended to more accurately approximate the effective dose, especially under conditions of specific energies, radiation types, and irradiation geometries that previously resulted in less precise estimations.

The possible introduction of the proposed system requires consideration of the advantages and disadvantages under the specific conditions in Germany, with reference to the objectives of radiological protection in scientific, technical, practical and economic terms. The assessment must primarily address the impact on radiological protection practice, including the availability of dosimeters, the costs of transition, potential for improvement, European and international harmonisation, the continuity of radiological protection registers, dose traceability, and public confidence in radiological protection.

The advisory mandate issued by the Federal Ministry for the Environment, Climate Action, Nature Conservation and Nuclear Safety (BMUKN) to the Commission on Radiological Protection on 17 April 2025 regarding this matter comprises the following questions:

- What are the scientific benefits of the new dosimetric quantities?
- What are the expected practical consequences of their introduction, and what additional value would the new quantities bring compared to those currently defined by law?
- What are the impacts of a possible introduction on dosimetry and the production of radiation protection dosimeters? How would requirements for dosimeters and their test and calibration conditions need to be adapted?
- Implementation in Germany would probably take several years. How stable are the new operational quantities over this period and beyond? To what extent do past and anticipated changes in the calculation of effective dose, resulting from new scientific findings, affect this stability?

- After introduction, a reduction in personal dosimeter readings by approximately 20 % is anticipated. How can these changes in measured values of personal dosimeters be transparently communicated to the public, and what further challenges arise for communication with the public and occupationally exposed persons? How can it be ensured that protective measures are not subsequently relaxed?
- What possible long-term consequences are expected if the new operational quantities are not introduced, and how should they be rated?

This recommendation is organised according to these questions.

2 Recommendation of the German Commission on Radiological Protection (SSK)

The German Commission on Radiological Protection (SSK) currently considers the expected benefit of introducing the proposed operational quantities as insufficient at this time, in relation to the anticipated effort and associated costs, to justify a prompt introduction. In the event of internationally coordinated harmonisation and a future implementation, a new assessment could yield a different result.

Based on current knowledge, only limited, practically relevant advantages are identified for operational radiological protection. At the same time, significant resource requirements would be expected. The modest advantage is mainly due to uncertainties in practical application in both the current and proposed systems – such as inappropriate dosimeter wearing positions, different calibration and evaluation methods, the presence of persons in inhomogeneous radiation fields, as well as potential inconsistencies and resulting application errors during a transition period (see Chapter 3).

Therefore, the SSK recommends:

- not to introduce the new operational quantities as defined in ICRU Report 95 (ICRU 2020) for the time being;
- further, in order to ensure the continued use of an internationally harmonised set of operational quantities in radiation protection dosimetry in the future, to working toward harmonisation at European and international levels. Such harmonisation should take into account the concerns regarding rapid implementation. In the longer term, scenarios both for introduction and for non-introduction are conceivable.

These recommendations are based on the following findings, which are explained in subsequent chapters in accordance with the terms of reference:

- The positive effects of the proposed quantity definitions on practical radiological protection and on maintaining the level of protection are considered minor in most aspects. There is currently no practical requirement in Germany for new operational quantities (cf. Section 3.4).
- The proposed definition of the operational quantities is extended to higher particle energies and additional particle types. However, corresponding radiation fields only occur in very rare cases for which already now alternative dose assessment methods are established (see Section 3.4).
- The new operational quantities can, in certain exposure scenarios, provide a better estimation of the effective dose and dose to the lens of the eye. This would reduce the current (conservative) overestimations, in principle allowing more targeted and potentially less restrictive radiological protection measures. However, such benefit is only robust if

the improved dosimetric representation in the specific application is not masked by other uncertainties of similar magnitude – notably anatomical deviations from reference voxel phantoms, inhomogeneous radiation fields, application/placement errors of doseimeters, and uncertainties in irradiation geometry. Since these influences are, at present, partly covered by conservative assumptions, the introduction of the new operational quantities does not automatically or generally create scope for relaxation in protective measures. On the other hand, specific adjustment of radiological protection measures is already possible within the current system, when justified by concrete exposure analyses.

- A more precise conceptual estimation of the protection quantities might, considering the aforementioned anatomical differences and uncertainties in practice, be of use for medical and epidemiological interpretations (see Section 3.2). However, uncertainties in dose interpretation may also arise if changes in measurement protocols are not accounted for in epidemiological studies.
- A relevant advantage of the new operational quantities would be an improved conceptual agreement of official dosimetric readings for ground-based occupational workers with those for flight personnel, as the latter are already calculated by similar concepts (see Section 3.4).
- Existing calibrations and energy/angle dependencies of doseimeters for photons, electrons, and neutrons could, in principle, be converted to the new operational quantities without further measurements. However, to meet quality standards for doseimeters measuring photon radiation below approximately 70 keV, technical redesigns are necessary (e.g. updated calculation algorithms, modified doseimeter design/detectors – see Section 3.6).
- As the new operational quantities consider different regions and organs within the body, rather than specific reference depths of 10 mm, 3 mm, or 0.07 mm, they can no longer be implemented using simple single-detector doseimeters.
- Revision of standards and regulations for doseimeter testing and calibration and updates to regulatory and administrative documents would be required.
- Based on experience with the implementation of the current operational quantities, a multi-year transitional phase can be expected in which various countries use different systems or old and new operational quantities in parallel, complicating the comparability of measurement results.
- European and international coordination is essential for an introduction since adoption in certain countries only would bring the disadvantages of insufficient harmonisation, discontinuities, and increased costs.
- Risk communication in the field of ionising radiation is quite complex already now. Therefore, it would demand significant effort due to the complicated subject matter (see Section 3.8). While the new operational quantities are conceptually closer to the protection quantities and thus may be easier to explain to newcomers in the field, a consistent communication strategy is required among all stakeholders (expert panels, authorities, measurement institutes, doseimeter manufacturers, radiation protection officers, occupationally exposed persons, and potentially the public). Particularly sensitive areas are those where dose readings are directly linked to personal risk or protection measures – i.e., personal dosimetry including lens dosimetry, emergency scenarios, and publicly perceived fields such as environmental monitoring or contaminated sites. Lack of understanding is especially likely if readings change because of the new operational quantities or because of changed calibration or evaluation methods, even though exposure has not changed. While the limits in the German radiological protection system are legally defined in terms of protection quantities, in practice the measured operational quantities are often used for classifying working areas and exposure scenarios. As the introduction of the new operational quantities decreases the degree of conservatism between operational and

protection quantities, there is a risk that these changes may be interpreted as a lowering or raising of the protection level or undermine the confidence in readings, limits, or official assessments.

3 Justification

3.1 Occupational radiation exposure and personal dosimetric monitoring

Legal provisions on radiological protection have established various dose limits to protect people from the harmful effects of ionising radiation. Besides the general population, particular attention is given to those exposed to radiation due to their professional activity. For these occupationally exposed persons, the maximum permissible effective dose per calendar year is set at 20 mSv. At the same time, § 8 (2) StrlSchG (StrlSchG 2017) requires that every exposure, even below the limit values, be kept as low as reasonably achievable (the minimisation principle ALARA).

In Germany, all persons who, in their working environment, are exposed to ionising radiation and can exceed set dose values per calendar year (e.g. 1 mSv effective dose due to their occupational activity), are subject to radiological protection monitoring (SSK 2018, StrlSchG 2017). This applies to persons in planned exposure situations (medicine, nuclear technology, general industry, research and teaching, flight personnel), in existing exposure situations (employees at workplaces with increased exposure due to radon or radioactive legacy sites), as well as in emergency exposure situations. As part of the monitoring, dose values for all affected employees are collected and recorded in the national dose register.

Overall, for workplaces associated with planned exposure situations, average occupational exposures are at a low level compared to the average natural radiation exposure of the population (approx. 2.1 mSv per person per year; BfS 2025). Over the past decades, a downward trend in average values has also been observed, indicating successful optimisation measures in the spirit of the minimisation principle.

According to Directive 2013/59/EURATOM (Euratom 2014), official personal dose monitoring is only required if a possible annual effective dose of 6 mSv may be reached. In Germany, this threshold has been set at 1 mSv. Of the approximately 400,000 persons under personal dose monitoring, less than 1 % of those monitored with dosimeters have a registered annual dose of 1 mSv or more. The situation is different for persons whose occupational dose is determined by calculation methods (e.g. aircrew). In these cases, 1 mSv per year is very frequently exceeded.¹

3.2 Operational Quantities in Radiation Protection: Current System and Proposals According to ICRU Report 95

3.2.1 Fundamental definitions

Before interaction takes place, ionising radiation is characterised by so-called radiation field quantities, such as particle fluence or energy fluence. The particle fluence is defined as the number of particles traversing a surface element divided by its area; as such, it is a property of the radiation field and not directly a dose quantity, which should be considered with respect to the interaction of radiation. For incident, outgoing, or scattered radiation, relevant partial

¹ The dose values for aircrew are calculated based on their flight routes. According to (BfS 2025), 11,598 individuals are reported with an effective dose ranging from 1 mSv to 1.5 mSv.

fluence quantities can be considered. Ionising radiation interacts differently with matter depending on the type and energy of the radiation. For photons, photoelectric effect, Compton scattering, and pair production dominate; for charged particles, Coulomb interactions; for neutrons, scattering and nuclear reactions. The importance and frequency of these processes are described by cross-sections and interaction coefficients. Dosimetric quantities such as kerma and absorbed dose are based on these, as they determine the energy transferred by ionising radiation to the material. For the evaluation of biological effects in radiation protection, it is also necessary to consider the type of radiation, exposure conditions, and the varying radiation sensitivity of different tissues.

3.2.2 Protection quantities and operational quantities

In practical radiation protection, both protection quantities and operational quantities are used. Protection quantities pertain to extended tissue regions (e.g., whole organs) or the entire body so as to quantify the risk of possible damage and to limit this risk through defined limits. However, these quantities generally cannot be measured directly but must be calculated based on measurements of other quantities. It is not possible to calibrate measuring devices directly in terms of the protection quantities. As measurable quantities for calculations, which can be determined with calibrated devices, so-called operational quantities are used, serving as estimators for the protection quantities. They are defined so that they can be determined by physical detector systems and serve as a conservative approximation for the dose influencing the human body. Thus, they bridge the gap between physically defined interaction quantities and practical dose monitoring.

The protection quantities defined by the ICRP in Publication 103 (ICRP 2007) are the effective dose² (effective whole-body dose), as well as the organ equivalent dose to the lens of the eye and to local skin³. These protection quantities are not measurable⁴.

