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Radiological protection — Procedures for monitoring the dose to the lens of the eye, the skin and the extremities

Radioprotection — Procédures pour la surveillance des doses au cristallin, à la peau et aux extrémités

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Foreword

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The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

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For an explanation on the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the WTO principles in the Technical Barriers to Trade (TBT) see the following URL: Foreword - Supplementary information

The committee responsible for this document is ISO/TC 85, *Nuclear energy, nuclear technologies and radiological protection*, Subcommittee SC 2, *Radiological protection*.

This second edition cancels and replaces the first edition (ISO 15382:2002), which has been technically revised. The main changes are the addition of procedures for monitoring the dose to the lens of the eye.

Introduction

The human body has to be protected from effects of ionizing radiation. The stochastic effects are covered by the limit on the effective dose while tissue reactions (deterministic effects) are covered by the dose limits for specific organs. The human skin has to be protected from tissue reactions, like erythema and ulceration. For the lens of the eye, there is the risk of radiation induced opacities and cataract at elevated exposures. To protect the skin of the whole body, the extremities, and the lens of the eye, separate dose limits are recommended by the International Commission on Radiological Protection (ICRP). These separate dose limits are needed because, in case of localized exposures, the organ doses to the skin and the lens of the eye could exceed these limits even if the effective doses were lower than the limit.

Specific dosimetry is needed to monitor these doses and to assess compliance with applicable limits. There are some situations where the correct assessment of the exposure of the skin, extremities, and lens of the eye can be important. In the nuclear sector, there can be exposure due to weakly penetrating radiation caused by unshielded open radioactive sources, or by work in glove boxes. These types of exposure can occur, in particular, in connection with contamination. Exposure to weakly penetrating radiation from radioactive noble gases in room air also has to be considered. In the medical field, doses to extremities and doses to the lens of the eye can be important during interventional procedures and in nuclear medicine.

Monitoring the extremities and the lens of the eye is not always straightforward, and many practical problems arise for the application of monitoring in the workplace. As a result, monitoring is often not done as it should be, or not done at all. This International Standard provides guidance on how and when this monitoring should be done, for all the different types of workplace fields.

This International Standard is directed to all who are involved in the dosimetry of the skin, extremities, and the lens of the eye, like for example, radiation protection officers, regulators, workers, dosimetry services, etc.

Radiological protection — Procedures for monitoring the dose to the lens of the eye, the skin and the extremities

1 Scope

This International Standard provides procedures for monitoring the dose to the skin, the extremities, and the lens of the eye. It gives guidance on how to decide if such dosemeters are needed and to ensure that individual monitoring is appropriate to the nature of the exposure, taking practical considerations into account. National regulations, if they exist, provide requirements that need to be followed.

This International Standard specifies procedures for individual monitoring of radiation exposure of the skin, extremities (hands, fingers, wrists, forearms, feet and ankles), and lens of the eye in planned exposure situations. It covers practices which involve a risk of exposure to photons in the range of 8 keV to 10 MeV and electrons and positrons in the range of 60 keV to 10 MeV.

This International Standard gives guidance for the design of a monitoring program to ensure compliance with legal individual dose limits. It refers to the appropriate operational dose quantities, and it gives guidance on the type and frequency of individual monitoring and the type and positioning of the dosemeter. Finally, different approaches to assess and analyse skin, extremity, and lens of the eye doses are given.

It is not in the scope of this International Standard to consider exposure due to alpha or neutron radiation fields.

2 Normative references

The following documents, in whole or in part, are normatively referenced in this document and are indispensable for its application. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO/TS 18090-1, *Radiological protection — Characteristics of reference pulsed radiation — Part 1: Photon radiation*.

IEC 62387, *Radiation protection instrumentation — Passive integrating dosimetry systems for personal and environmental monitoring of photon and beta radiation*

IEC 60846-1, *Radiation protection instrumentation — Ambient and/or directional dose equivalent (rate) meters and/or monitors for beta, X and gamma radiation — Part 1: Portable workplace and environmental meters and monitors*

IEC 61526, *Radiation protection instrumentation — Measurement of personal dose equivalents Hp(10) and Hp(0,07) for X, gamma, neutron and beta radiations — Direct reading personal dose equivalent meters*

ICRP, 2007. The 2007 Recommendations of the International Commission on Radiological Protection, ICRP Publication 103. Ann. ICRP 37 (2-4)

ICRP, 2010. Conversion Coefficients for Radiological Protection Quantities for External Radiation Exposures, ICRP Publication 116, Ann. ICRP 40(2–5), 2010

ICRP, 2012. ICRP Statement on Tissue Reactions / Early and Late Effects of Radiation in Normal Tissues and Organs – Threshold Doses for Tissue Reactions in a Radiation Protection Context, ICRP Publication 118. Ann. ICRP 41(1/2)

ICRU, 2011. Fundamental Quantities and Units for Ionizing Radiation, ICRU Publication 85. J. ICRU 11(1)

3 Terms and definitions

For the purposes of this document, the terms, definitions and units given in ICRP 103, ICRP 116, ICRP 118 and ICRU 85 apply.