The effective dose is the sum of the organ equivalent doses, weighted with factors w_T based on the radiation sensitivity of each organ. An organ equivalent dose is the sum of the absorbed doses in a tissue, weighted by radiation weighting factors (w_R) for the respective radiation types (photon, electron, proton, neutron, ion, and alpha particle radiation). The organ equivalent dose to the lens of the eye and local skin D are each the product of the mean **absorbed dose** $D_{T,R}$ to the lens of the eye or local skin and the **radiation weighting factor** w_R according to ICRP.

² A weighted average across the organs and tissues of the entire body to estimate or limit the risk of cancer (stochastic effect).

³ In practical radiation protection, the equivalent dose to the lens of the eye and to local skin are particularly relevant; in special cases, however, the equivalent dose to the hands, forearms, feet, and ankles is also relevant.

⁴ Averaged over the entire lens of the eye or over 1 cm² of skin to estimate or limit damage such as cataracts of the eye lens or erythema of the skin above a threshold value (deterministic effect).

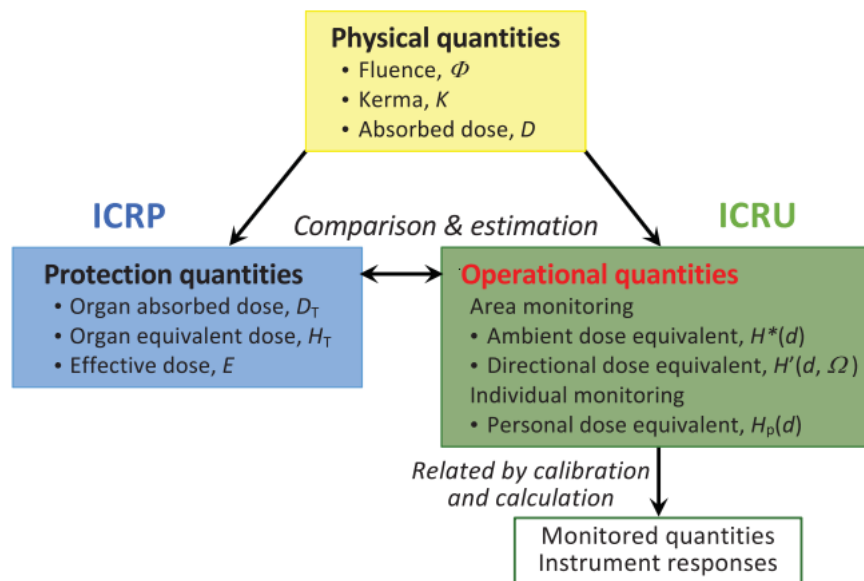


Figure 1: Overview of dose quantities in radiation protection (see explanations of the relationships in the text) (ICRU 2020)

For the non-instrumental determination of protection quantities, simulation calculations are performed based on fluence, using tissue-equivalent virtual phantoms (such as voxel phantoms for personal dose). For the determination of the organ equivalent dose to the lens of the eye, an eye lens model is used, and for the local skin dose, a tissue-equivalent cube is employed. This is done considering the respective radiation fields and their interactions. The composition and dimensions of the reference persons used for the calculation are defined by ICRP Publication 103 (ICRP 2007). The corresponding reference phantoms for adults are described in ICRP Publication 110 (ICRP 2009), and for paediatric phantoms in ICRP Publication 143 (ICRP 2020a).

3.2.3 Operational quantities currently in use

The currently valid operational quantities were developed in the 1980s (ICRU Reports 33, 51, and 57, ICRU 1980, ICRU 1993, ICRU 1998) and introduced in Germany in the early 2000s. After a transition period of several years, they became widely accepted and proven in practice. The current system uses simplified phantoms, such as sphere, slab, rod, or cylinder, to transform physical basic quantities via tabulated conversion coefficients into operational quantities. These coefficients are calculated for defined radiation types, energies, and directions of incidence. For example, air kerma for photons, fluence for neutrons, and absorbed dose or fluence for electrons are converted into the operational quantities of area dosimetry ($H^*(10)$, $H'(3;\Omega)$, $H'(0.07;\Omega)$) and personal dosimetry ($H_p(10)$, $H_p(3)$, $H_p(0.07)$). The area dose is the **dose equivalent H** measured at a specific point. A distinction is made between the dose resulting from penetrating radiation, i.e., the ambient dose equivalent $H^*(10)$, and that from weakly penetration radiation, i.e., the directional dose equivalent $H'(0.07)$. The personal dose is the **measured dose equivalent** at the location of the body representative for the respective **exposure** situation. The depth values 10 mm, 3 mm, and 0.07 mm refer to the respective reference depths in the tissue-equivalent phantom and represent whole-body, lens, or skin exposures, respectively.

The dose quantities employed as protection or operational quantities, with the unit Sievert (Sv), are absorbed doses weighted for their radiation biological effectiveness. For the effective dose, the different radiosensitivity of individual organs/tissues is also included.⁵

While effective dose primarily addresses stochastic risks, deterministic tissue reactions with a threshold dose are considered using organ or tissue equivalent doses and specific limits, e.g., for the lens of the eye, local skin, and extremities.

Protection measures are established based on corresponding dose limits (SSK 2018). The currently used system intentionally employs simplifications, e.g., regarding phantoms, in order to provide generally applicable dose quantities. Moreover, a conservative approach is chosen so that the measured dose values tend to overestimate (rather than underestimate) the real values of the protection quantities, to ensure that the actual radiation risk does not exceed the estimated risk, even under various conditions. This, at least partially, accounts for deviations of actual human anatomies from the phantoms as well as uncertainties in the use of dosimeters. These uncertainties are, e.g., caused by varying dosimeter wearing positions on the body or under/over (protective) clothing, the presence of inhomogeneous radiation fields, the generally large uncertainty of dose determination (by a factor of 1.5, ICRP 1997)⁶ or more, but also application errors such as incorrect orientation of the dosimeter.

3.2.4 New operational quantities according to the ICRU proposal

In 2020, the ICRU proposed a new system of operational quantities (ICRU 2020) aimed at estimating the protection quantities more accurately and consistently through new definitions. Motivations for recommending the new operational quantities introduced in ICRU Report 95 (ICRU 2020) included the desire for more precise representation of the protection quantities, extension of the definition to higher energies and additional radiation types, and conceptual harmonisation and simplification.

Their introduction aims to change, among others, the following aspects of the current system:

- **Different phantoms:** The phantoms⁷ used for the current operational quantities differ from those used for the protection quantities, and different ones are used for area and personal dosimetry. In area dosimetry, the so-called ICRU sphere is used, in personal dosimetry e.g. rod, cylinder, or slab phantom.
- **Simplified geometries:** The current definitions for operational quantities in area and personal dosimetry refer to single points in highly simplified phantoms. This leads to over- or underestimates of effective dose, depending on particle type and energy.
- **Different model assumptions for radiation effects:** The quality factor $Q(L)$ used for the operational quantities and the radiation and tissue weighting factors w_R and w_T used for the protection quantities are based on different models and are not directly comparable: $Q(L)$ is based on the varying biological effectiveness with regard to stochastic radiation damage depending on the linear energy transfer of the ionising

⁵ The absorbed dose itself is given in the unit gray ($1 \text{ Gy} = 1 \text{ J kg}^{-1}$).

⁶ The uncertainty of the actual dose measurement with today's personal dosimeters is often lower and can be estimated at a maximum of 30 % (DIN IEC/TR 62461:2015-07)

⁷ Phantoms for current operational quantities: sphere for ambient dose equivalent; slab, pillar, cylinder, and rod for trunk, extremity, head, and finger. Phantoms for protection quantities: mathematical/human-like (voxel, eye, skin).

radiation at the point of measurement. Therefore, this factor is described using different mathematical formulations for three regions of linear energy transfer. The factors w_R and w_T are also based on different biological mechanisms with respect to stochastic radiation damage. However, unlike $Q(L)$, this assessment is not based on the local LET, but rather on an estimate of the average relative biological effectiveness depending on the radiation type or, for neutrons, on their energy. The tissue weighting factors w_T additionally take into account, besides the probability of stochastic effects in a given organ or tissue, aspects of the severity of harm, in particular lethality, reduction in life expectancy, and non-lethal health impairments. The differing definitions make it more difficult to interpret the measurement results in terms of biological effect.

- **Limited applicability for higher energies and other radiation types:** The current operational quantities consider photons and electrons up to 10 MeV, and neutrons up to 200 MeV for $H^*(10)$ and 20 MeV for $H_p(10)$. For higher energies and other particle types such as protons, alpha particles, or additional particles relevant to space radiation they are not defined.

In the current system, the effective dose in various energy ranges and for different radiation types is sometimes over- or underestimated by the operational quantities. Most notably, this is true for photons below 70 keV, where the effective dose may be overestimated by up to a factor of five by the current operational quantities (in real, usually wide energy spectrum fields up to a factor of three; see Figure 2).

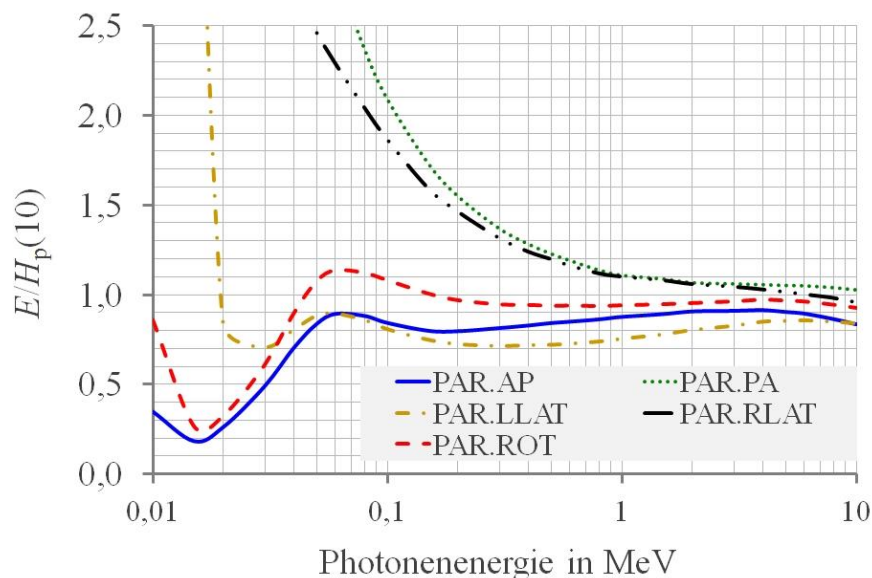


Figure 2: Ratio of effective dose E to personal dose equivalent $H_p(10)$, calculated in an anthropomorphic phantom at the left chest, (conversion factor f_k / f_p) as a function of photon energy and irradiation geometries PAR.AP (parallel beam geometry anterior-posterior), PAR.PA (posterior-anterior), PAR.LLAT (left-lateral), PAR.RLAT (right-lateral), PAR.ROT (rotational symmetry) (ICRP 2010, Zankl 1999, SSK 2016).

The ICRU now proposes the new operational quantities H^* (ambient dose) and H_p (personal dose). They are calculated from the particle fluence at the measurement position and conversion coefficients h :

$$H = \phi \cdot h$$

(instead of previously $H = Q(L) \cdot D$ based on the absorbed dose D in tissue)

These conversion coefficients are based on the same phantoms as used to calculate the protection quantities. The new operational quantities are thus conceptually very close to the protection quantities. By taking into account the entire (voxel) phantom, rather than a fixed depth definition of 10 mm, the proposed quantities more precisely represent the protection quantities in different exposure situations. The new approach enables, in principle, simpler extension to higher energies and other particle types, as well as more targeted radiation protection measures due to the improved dose estimation. Moreover, the conceptual approach is similar to that already used for evaluating dose to aircrew personnel.

The new operational quantities H^* and H_p are (whole-body) doses that take radiobiological weighting factors into account.

For estimation of the dose to the lens of the eye and local skin, the quantities $D'_{\text{lens}}(\Omega)$ and $D'_{\text{local skin}}(\Omega)$ (area dose), and $D_{p \text{ lens}}$ and $D_{p \text{ local skin}}$ (personal dose) are proposed. They are calculated from the fluence ϕ and an appropriate conversion coefficient d (d'_{lens} , $d'_{\text{local skin}}$, $d_{p, \text{lens}}$, $d_{p, \text{local skin}}$):

$$D = \phi \cdot d$$

In contrast to earlier definitions, also here no fixed depth is assumed for these organs. Area and personal dose are no longer defined differently for these quantities. D_{lens} and $D_{\text{local skin}}$, however, unlike in the current system, are absorbed doses without radiobiological weighting, thus measured in gray (Gy).

Table 1 provides a summary comparison of the current and proposed radiation protection quantities.

Table 1: Comparison of current and proposed radiation protection operational quantities (ICRU 1993, ICRU 1998, DIN 6814-3:2016-08, ICRU 2020)

	Operational quantities according to the current system (ICRU Reports 51 and 57 / DIN 6814-3)	Proposed quantities according to ICRU Report 95
Operational quantities for area dosimetry		
Whole body	$H^*(10)$ ambient dose equivalent	H^* ambient dose
Eye lens	$H'(3;\Omega)$ directional dose equivalent at 3 mm depth	$D'_{\text{lens}}(\Omega)$ directional absorbed dose in the eye lens
Skin	$H'(0.07;\Omega)$ directional dose equivalent at 0.07 mm depth	$D'_{\text{local skin}}(\Omega)$ directional absorbed dose in local skin
Operational quantities for personal dosimetry		
Whole body	$H_p(10)$ personal dose equivalent at 10 mm depth	H_p personal dose
Eye lens	$H_p(3)$ personal dose equivalent at 3 mm depth	$D_{p \text{ lens}}$ personal absorbed dose in the lens of the eye
Skin	$H_p(0,07)$ personal dose equivalent at 0.07 mm depth	$D_{p \text{ local skin}}$ personal absorbed dose in local skin

In Figure 3, as an example for photon radiation, the change of conversion coefficients from physical dose values (in this case total air kerma) the current operational quantity $h_{pK}(10) = H_p(10)/K_a$ to the new $h_{pK} = H_p/K_a$ is shown as a ratio of conversion coefficients.

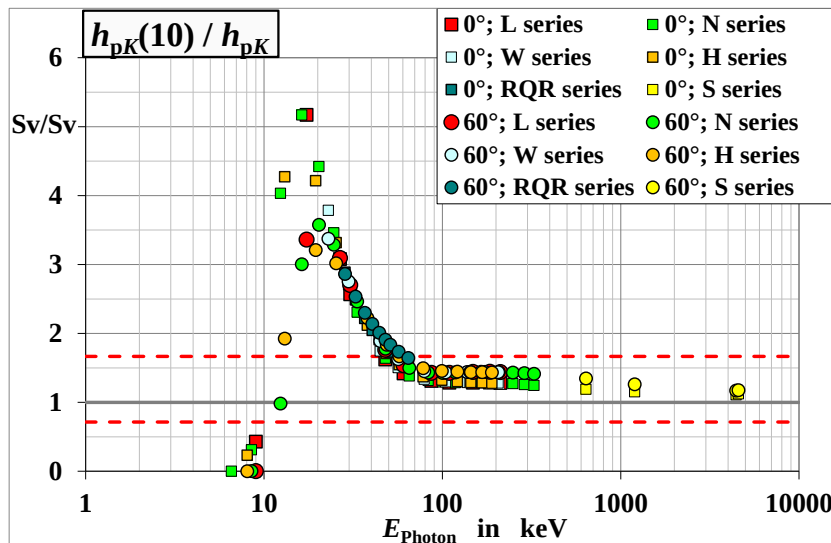


Figure 3: Ratio of the conversion coefficients for the current operational quantities and the newly proposed ones for the personal dose (Behrens and Otto 2022) as a function of the mean photon energy of X-ray qualities (according to ISO 4037-1:2019-01) from the series L: heavily filtered; N: strongly filtered; W: moderately filtered; H: weakly filtered and according to (DIN EN 61267:2009-01) from the series RQR of diagnostic radiation qualities, and for angles of radiation incidence of 0° and 60° (rotation of the respective phantom about its vertical axis).

The reason for this change is that the current operational quantities are defined at a fixed tissue depth of 10 mm while internal organs lie deeper and low-energy photons are attenuated before reaching the organs. The current operational quantities thus significantly overestimate organ equivalent doses at low photon energies. This is avoided with the new ICRU 95 concept (ICRU 2020). As a result, dosimeters for measuring H_p and H^* according to the new definitions would have to be less sensitive for low photon energies compared to existing $H_p(10)$ and $H^*(10)$ devices and would, for the same exposure, generally display lower readings than dosimeters for the current quantities.⁸

The dose to the lens due to beta radiation would be determined much more accurately by the new operational quantities than by the present quantities which can over- or underestimate the protection quantity by up to a factor of 5 (due to the presently fixed phantom definition depth of 3 mm versus the actual extent of the lens) (see Figure 4).

⁸ Low photon energies occur particularly in mammographic imaging. In this case, larger deviations between the current and the newly proposed operational quantities may arise, which would remain significant even when taking into account the uncertainties for potentially affected occupationally exposed persons due to the dosimeter wearing position and individual exposure scenarios. However, this effect can generally be neglected when determining the personal dose for occupationally exposed individuals, given the typical characteristics of the radiation fields and the existing radiation protection measures.

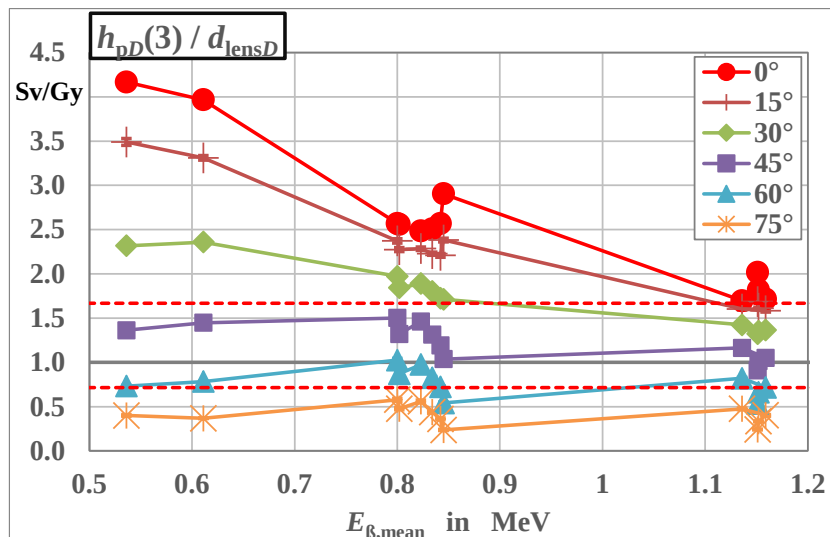


Figure 4: Ratio of the conversion coefficients for the currently used quantity to estimate the dose to the lens of the eye $H_p(3)$ and the corresponding newly proposed quantity D_{lens} , based on the dose in the entire lens (Behrens 2021)), for angles of radiation incidence from 0° to 75° (rotation of the respective phantom about its vertical axis).

For local skin dosimetry, the effects of the new quantities are likely small, as $H_p(0.07)$ and $D_{\text{local skin}}$ are numerically close owing to similar depths and calculation phantoms. Existing $H_p(0.07)$ dosimeters will often adequately approximate $D_{\text{local skin}}$ under many practical circumstances, so the benefit of switching in the beta radiation region is primarily to be weighed against the effort needed for calibration, terminology, and standardisation (Bossin et al. 2024).

Neutrons differ from photons and electrons both in terms of biological effectiveness and energy-dependent penetration depth. Assuming that the new operational quantities based on the full voxel phantoms and biological effectiveness give a more precise depiction of effective dose, comparison of conversion coefficients shows that, in the current system, neutron radiation effects are overestimated for thermal energies and increasingly underestimated above 40 MeV (Al Qaod et al. 2023). There are also differences for varying angles of incidence. This is related to the currently fixed phantom depth definition of 10 mm, which, for neutrons, is of limited suitability (see Figure 5).