4 Individual monitoring

4.1 Quantities

Skin and extremity monitoring involves the measurement of $H_p(0,07)$, the estimator of the equivalent dose to the skin.

Lens of the eye monitoring involves the measurement of $H_p(3)$, the estimator of the equivalent dose to the lens of the eye. If the radiation field is well known, $H_p(3)$ can be estimated by the use of dosemeters type tested and calibrated in terms of other quantities, i.e. $H_p(0,07)$ and $H_p(10)$, as in many cases they can provide an adequate estimate of the dose to the lens of the eye (depending on the radiation field). Technical specifications of dosemeters are provided in Annex A. Guidance on which type of dosemeter can be used for the lens of the eye (depending on the radiation field) is provided in Annex B.

4.2 Dose limits and monitoring levels

The dose limits for skin, extremities, and lens of the eye for planned exposure situations are given in national regulations.

ICRP has given more recent recommendations on the dose limits (ICRP 103 and ICRP 118) to avoid tissue reactions. Requirements equivalent to these recommendations are given by the IAEA in the Basic Safety Standards (BSS).[1] These recommendations from ICRP and IAEA constitute the basis for the recommendations in this International Standard.

The ICRP recommended dose limits are the following:

a) an equivalent dose limit to the extremities (hands and feet) or the skin of 500 mSv in a year. The equivalent dose limits for the skin apply to the average dose over 1 cm^2 of the most highly irradiated area of the skin. In practice, an estimate of equivalent dose to the skin is a conservative estimate of equivalent dose to the extremities;

b) an equivalent dose limit to the lens of the eye of 20 mSv per year averaged over 5 consecutive years (100 mSv in 5 years) and of 50 mSv in any single year.

Individual monitoring is required to verify compliance with dose limits as they are described in the national legislation. Extremity, skin, and lens of the eye monitoring should be undertaken for workers who have a reasonable probability of receiving per year an equivalent dose higher than 3/10th of one of the above mentioned yearly limits. National regulations can require monitoring from different values, in that case they replace the following values.

The following monitoring levels are recommended:

a) for the extremities or the skin, this means monitoring should be undertaken if there is a reasonable probability to receive a dose greater than 150 mSv per year;

b) for the lens of the eye, monitoring should be undertaken if there is a reasonable probability to receive a dose in a single year greater than 15 mSv or in consecutive years greater than 6 mSv per year.

For dose levels expected to be lower than the recommended monitoring levels given above, a survey demonstrating that the levels are not exceeded, should be sufficient.

The expected annual dose can be estimated via one or more of the methods given in Clause 5.

4.3 Monitoring period

The choice of the length of the monitoring period is related to the levels of the expected doses and to the relevant dose limit.

For doses above the monitoring level, a monitoring period of one month is recommended. For workers whose doses are likely to stay below the monitoring level, providing monitoring can be considered. The monitoring period in the latter case can be longer, e.g. three months. Shorter monitoring periods can be chosen (weekly monitoring or even monitoring per procedure), when setting up new procedures, when optimizing working conditions or when there is a risk of potential high exposure.

Regulatory bodies and/or expert committees also can provide appropriate recommendations for monitoring periods.

4.4 Extremity, skin and lens of the eye monitoring

The dose to the extremities, skin, and the lens of the eye needs to be monitored in situations with non-homogeneous exposure conditions for which the whole-body monitoring does not provide an adequate estimate of the dose to the skin, the dose to the extremities, or the dose to the lens of the eye. Exposures can be significant when weakly penetrating radiation such as low energy photons or beta radiation is present.

Hand or finger monitoring shall be considered for workplaces where extremities are particularly close to the radiation emitter or radiation beam, such as situations where radioactive sources are handled in, for example, research, nuclear medicine, and dismantling applications. Other important examples where extremity monitoring can be necessary are interventional radiology and nuclear medicine workplaces. Skin monitoring shall be considered for workplaces where skin is close to the radiation emitter or the beam. Also when there is a risk for skin contamination, monitoring should be considered. Examples of such situations are handling of contaminated components or unsealed radioactive sources.

Monitoring of the lens of the eye shall be specifically considered for workplaces where the eyes are particularly close to the radiation emitter (which can also be a source of scattered radiation) or the radiation beam (for example in interventional radiology) while the rest of the body can be protected by, e.g. a lead apron. Workers exposed in high energy beta fields can receive significant doses to the lens of the eye.

4.5 Uncertainties

An essential aspect of quality assurance in individual monitoring is assessing the quality of the measurement results. In the evaluation of the uncertainty, all knowledge of the dosemeter and evaluating system should be used, possibly in combination with information from the client/customer such as local exposure and storage conditions. The amount of effort put into the uncertainty should be realistic in view of its purpose in radiation protection.