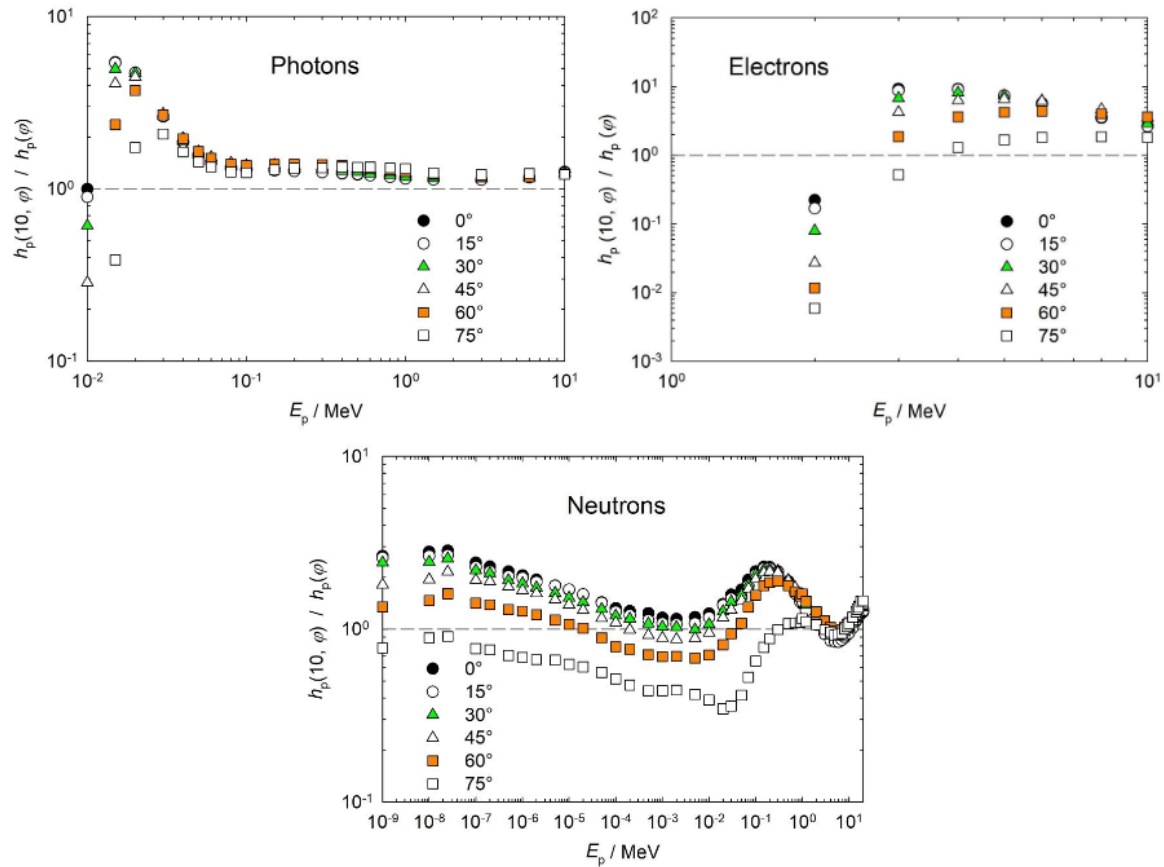


Figure 5: Ratio $H_p(10)$ to H_p as a function of energy and angle of incidence for photons, electrons, and neutrons (EURADOS 2022)

- Based on the proposed definitions of the new quantities, the following aspects must be considered:
- It must be examined whether, and under what conditions, the improved conceptual alignment with the protection quantities also leads to improved accuracy in the dose values measured in practice.
- It must be examined to what extent the expected benefits – such as more targeted radiation protection measures – require the formal introduction of the new dosimetric quantities, or whether comparable improvements could also be achieved through supplementary corrections and guidelines within the existing system.
- Do situations arise in practice where radiation protection measures are not reasonably proportionate to the actual risk? And would the new quantities resolve this problem in such situations?

3.3 Evaluation of the scientific benefit of the new dosimetric quantities

The proposed new quantities are, as described above, calculated from particle fluences at the measurement location and conversion coefficients that use the same virtual extended phantoms as for the protection quantities. This is the key distinction from the currently valid quantities, which are defined at certain, fixed depths in simple phantoms. As a result, the measured new area and personal doses are conceptually more precise in estimating the protection quantities.

Regardless of the primary practical objectives of radiological protection, the extensive recording of dose values can also be used for scientific purposes.

If the greater precision described above could be realised in practice, a scientific benefit could be derived because the measured values would allow for a more accurate estimate of protection quantities. This benefit would be particularly important in contexts where statistical analyses of more accurate dose values for large numbers of individuals with varying exposure scenarios are relevant, such as in epidemiological studies.

On the other hand, dose quantities in radiological protection, which are summarising biological effectiveness factors across wide energy ranges, are only suitable to a limited extent for detailed investigations into the causal relationship of ionising radiation damage. For this, absorbed dose in single organs or body regions is often preferred and related to cell biological effects or health effects.

Because the new conversion coefficients are directly linked to biologically motivated weighting factors and human anatomy, results of dosimetric measurements according to the newly proposed quantities could in future be interpreted more accurately.

Since the epidemiological foundations of radiological protection assessment were in some cases based on the old quantity system, an evaluation based on the new quantities would either require new data collection or a comprehensive retrospective reconstruction of earlier exposures in the new quantities.

Due to the lack of necessity for the assumption of secondary electron equilibrium⁹, the proposed quantities can be applied to much greater energy ranges and further particle types than before, representing an advantage for scientific applications.

However, since only a few exposure situations with sufficiently large and homogeneous cohorts exist in these areas, it is not expected that simply by the larger range of applicability for measurements statistically robust new findings for radiological protection will quickly emerge.

The use of absorbed dose instead of equivalent dose for measuring the lens and local skin dose would be advantageous, as their corresponding limits target tissue reactions. This change is positively assessed, since the ICRP already recommends absorbed dose or RBE-weighted absorbed dose for tissue reactions (ICRP 2012) and will presumably define the relevant protection quantities for lens and skin as absorbed dose in the future.

If corresponding dosimeters for the lens dose were developed in the future, there would be a strictly scientific benefit in that more precise dosimetry of the lens could enable more accurate epidemiological studies on cataract development from exposure to ionising radiation.

The new concept opens perspectives for more personalised dosimetry. With more detailed phantoms, it would in future be possible, if desired, to consider gender-specific differences, for example with separate conversion coefficients for women and men. Dosimeters or calculation models for pregnant persons and age-related factors could also be considered. As scientific topics these approaches may be of interest, but further differentiation is not obvious, although these topics are under current research (ICRP 2023).

⁹ Secondary electron equilibrium (SEE) or, generally, charged particle equilibrium (CPE), is established at increasing depths within matter as the photon energy increases (e.g. for gamma radiation from the decay of ¹³⁷Cs at 662 keV at a depth of 2 mm in Plexiglas, whereas at approx. 7 MeV, it is only established at a depth of approx. 25 mm in Plexiglas).

The large variation in human anatomy, practical measurement uncertainties, and over- or underestimations of dose due to simplified phantoms were known when the current quantities were introduced. The quantities $H_p(10)$ and $H^*(10)$ were defined conservatively for this reason (Alberts et al. 1994).

Studies using individual voxel phantoms show that organ and effective doses can vary considerably even for the same physical process or reference phantom-based dose estimate. The differences are especially pronounced for low-energy photons, superficial organs, and highly directional exposures (Lee et al. 2024). In X-ray diagnostics, differences between real patients and standard phantoms have been described as relevant sources of uncertainty, with deviations of up to ± 50 % for individual organs and ± 20 % for effective dose (Kelaranta et al. 2016). Thus, even with closer alignment of new operational quantities to the protection quantities, significant uncertainties due to individual anatomy, exposure geometry, and application practice remain.

In summary, according to the assessment of the SSK, the scientific benefit does not justify, in view of the associated effort, measurement uncertainties in occupational dosimetry and expected discontinuities, the introduction of the proposed quantities. Moreover, in epidemiological studies, absorbed dose continues to be preferred.

3.4 Impact on practical radiation protection

Comparability of personal dosimetric assessments within Germany, and also with European neighboring countries, is essential for evaluating different protection concepts and for enabling subsequent optimisation. However, it must be stated that, due to the different concepts for individual monitoring, comparability in practice is already hardly achievable. In Germany, e.g., the whole-body dose is measured at a location on the torso under possible protective clothing. In numerous other countries, the measurement is taken above the protective clothing, sometimes involving double dosimetry at two locations. It is unclear how to account for the body regions not covered by protective clothing, especially since there are different types of protective clothing. If the measurement is performed above protective clothing, the problem reverses, as the protective effectiveness of the clothing would then need to be factored into the calculation of the effective dose. The results arising from these distinct application concepts are therefore only difficult to compare.

Generally, the issue of estimating whole-body dose with a single-point measurement remains unresolved, particularly if the monitored person spends time in strongly inhomogeneous fields, as is the case during radiological interventions or when handling radionuclides. Additionally, the measurement of pulsed radiation requires specialised instrumentation. The introduction of the new operational quantities will hardly change this aspect: the new quantities estimate the whole-body dose based on assumptions concerning body constitution, notably the size and weight of the reference voxel phantoms. However, as already mentioned in section 3.3, actual human body proportions vary significantly and sometimes systematically deviate from those assumed in the reference voxel phantoms.

Because actual organ and body doses for the same nominal exposure depend substantially on individual anatomy – especially the thickness of the irradiated tissue volume, organ position, and tissue composition – differences between reference phantoms and real individuals can substantially affect dose assessment. This has been demonstrated for chest radiography with patient-thickness-dependent conversion coefficients and for patient-specific whole-body models in CT dosimetry (Cho 2017, Frenzel et al. 2014). These studies mainly stem from patient dosimetry and therefore cannot be directly quantified for occupational exposures. Nonetheless, they show that individual anatomy, body thickness, and organ position influence the connection

between a nominal dose quantity and the actual organ or body dose. In occupational radiological protection, additional factors play a role, particularly dosimeter position, body posture, shielding, exposure geometry, and inhomogeneous radiation fields. Although these studies do not offer concrete correction factors for occupationally exposed persons, they support the view that introducing new operational quantities does not eliminate individual and practical uncertainties.

As outlined in section 3.3, the newly proposed concept for determining operational quantities could, in principle, allow for individualised personal dosimetry. However, this potential for personalisation is not decisive for practical radiation protection. For pregnant individuals, there are already clear, conservative regulations; children and adolescents are not generally relevant in occupational radiation protection, except for underage trainees. Gender-specific differences must be considered relative to the generally broad anatomical and physiological variability among women and men. The current system already accounts for such variabilities and application uncertainties using deliberately conservative conversion coefficients and limits to ensure adequate protection for all monitored persons.

The proposed concept for operational quantities is, in principle, more consistent and precise. However, due to uncertainties during practical implementation in widely varying exposure situations, this advantage is, according to the assessment of the SSK, mostly lost. These uncertainties include the transferability of reference-phantom-based conversion coefficients to individuals, the representativeness of dosimeter positioning in inhomogeneous fields, the practical assessment of partial-body exposures (such as lens, skin, and extremities), and possible application or wearing errors. Additional sources of uncertainty may include different radiation qualities, energies, and incident directions, as well as mixed radiation fields. This means it is not assured that the conceptually higher precision of the new operational quantities will translate into an equivalently improved evaluation of exposure in operational practice.

The new operational quantities H_p and H^* would also weaken the previously deliberately conservative character of operational quantities, since they more closely approximate the effective dose. While this offers the potential for relaxation of radiological protection measures – with attendant economic advantages and potentially greater acceptance of truly necessary protection measures – it could, however, also lead to uncertainty and thus to a loss of confidence among occupationally exposed individuals and the public.

Photons play the largest role in practical radiological protection, especially in medical diagnostics and treatment, as well as in many other applications, such as materials testing, food irradiation and inspection, baggage screening, and process control (for example, thickness regulation during rolling operations). In environmental monitoring and radiological emergency protection, photons are the dominant type of radiation. Thus, particular weight must be given to how the introduction of the new operational quantities would affect photon measurement.

Electrons primarily play a role in practical radiation protection in the form of beta radiation up to a few MeV, since higher-energy electrons (for example, from accelerators) are rare in workplace settings. For beta emitters, the operational quantities for lens of the eye and local skin are of particular concern, as beta radiation typically does not significantly contribute to the effective dose due to its relatively low penetration depth.

For eye lens and, in particular, finger ring dosimeters, the representativity of the measurement position remains a central problem. This is especially true for nuclear medicine, as hand exposure can be spatially highly inhomogeneous, and the peak local skin dose often does not occur at the location where the dosimeter is worn. The highest doses are seen, depending on the work, at the fingertip, index finger, or thumb, while finger ring dosimeters are typically worn at the base of the finger. As a result, the dose measured at the finger base may significantly under-

estimate the peak local skin dose. Sans Merce et al. (2011) show that the positioning of the extremity dosimeter is crucial for correctly estimating the maximum skin dose. In nuclear medicine, ratios between fingertip and ring dosimeter positions in the range of about 1.4 to 7 have been reported (Sans Merce et al. 2011, Kollaard et al. 2021). For routine monitoring, it has therefore been proposed to wear the finger ring dosimeter at the base of the index finger of the non-dominant hand with the detector facing the palm, and to multiply the measured value by a factor of 6 to estimate the maximum local skin dose (Carnicer et al. 2011; BfS 2013, Kemerink et al. 2012). There are also reduced reporting thresholds from which the radiation protection officer must check whether and which factors are to be considered in the case of a substitute dose.

This illustrates that not only the choice of operational quantity, but also the practical measurement position exerts considerable influence over the significance of dosimetry results. This affects both potential scientific studies and the assessment and optimisation of practical radiation protection.

In lens dosimetry, too, the measured dose can deviate significantly from the true lens dose depending on dosimeter position, asymmetrical eye exposure, dependence on protective eyewear, and exposure geometry (Hirakawa et al. 2022, Haga et al. 2017). Changing the operational quantity does not solve the measurement position problem.

The conceptual differences between ICRU Report 57 (ICRU 1998) and ICRU Report 95 (ICRU 2020) are smaller for neutrons than for photons and electrons, as fluence has already been used as the physical basis quantity in neutron dosimetry. Thus, using H^* instead of $H^*(10)$ and H_p instead of $H_p(10)$ is the more consistent concept for neutrons.

However, the changes expected from using H^* and H_p are generally smaller than the systematic uncertainties of current practical neutron dosimetry. Existing dosimeter types can only roughly replicate the energy and angle dependencies of current operational quantities. Since the proposed operational quantities do not introduce any changes in the challenging measurement of neutron radiation (including consideration of energy and angle distribution), no significant advantages for neutron dosimetry are apparent.

With respect to the higher energy ranges and radiation types for which the new operational quantities are suitable, for practical radiation protection it can be summarised that radiation types other than photons, electrons, and neutrons or energies above 10 MeV for photons and electrons and 200 MeV for neutrons, seldom play a relevant role in practice. Medical linear accelerators typically operate with nominal photon energies up to about 15 MeV and electron energies up to about 21 MeV. However, for operational radiation protection outside of the primary beam, it is often not the maximal primary energy, but rather the stray and leakage radiation quality that is decisive. Patient and room scatter radiation show a considerably softer spectrum than the primary beam, so the prevalent, operationally relevant photon component generally lies below the nominal maximum energy of 10 MeV of the current quantities. Still, it must be noted that with high-energy photon beams – particularly with peak energies above about 10 MeV – accelerator-head leakage radiation, photoneutrons, and activation products can also become relevant for radiation protection.

Higher energies and additional radiation types are only present in a few environments, such as high-energy accelerators, at high altitudes, or in space. In aviation and space, the dose is already determined directly based on the calculation of protection quantities. On the basis of the new concept, this is a real advantage, as exposure values for occupationally exposed persons would be more consistent. Whether this has practical radiation protection consequences – except for better explainability – is questionable.

If, however, instead of a single point measurement, the whole exposure scenario (e.g., through video and AI-assisted personal dosimetry or "online dosimetry") were considered (EURADOS 2022, ICRP 2021a), the potential of the new definition of operational quantities could be exploited. However, online dosimetry is still under development and will foreseeable only be possible in a few, well-defined environments like operating rooms or some nuclear installations. Such methodology is currently being further developed in European research projects.

Because the new operational quantities correspond more accurately to the protection quantities, they may be advantageous in legal questions concerning radiological harm or for medical applications.

In conclusion, according to the assessment of the SSK, it is currently not evident that practical radiological protection would significantly benefit from the introduction of the new dose quantities. Instead, some adverse effects may occur, especially discontinuities in dose registers and long-term statistics as values before and after the changeover are not directly comparable. There is also the risk that lower measurement values – due to changed quantities or calibrations – could be incorrectly interpreted as a real reduction in exposure or as higher safety levels. This could lead to decreased care in work processes, lower acceptance for conservative protection measures, or to insufficiently dimensioned shielding and monitoring concepts. Such risks are especially critical if not remedied by clear transitional rules, parallel evaluations, and targeted communication efforts. Against this background, there is currently no sufficient practical need for introducing new operational quantities.

3.5 Impact on the production of radiation protection doseimeters

3.5.1 General perspective

The current measurement quantities for estimating effective dose, $H_p(10)$ and $H^*(10)$, are defined as the dose at a single point at 10 mm tissue depth. In principle, measurement devices today can consist of tissue-equivalent detector covered by a 10 mm filter of tissue-equivalent material to create a dosemeter that replicates the measurement quantity. As long as the 10 mm thickness of the covering tissue-equivalent material is ensured even for oblique incidence, the value indicated by the dosemeter corresponds to the measurement quantity even in case of oblique radiation incidence. This principle serves as the basis for the construction of simple measurement devices.

In contrast, the new quantities, H_p and H^* , are defined as a weighted sum of several organs in the voxel phantom. The fact that a distribution of definition depths over the entire phantom must be considered means that this "fundamental replication" of the measurement quantity can no longer be realised with a simple measurement device. Instead, multiple detectors must be used, and their signals must be appropriately combined for the overall indication. The result can be determined either as a linear combination of the individual signals or, if that's not possible, by nonlinear algorithms, possibly even using AI-based approaches. Such algorithms usually use signal ratios from the individual detectors to provide various corrections for dose determination (Pathan et al. 2025). However, this leads to an increase in uncertainty for small dose and signal values and thus for the determined dose values as well. Alternatively, newer methods such as artificial intelligence may be used (Rindhatayathon et al. 2025), requiring new methods for uncertainty estimation, but this is fundamentally feasible.

So far, there is no general evidence that the current standards requirements (DIN EN IEC 62387:2023-08, PTB 2013) can still be met; if necessary, the permitted measurement deviations

would have to be widened. Whether this will be necessary and to what extent is not yet clear. The same applies to the upcoming generation of so-called hybrid dosimeters, which are to be deployed like passive dosimeters but also have an (electronic) reading unit. The potentially additional measurement deviations that are possible would have to be evaluated in the context of the increased agreement with the protection quantities that the new measurement quantities seek to achieve. However, it should be noted that this contribution is of lesser significance compared to other uncertainties in practical personal dosimetry, such as dosimeter position, way of wearing, exposure geometry, and inhomogeneous radiation fields.

Below, the expenses for the establishment of new dosimeters of various types are compared with their intended uses.

Passive radiation protection dosimeters are generally used for legal monitoring by the individual monitoring services (IMS) and serve to provide evidence of compliance with occupational dose limits. Currently, approximately 75 % of the monitored persons do not receive a significant (measurable) effective dose¹⁰ (BfS 2025). Of the remaining 25 %, only 60 % are monitored with dosimeters, while the dose for the other 40 % is calculated in flight dosimetry. As a result, about 85 % of those monitored with dosimeters receive no measurable dose. For these individuals, the introduction of the new quantities would have no effect at all. Conversely, the measured and calculated dose values for occupationally exposed persons would match conceptually better. However, this does not solve the problem of uncertainties in dose determination.

In cases where, for example, the annual dose or the limits in single measurements are reached or exceeded, there are procedures for evaluating the individual measurements to more precisely assess the effective dose by including the specific exposure conditions and considering the energy-angle dependence of the dosimeter (SSK 2016). Systematic underestimations are possible, particularly if the dosimeter is not worn in a representative position for the most highly exposed parts of the body. A change in measurement quantity does not solve this practical problem of dosimeter placement.

In Germany, mainly dosimeters where only one detector element is applied for the determination of $H_p(10)$ are in use (see Section 3.5.2). The technology and the software are designed for them. With currently about 400,000 monitored persons and a demand for 2.5 times as many devices for practical use, there are expected costs in the double-digit million range required for the necessary redesign or innovative reading software and the associated research and development, testing, accreditation and approval (Figel 2024), which would ultimately have to be borne by users. Since in the vast majority of cases only very little or no dose is measured, which is not affected by the new measurement quantity definition, the introduction of the proposed quantities cannot be justified from this.

Currently, there are people under legal monitoring working in areas where monitoring could theoretically be dispensed with. Given the costs incurred by the introduction of the new quantities, it is expected that many people will refrain from non-mandatory monitoring, which could mean that unexpectedly or exceptionally high dose values may go undetected. Conversely, there

¹⁰ Due to rounding rules for the calculation of effective dose, for measured values below 0.05 mSv, a dose of 0.0 mSv is indicated for the effective dose – see (MessRL 2001, Guideline on requirements for personal dosimetry services under the Radiation Protection Ordinance and X-Ray Ordinance of 10 December 2001 (GMBL 2002, No. 6, p. 136)).

is also a potential for a reduction in bureaucracy and cost savings, which might be discussed in the context of introducing new measurement quantities.

Assuming that there is to be no reduction in the number of persons legally monitored by dose-meter, there is concern that the current shortage of suitable dosimeters could worsen. The economic incentive for manufacturers to invest in development is limited, as the potential market is small both nationally and internationally. If existing, approved types of dosimeters must be replaced, there is a risk that, given limited resources for radiation protection, other, more urgent, device developments will not take place (see also Section 3.9). If international harmonisation succeeds, a larger demand and potentially more interest from industry could be generated.

There is already demand for type-approved $H^*(10)$ area dose rate meters for photon energies below 65 keV (currently, only one type exists in this range) and, in particular, for pulsed photon radiation for which none is currently available. There are also no approved instruments for the area dose quantities $H'(3)$ and $H'(0.07)$.

The impact on active dosimeters is especially severe for area dosimetry. Due to the shortage of approved active area dosimeters, experts often have to use "makeshift solutions", sometimes relying on older devices measuring obsolete quantities and then converting as appropriately as possible. Since the new operational quantities do not bring simplifications regarding the construction of dosimeters (see Sections 3.5.2 and 3.5.3), this situation would only improve if international harmonisation creates an international demand for approved dosimeters.

It is to be expected that for a period of ten years or more, area dose rate meters for $H^*(10)$ and H^* will operate in parallel. The corresponding measuring instruments could each be approved and verified and would thus give valid, but different, measured values. Direct conversion were not possible due to differing energy dependencies.

Historically, when photon dose equivalent H_X was replaced with the now valid $H^*(10)$ in 2001 (in Germany), the numerical value for a reference radiation of 662 keV increased by 6 %. With the introduction of H^* , it would decrease by 18 % – corresponding to the changes in conversion coefficients. At 40 keV, the value increased by 29 % in 2001 and would now drop by 44 %. At 20 keV, however, the value was reduced by 46 % and would now fall again by a further 78 %, i.e., to only 12 % of the indicated value of an H_X measuring device from before 2001. Since the proposal to introduce H^* is based not on newly gained knowledge of cancer incidence but on conceptual considerations, there is a risk of a loss of confidence in the concept of (area) dose rate measurement among the users.

Conversely, the more direct linkage of operational and protection quantities could, for future generations of radiation protection professionals, be easier to communicate.

From these considerations, no essential benefit arises from a change of measurement quantities; rather, disadvantages are to be expected.

3.5.2 Technical details on passive dosimeters

Passive dosimeters are typically thermoluminescence dosimeters (TLDs) or dosimeters based on optically stimulated luminescence (OSL). The passive dosimeters commonly used in Germany are TLD-100 (LiF:Mg,Ti), TLD-100H (LiF:Cu,P), or BeO (OSL). Of these passive detector materials, only BeO is approximately tissue-equivalent. TLDs represent roughly half

of all dosimeters used worldwide (McKeever et al. 1995). In Germany, their share is about 25 % to 35 %. They use one to four detectors to measure the personal dose $H_p(10)$.

In Germany, all four monitoring services use dosimeters in which $H_p(10)$ is measured with a single detector. Most OSL dosimeters, however, include at least two detector elements. For simple single-detector dosimeters (in particular, single-element TLD or OSL dosimeters), simulation studies have shown that — through targeted modifications of the filter elements — a norm-compliant (e.g., IEC-compliant) response can, in principle, also be achieved under ICRU95 starting at about 20 keV (Eakins und Tanner 2019, Hoedlmoser et al. 2020).

However, it is important to emphasise that this is by no means a matter of a simple, software-based recalibration of the existing dosimetry systems. Rather, this requires a structural and hardware modification of the entire dosimeter setup (at a minimum, the filter materials and their thicknesses). For the monitoring services in Germany, this would mean that the existing, proven and widely used inventory of dosimeter badges and holders would have to be extensively modified. The associated logistical, administrative, and financial effort is considerable. An alternative approach would be multi-detector systems. However, the number of detector elements needed to meet current accuracy requirements is still unknown. Some of these multi-detector systems would be larger, heavier, and significantly more expensive, since detector materials — especially for TLDs — have very high purchase prices. For OSL detectors, purchase costs are lower, and there are developments that differ only minimally in size and weight.

The impact on mixed photon-neutron dosimetry would be even greater. In Germany, the so-called albedo dosimeter is used as a passive dosimeter, based on thermoluminescence (LiF:Mg,Ti); it employs four elements with targeted filtering to measure both neutron and photon doses. The filtering of this dosimeter is optimised for neutron measurement. It uses one detector for measuring photon radiation, and the others for determining neutron radiation. Adjusting this dosimeter for the new photon operational quantity H_p may not be possible, since the badge is optimised for correct measurement of the neutron component. Current type approvals for the photon component of the albedo dosimeter show that for low-energy radiation, the overestimation is so large that all albedo dosimeters have a rather large lower limit for the approved energy and angle range. This issue would worsen due to the smaller conversion coefficients for the new operational quantities.

Expanding the albedo dosimeter with further detectors would result in even larger and heavier dosimeters, or users would have to wear two dosimeters in the future — that is, one each for photon and neutron radiation. Wearing heavier or more than one dosimeter without noticeable added value carries the risk of lower acceptance.

3.5.3 Aspects of active area dosimeters

Active area dosimeters are frequently used to determine controlled area boundaries and must therefore be reliably usable in the lower dose rate range. A controlled area is defined by the possibility of an effective dose exceeding 6 mSv in a calendar year. Assuming a simplified occupancy of 2,000 hours, this corresponds to an average effective dose rate of 3 μ Sv/h.

With the introduction of H^* , the underlying protection quantity — i.e., the effective dose — would remain unchanged. However, the operational quantity used to assess the radiation field and provide a practical estimate for the protection quantity would change. Because the conversion coefficients of H^* are lower than those of $H^*(10)$ in the soft X-ray region, the same physical detector signal would be assigned a lower measured value. The metrological signal quality of

the detector itself does not change initially; what changes is the interpretation of this signal with respect to the protection quantity.

However, this alters the previously existing conservative safety margin. $H^*(10)$ significantly overestimates the effective dose in certain low-energy photon fields. This overestimation can be useful in practical radiological protection because it provides additional conservatism when defining controlled area boundaries or in leakage and scatter radiation measurements. If H^* is used instead, the indicated value in the same radiation field can be lower. To maintain the previous level of conservatism, this would need to be taken into account by means such as suitable assessment factors, conservative calibration, or correspondingly cautious definition of operational ranges.

Otherwise, there is a risk that a device will formally display H^* correctly, but the practical decisions derived from it would be less conservative than before. This specifically affects radiation fields with significant low-energy photon components, such as soft X-rays or in leakage and scatter radiation measurements. However, in most cases, conservative estimations are used anyway, and the effect only applies to soft X-rays – then only for known fields and room geometries. It remains to be decided whether the current radiological protection system's fivefold conservatism (for mono-energetic radiation or, in X-ray diagnostics, up to a factor of 2) is necessary and desirable. On the other hand, the reasons for the changes must be clearly communicated (see Section 3.8).

Counting-type active area dose rate meters for photons are, as mentioned, also used for leakage and scatter radiation measurements. Particularly for such applications, a lower H^* reading compared to $H^*(10)$ at photon energies below approximately 70 keV can be practically relevant. The crux is not that the detector generates less signal for the same radiation field, but rather that the existing signal is assessed differently under the new operational quantity. For applications where the conservative indication of $H^*(10)$ was previously, consciously or unconsciously, used for a reliable assessment, this may mean that additional conservative assessment rules will become necessary.

As a possible alternative, manufacturers could forgo costly new developments or major modifications of area dose rate meters and instead change either the nominally specified energy range or the nominally specified dose rate range. Instruments previously specified from, say, 20 keV could continue to be offered with largely unchanged, but with the application range for H^* only from a higher energy, e.g., from 40 keV, or with a newly defined dose rate range. In the former case, H^* area dose rate instruments would no longer be operated within their specified range in fields with significant components below the specified energy range. Depending on the energy distribution, the indicated values could be conservatively elevated or associated with greater uncertainties.

In known radiation fields, adjustments can potentially be made via suitable calibration or correction factors. This is practically true for all fields in which known sources are operated in known room geometries. For digital display instruments, such a conversion is technically straightforward. In unknown radiation fields – for example mobile X-ray units with a possible low-energy component or at workplaces with changing working conditions and thus varying energy distributions – reliable recalibration or new calibration would, however, be difficult and associated with significant uncertainties.

In Table 2, the modifications required for different types of dosimeters when changing to the new quantity H^* are summarised.

*Table 2: Overview of required changes for different dosimeter types when changing to the new quantity H^**

Previous energy range $H^*(10)$	Detector type	Recalibration sufficient	Software modification required	Hardware modification required	New energy range (H^*)	Other performance features	Calibration or functional test with ^{137}Cs
from approx. 60 keV	All detector types	Yes	No	No	Unchanged or improved for lower energies	Unchanged	Unchanged
from approx. 20 keV	Pulse-counting or current-measuring detectors	No	No	Additional hardware filtering (e.g. Cu, Sn, Pb) required in individual cases	Case-by-case consideration required	Degraded when used for leakage or contamination search	Increased need for additional testing with X-rays
from approx. 20 keV	Detectors with pulse height analysis (spectral analysis) or multi-sensor detectors	No	Yes	Possibly smaller detectors for X-rays, possibly new hardware filtering	Case-by-case consideration required	Possible restriction of dose rate range in the X-ray range or of detection sensitivity	Increased need for additional testing with X-rays

3.5.4 Further types of dose ionisation meters

In the field of neutron dosimetry, the types of dosimeters currently available only roughly reflect the energy and angular dependence of the current operational quantities. They can, in principle, continue to be used, since the anticipated changes are essentially smaller than the current systematic uncertainties of practical neutron dosimetry. For commonly used calibration fields for neutron radiation, changes to the conversion coefficients have already been investigated, and they are in the range of up to about 20 % (Al Qaaod et al. 2023). Calibration factors for devices would change by this amount only.

In the field of photon dosimetry, the introduction of the new quantities would not significantly change the measurement of local skin dose and lens dose, since the corresponding conversion coefficients for the current and new quantities only differ slightly. Calibrations could be recalculated, and existing ring or lens dosimeters could largely continue to be used.

For electrons and beta radiation, only slight adjustments to calibration factors would typically be required for the local skin dose and thus for existing extremity/ring dosimeters. Approved ring dosimeters could mostly continue to be used. Dosimeters for determining the lens dose for beta radiation are not yet available, so the issue of continued usability does not arise.

3.5.5 Further impacts on standardisation

Requirements for radiation protection dosimeters are mostly specified in IEC and, to some extent, in ISO standards (IEC 60846-1: 2009, IEC 60846-2: 2015, DIN EN IEC 62387:2023-08, DIN IEC 61526: 2020-08, IEC 61005:2014, ISO 21909-1:2021, ISO 21909-2:2021). Here, revision of a large number of standards would be necessary, mainly to adjust the terminology of the dosimetric quantities. In some cases, the requirements would have to be relaxed because, as explained in Section 3.4, it is not possible to “replicate” the measurement quantity in a simple dosimeter, and the previous quality may not be achievable (Pathan et al. 2025). Such revisions

could be performed with moderate additional effort as part of regular revisions for general improvement and/or extension.

3.6 Adjustment of testing and calibration conditions

Dosemeters are tested or calibrated in reference radiation fields (for photons, under secondary electron equilibrium (SEE)). These fields are standardised in three ISO standards series for photons, neutrons, and electrons. For all these radiation fields, the conversion coefficients for the new operational quantities are already available (Behrens and Otto 2022, Al Qaaod et al. 2023, and Behrens 2021). Therefore, revising the relevant standards would be relatively straightforward by simply updating the terms and conversion coefficients.

Given that actual workplace fields can differ from the idealised reference radiation fields and that secondary electron equilibrium is not always present, supplementary test or calibration conditions could become part of future standardisation discussions. These issues are already being discussed internationally, for example regarding Cs-137 and Co-60 reference radiation fields in relation to secondary charged particle equilibrium (Behrens et al. 2009), as well as in relation to detector response to the new operational quantities (Otto 2019). Should future calibrations also be performed under non-SEE conditions, standards for photon reference radiation fields would need to be supplemented accordingly.

3.7 Assessment of the stability of the new operational quantities

In both the proposed and the currently valid system, it must be considered that biological weighting factors and reference phantoms have historically not been immutable quantities but have always been adapted to new scientific findings. This applies to both the radiation weighting factors w_R and the tissue weighting factors w_T . These quantities, for example, were revised in ICRP Publication 103 (ICRP 2007) compared to earlier recommendations; likewise, the calculation bases, such as the reference phantoms, were further developed through the voxel-based reference phantoms of ICRP Publication 110 (ICRP 2009) and the associated conversion coefficients of ICRP Publication 116 (ICRP 2010). Future adjustments to w_R , w_T , and reference phantoms are, therefore, in principle, possible as a result of ongoing scientific progress.

In particular, the transition from voxel to mesh phantoms demonstrates that the anatomical and dosimetric basis for the calculation in the radiological protection system is evolving. However, such changes initially affect the calculation of organ and tissue doses and the derived protection quantities and conversion coefficients (Bozzato et al. 2026), but not directly the values of the limits. In the proposed system, such changes could, in principle, be incorporated directly into the definition of the operational quantity. However, this would weaken the long-term stability of dosimeter requirements and calibrations. In the current system, the operational quantities are more decoupled from changes in protection quantities, so that new biological or anatomical findings do not necessarily lead to fundamental changes in dosimeter requirements (ICRP 2020b, ICRP 2021b). Conversely, this means that the representativeness of the protection quantities by the operational quantities would change if the weighting factors were adapted but the calculation bases for operational quantities were not adjusted accordingly.

The essential difference, therefore, is that the operational quantities in the current system are deliberately defined as practical, conservative surrogate values for the non-directly measurable protection quantities. Changes to biological weighting factors, risk models, or reference phantoms thus initially affect the calculation and assessment of the protection quantities, but not necessarily the calibration quantity of a dosimeter. In the proposed system based on ICRU

Report 95 (ICRU 2020), on the other hand, the operational quantity would be more closely linked to the then-current protection quantities and their calculation models. This would allow for new scientific findings to be incorporated more directly, but it would, at the same time, decrease the long-term stability of the operational quantity, as changes to phantoms, weighting factors, or conversion coefficients would be more likely to lead to changes in calibration factors, test requirements, or device specifications.

Thus, the simplified assumptions of the currently valid operational quantities lead to greater stability than the definitions in the proposed system. Since in the proposed system the operational quantities are aligned with the protection quantities, both changed w_R and w_T values and new phantoms for the calculation of the protection quantities would more likely result in changes to the operational quantities. Therefore, discontinuities in practical radiological protection and the need for ever-new dosimeters would be more probable in the proposed system. Experience with the current system and especially with regard to the international context also suggests that such refinements would not be implemented uniformly worldwide, leading to corresponding disadvantages in comparability.

3.8 Communicative risks and critical success factors

Communication about ionising radiation is challenging, particularly in the context of radiological risk communication within radiation protection. The complexity of the radiation protection system, with its many dose quantities, adds to this challenge. Moreover, because ionising radiation is not perceptible without technical means and due to additional influencing factors, risk perception among the public often includes an emotional component beyond scientific evidence (IAEA 2012, Slovic et al. 2004). Any change in the quantities underlying the radiation protection system may, therefore, impact the perception and understanding of radiation protection measures and trust in the system.

Thus, when weighing the meaningfulness of introducing the proposed new operational quantities, risks and the communication effort required for such an introduction must be considered, just as much as the potential simplification of the system. At this point, an assessment of the required effort can only be qualitative.

3.8.1 Success factors for effective change communication

Changes require those affected to make adjustments (explained in detail in Section 3.8.3). If these adjustments are not made or only partially in accordance with the desired future state, the objective of the change is at risk (Lewin 1947). The cause is often a lack of motivation among those affected to support the change. To generate and maintain this motivation, effective change communication is needed throughout the process. The success of this communication depends on several factors or questions (Armenakis und Harris 2002):

- Is the change necessary/useful?
- Does the result justify the effort?
- Are the necessary skills and financial resources available?
- Will all affected parties join in and implement the change?
- Is the change not just generally beneficial, but potentially also individually so for each affected person?

The successful communication of change – and thus the successful implementation of an innovation – requires that as many of these questions as possible can be answered affirmatively.

3.8.2 Aspects of risk communication

The mere introduction of new operational quantities does not initially raise questions of risk communication. Indirectly, however, the consequences of introducing new quantities can affect perception and the individual evaluation of radiological risks, and these should be considered in risk communication and addressed in the accompanying communication efforts.

Particular attention should be paid to changes in personal and area dosimetry, where the introduction – in photon reference radiation fields, and especially in the low-energy X-ray range – would lead to a significant reduction in displayed dose values. This should be contextually explained through communication to prevent misinterpretation of radiological risks. On the other hand, a potential advantage is that the relationship between the new operational quantities and the protection quantities becomes more direct and therefore more intuitive. This could make it easier to relate calculated dose values (e.g., for flight personnel) to measured values (e.g., for medical personnel). Training and communication efforts might be reduced in the long term, and parallel interpretation or conversion steps avoided. Such simplifications would only be expected after a completed transition phase and consistent implementation in standardisation, calibration, and regulatory practice.

However, during the transition, the simultaneous use of $H^*(10)$ and H^* (and possibly also H_X) could lead to confusion, a lack of consistency, and thus uncertainty in all areas of application. Such uncertainty can lead to a loss of credibility and trust in radiation protection, because consistency and absence of contradiction are prerequisites for effective risk communication (BBK 2022).

3.8.3 Communicative impacts by stakeholder groups

a) Dosimetry professionals

Among dosimetry professionals, it may generally be expected that the changes described in (ICRU 2020) are already known and have been discussed through relevant professional and scientific platforms or international organisations. For this group, communication efforts by the responsible authorities could focus on the timeline and concrete statutory requirements. The main risk is inconsistent communication regarding timelines and other regulatory parameters. Dosimetry professionals should be included in all communication with other target groups, to translate the complex relationships into understandable messages for non-experts.

b) Radiation protection professionals

Although professionals working in radiation protection already have extensive knowledge of dosimetry aspects, communication and training regarding the purpose, specific impacts, and cost-benefit ratio are necessary. Radiation protection officers (RPO) and experts (RPE) in companies and organisations need to communicate the changes internally to guarantee their correct implementation by all users. Developing and providing a nationwide consistent communication strategy would be desirable to ensure consistent information across all companies and organisations.

In emergency protection, extensive communication and training measures in the professional community are also necessary. In an emergency, possible confusion through parallel use of old and new quantities with differing measured values would be especially critical.

c) Medical staff

In the medical field, introducing the new operational quantities could enable more optimised radiation protection for staff, as especially in radiology, reduced dose values would result for the same exposure (see Section 3.2). Here, a comprehensive communication campaign is

required regarding the effects and handling of the new quantities. Information must be provided to explain the resulting opportunities for more targeted and possibly less expensive radiation protection measures, while emphasising that adequate protection levels are maintained.

d) Occupationally exposed persons and emergency personnel

The majority of occupationally radiation-monitored persons (in Germany about 400,000, BfS 2025) are medical staff, as already addressed above (c). To this staff in nuclear technology or general industry adds up. Also, for these groups, the content of radiation protection training courses would need to be updated and additional information materials developed.

Emergency personnel will have high communication needs. When the fire service guideline FwDV 500 (AFKzV 2022) was revised to raise the reference value for environmental or property protection from 15 mSv to 20 mSv, this led to controversial discussions. Even though this reference value would not be affected, the adaptation of dosimeters and, in turn, lower measured values, could lead to skepticism and renewed discussion of radiological risks in emergency response.

e) General public/media

Generally, it is assumed that, without further cause, the introduction of the proposed new quantities will not trigger sustained public interest. A communication campaign for the general public does not seem necessary. There might be isolated media coverage when the decision is announced. There is, however, a small risk that reduced measured values, out of misunderstanding or deliberately, could be interpreted as a lowering of the protection standard, potentially damaging confidence in radiation protection. More problematic, however, would be contradictory information due to inconsistent dose and dose rate specifications in an emergency if old and new quantities are used in parallel, or inconsistencies between countries in cross-border emergencies. Therefore, at the very least, a uniform system should be strived for with neighboring countries or, for example, within the European Community.

3.8.4 Summary assessment of communication

The introduction of new operational quantities according to (ICRU 2020) brings both advantages and certain risks – as well as considerable communication expenses. For successful implementation, it is necessary to convincingly communicate a clearly positive benefit-cost ratio to the main stakeholder groups. While significant implementation costs are anticipated (for technical adaptation, training, and communication), but relevant benefits for practical radiation protection are currently not apparent.

Based on experience during the introduction of the current operational quantities, a longer implementation period of up to two decades can be expected, during which communication must also be maintained.

3.9 Possible long-term consequences in the event of non-Introduction

The decision whether or not to introduce the ICRU95 operational quantities is not an isolated national one. In Europe, an introduction would be linked to an amendment of Directive 2013/59/Euratom (Euratom 2014), which must be implemented in national radiation protection legislation. When seeking the appropriate European consensus, the international situation should be taken into account or influenced accordingly, including how the IAEA deals with the new operational quantities.

European and international alignment is essential for such a decision, as pursuing an internationally inconsistent approach would bring the disadvantages of a lack of harmonisation, dis-

continuities, increased costs, and a more complex international standardisation landscape. Additionally, higher communication efforts would be necessary to make the coexisting different quantity systems understandable. This also applies if the new quantities are introduced internationally but, for example, only Germany does not implement them. Furthermore, non-uniform systems of operational quantities may also create risks for practical radiation protection if measurement results between countries, sectors, or monitoring systems are no longer directly comparable or are interpreted differently. This could lead to misjudgement of exposure situations, uncertainties in dose monitoring, and delays in protective measures, especially concerning cross-border employment relationships, internationally active companies, aviation, the medical sector, and emergency protection.

3.10 Conclusion

Overall, the SSK assesses that the introduction of the proposed operational quantities could offer scientific benefit but currently provides no relevant advantages for practical radiation protection, for which these quantities are primarily intended. It should, however, be noted that the newly proposed operational quantities are directly related to the protection quantities and are thus scientifically well-founded in their derivation (see also Otto et al. 2026).

This results in fundamental conceptual advantages, for example:

- a closer linkage to the protection quantities,
- improved comparability with calculated dose values for flight personnel,
- possible benefits regarding certain medical applications,
- and, after full transition, a potentially overall system that is easier to explain.

In the opinion of the SSK, however, these advantages are significantly outweighed by other uncertainties. These include, in particular:

- individual anatomical differences,
- the position and way of wearing dosimeters,
- inhomogeneous radiation fields and further uncertainties of practical dosimetry,

In addition, there are the effort and challenges associated with a prolonged transitional phase.

Therefore, it should be emphasised that, in the context of practical implementation, especially in times of desired reduction in bureaucracy and considering the considerable effort linked to an introduction, the SSK does currently consider a switch not to be advisable.

The currently valid system can be regarded as well-functioning and appropriate.

In cases where the current operational quantities such as $H^*(10)$ and $H_p(10)$ are not sufficiently suitable, alternatives have already been established (for example, the direct use of the effective dose in aviation dosimetry). The assessment of protection levels or barriers to innovation does not primarily depend on the definitions of the quantities but on the specified limits and normative requirements. Thus, apart from a lack of international harmonisation, there are no significant disadvantages in the event of non-introduction. However, international harmonisation would be a decisive advantage and should in any case be pursued — currently, from the perspective of the SSK, preferably focused on the existing system of operational quantities. This recommendation explicitly reflects an assessment of the current framework conditions and does not preclude a re-evaluation in the event of changes in international circumstances.

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List of abbreviations

ALARA	As Low As Reasonably Achievable
BeO	Beryllium oxide
BfS	Federal Office for Radiation Protection (Bundesamt für Strahlenschutz)
BMUKN	Federal Ministry for the Environment, Nature Conservation, Nuclear Safety and Consumer Protection (Bundesministerium für Umwelt, Klimaschutz, Naturschutz und nukleare Sicherheit)
EURADOS	European Radiation Dosimetry Group (network of European (research) institutions for general exchange and joint research, https://eurados.sckcen.be/en)
EURATOM	European Atomic Energy Community (EAEC)
IEC	International Electrotechnical Commission
ICRP	International Commission on Radiological Protection
ICRU	International Commission on Radiation Units and Measurements
ISO	International Organization for Standardization
OSL	Optically Stimulated Luminescence
SEE	Secondary electron equilibrium
SSK	Commission on Radiological Protection (Strahlenschutzkommission)
StrlSchG	Act on the Protection against the Harmful Effects of Ionising Radiation (Radiation Protection Act)
TLD	Thermoluminescence dosimeter
TLD-100	TLD material (LiF) with natural isotopic distribution of Li-6 and Li-7
TLD-100H	TLD material (LiF) with natural isotopic distribution of Li-6 and Li-7 and especially high sensitivity

Glossary of terms

Absorbed dose The absorbed dose is the differential quotient $d\bar{\epsilon}$ by dm ; here, $d\bar{\epsilon}$ is the mean energy imparted by the interaction of ionising radiation with the material in a volume element dV , and $dm = \rho dV$ is the mass of the material with density ρ in that volume element:

$$D = \frac{d\bar{\epsilon}}{dm} = \frac{1}{\rho} \cdot \frac{d\bar{\epsilon}}{dV}$$

The unit of absorbed dose is J kg^{-1} , called gray (Gy).

The specification of an absorbed dose always includes the reference material, i.e. the material of dm . Examples: water absorbed dose D_w , air absorbed dose D_a .

Air kerma For air kerma, air is the irradiated medium. The unit of air kerma is gray (Gy).

Controlled area Controlled areas are areas in which persons may receive an effective dose of more than 6 millisieverts in a calendar year, or higher organ equivalent doses than 15 millisieverts for the lens of the eye or 150 millisieverts for the local skin, hands, forearms, feet, and ankles. (translated from: Koelzer, W. Lexikon zur Kernenergie. Edition January 2019. KIT Scientific Publishing. ISBN 978-3-7315-0881-6)

Conversion coefficients In practical radiation protection, conversion coefficients refer to the ratio between directly measurable quantities (e.g., air kerma) and non-directly measurable quantities (e.g., $H^*(10)$).

Effective dose The effective dose is the sum of the organ equivalent doses H_T in relevant organs and tissues, each multiplied by the tissue weighting factors w_T as recommended by the ICRP and specified in the Radiation Protection Ordinance:

$$E = \sum_T w_T \cdot H_T = \sum_T w_T \sum_R w_R \cdot D_{T,R}$$

H_T is the organ equivalent dose in a tissue or organ T ; w_T is the tissue weighting factor, w_R is the radiation weighting factor. The unit of effective dose is J kg^{-1} . To indicate that this is a weighted dose quantity, the unit Sievert (Sv) is used instead of Gray (Gy), as with the equivalent dose.

Kerma Kerma (Kinetic Energy released in matter or Kinetic Energy released per unit mass) denotes the sum of the initial kinetic energies of all secondary electrons released in a volume element of the irradiated medium. It is a physical quantity dependent on the medium. In contrast to absorbed dose, which is defined as the energy taken up by the material, kerma refers to the energy delivered there.

Following interaction of indirectly ionising radiation with matter, charged particles (secondary electrons) are released. Secondary electrons deposit their energy in atoms and molecules of the material. In dose

	measurements, only the energy effective within the measurement volume is recorded. Secondary electron equilibrium refers to the condition where the sum of electron energies released outside the measurement volume equals the sum brought in by electrons from the surroundings. In the case of secondary electron equilibrium, the value for kerma is approximately equal to that of the absorbed dose. The unit for kerma is gray (Gy).
Mesh phantom	Computer-based reference computational phantom (MRCP) based on polygonal meshes, allowing anatomical structures to be represented more realistically compared to voxel phantoms.
Organ equivalent dose	The organ equivalent dose H_T is the product of the mean absorbed dose $D_{T,R}$ in an organ or tissue and the radiation weighting factor w_R as per ICRP. The values of the radiation weighting factor w_R as per ICRP depend on the type and quality of the radiation (photons, electrons, neutrons, protons, alpha particles).
Particle fluence	Particle fluence describes the number of particles passing through a surface element of the infinitesimal unit sphere from any direction. The unit of particle fluence is m^{-2} .
Personal dose	The personal dose is the dose equivalent measured at the surface of the body representative for the radiation exposure. The unit of personal dose ($H_p(d)$) is $J\ kg^{-1}$, called sievert (Sv). There are various quantities describing personal dose: the deep personal dose $H_p(10)$, the surface personal dose $H_p(0.07)$, and the eye lens personal dose $H_p(3)$. The deep personal dose $H_p(10)$ – assuming suitable design, calibration and correct wearing of a personal dosimeter – provides, in cases of whole body exposure to penetrating radiation, an estimate for effective dose and the organ equivalent doses of deep-seated organs, in special cases also for the organ equivalent doses of the hands, forearms, feet and ankles. The value of the surface personal dose $H_p(0.07)$ is, in the case of full or partial body exposure, an estimate for the local skin equivalent dose, and in special cases also for the organ equivalent doses of the hands, forearms, feet and ankles. The measured value of the eye lens personal dose $H_p(3)$ gives an estimate for the eye lens equivalent dose. The most essential prerequisite for the possibility of such dose assessments is the correct wearing of the respective personal dosimeter.
Radiation weighting factor	The radiation weighting factor w_R is a dimensionless factor by which the absorbed dose in an organ or tissue is multiplied to account for the different biological effectiveness of various radiation types.
Secondary electron equilibrium	Secondary electron equilibrium exists at a point within a material when the sum of the kinetic energies of the secondary electrons generated by indirectly ionising radiation entering a volume element containing this point is equal to the sum of the kinetic energies of secondary electrons exiting that volume element. For radiation of indirectly ionising particles, achieving secondary electron equilibrium is important for determining the

	absorbed dose. Secondary electron equilibrium can, for directed radiation beams – as often occurs in the use of radiation sources – only be achieved approximately (see: https://www.bundesumweltministerium.de/fileadmin/Daten_BMU/Download_PDF/Strahlenschutz/strlsch_messungen_glossar.pdf).
Tissue weighting factor	Tissue weighting factors approximately describe the proportion of radiation risk that results for the total risk from a uniform irradiation of a tissue or organ T during whole-body exposure. Tissue weighting factors represent mean values, averaged over males and females of all age groups, and therefore do not pertain to the characteristics of individual persons. By means of the tissue weighting factors w_T , the individual organ equivalent doses H_T are weighted according to their relative contributions to stochastic radiation effects in the determination of the effective dose E . These factors w_T reflect the varying sensitivity of different organs, tissues, and body parts T to stochastic radiation effects (carcinogenesis, induction of hereditary effects).
Voxel phantom (reference phantom)	Computer-based anthropomorphic phantom based on tomographic images in which the anatomy is represented by small three-dimensional volume elements (voxels) specifying the density and atomic composition of the various organs and tissues.