ICRU makes recommendations on the acceptable levels for total uncertainty in Report 47[2] which are broadly consistent with the ICRP recommendation (ICRP 75).[3] ICRU recommends for single measurements of the operational quantities that "....in most cases, an overall uncertainty of one standard deviation of 30 % should be acceptable."

The expanded uncertainty (95 % coverage probability) for values of assessed annual dose values at or near the dose limit should not exceed 0,67 to 1,5 (factor 1,5) after all corrections have been made (ICRP 75).[3] This applies to values of effective dose, equivalent dose to a small area of skin, equivalent dose to lens of the eye or extremities, summed for all radiation types of the radiation field.

It shall be recognized that different requirements on accuracy may be needed for an estimate of the equivalent dose at another part of the body than the position of the dosemeter, for example an estimate of the equivalent dose to the finger tips from a measurement of $H_p(0,07)$ several centimetres away (RP160).[4]

4.6 Characteristics of radiation fields

Characterization of the radiation fields is an important step to determine the need for and the type of monitoring required.

Photon fields (X and gamma radiation) of any energy can contribute to the skin, extremity, and lens of the eye exposure.

Electrons (beta radiation) with energy above 60 keV penetrate 0,07 mm of tissue and can, therefore, contribute to the skin dose. Electrons (beta radiation) with energy above 700 keV penetrate 3 mm of tissue and can, therefore, contribute to the dose to the lens of the eye.

In medical fields, the type of radiation and radionuclides are very well known. Whole body exposures are mostly limited because of protection by the use of protective aprons and appropriate shielding, but doses to the extremities and to the lens of the eye can be high. Typical examples are the preparation of radionuclides in nuclear medicine and radio pharmacy, and the exposures to physicians during interventional procedures.

In nuclear installations, low energy betas are to be expected in the vicinity of unsealed radioactive materials, for example, on contaminated inner surfaces of power plant components, on system components or tools, and in contaminated areas. High values of the directional dose-equivalent rate can be produced, in particular, by beta radiation. In nuclear installations handling used fuel as well as in nuclear reactors experiencing fuel leakage, high energy betas (above 700 keV) should be expected. These are more readily monitored than the low energy betas.

The components on which contamination can occur are, as a rule, known from operational experience. If a high gamma ambient-dose-equivalent rate is measured on closed components (e.g. pumps, steam generators), a high percentage of low energy betas has to be expected when the component is opened. Information about the energy of beta radiation is obtained from the radionuclide composition, spectrometry or the attenuation of the radiation. Attenuation measurements can be used to characterize the radiation field by estimation of the penetration ability as well as the maximum energy of beta radiation.

5 Assessment of dose levels prior to routine monitoring

5.1 General

Prior to routine monitoring, it is important to assess the dose levels to the skin, the extremities, or the lens of the eye in a workplace field situation in order to decide which method, if any, and which period of routine monitoring is necessary.

The doses obtained by one or more of the following methods (5.2 to 5.6) should be extrapolated to annual doses and compared with the monitoring levels given in 4.2.

The assessment should be repeated when the working conditions or workload change significantly, or if the effect of such changes on doses to the skin, the extremity, or the lens of the eye cannot be estimated with confidence.

5.2 Indications from workplace measurements

In work situations with radiation fields that are predictable for a specific work task or over a long period (at least for several months) and with well established procedures, it can be possible to estimate the doses which workers will receive using workplace measurements at relevant locations.

Workplace surveys are recommended (for example measuring the dose equivalent rates) before starting to work on contaminated or activated objects in the nuclear sector, unless it is known from radionuclide analysis, or from earlier measurements that the working conditions (e.g. distance to the source) and the protective equipment is sufficient to attenuate and/or shield this type of radiation.

For determining the directional dose-equivalent rate $H'(0,07)/t$, suitable dose-equivalent rate meters (i.e. with thin walls and small detector thickness) shall be used. If protective clothing is worn, $H'(0,07)$ shall be measured behind the respective layer of clothing.

The measurement position shall be representative of the exposure conditions of the person surveyed. Also the distance that low energy photons and betas travel in air is important. If it cannot be avoided that contaminated objects are touched with the hands, measurements shall be performed both near the surface (at closest position) and at the usual working distance of the trunk (approximately 30 cm). If tools are used, measurements shall be performed at the distance appropriate for the use of such tools.

On the basis of the measured dose-equivalent rates $H'(0,07)/t$, $H'(3)/t$, and $H^*(10)/t$, and the time the person is present in the radiation field, it can be evaluated whether the work to be carried out requires wearing a personal dosemeter and/or additional protective measures.

The technical specifications for area dosemeters measuring the quantities $H'(0,07)$ and $H^*(10)$ shall be as defined in IEC 62387 for passive dosemeters and IEC 60846-1 for active dosemeters. For area dosemeters measuring the quantity $H'(3)$, no International Standard is yet available.

5.3 Indications from whole body dosimetry

When individual monitoring is performed, a dosemeter worn on the trunk is used for the estimation of effective dose. The results from the whole body dosemeter can give an indication of the level of exposure to the extremities, the skin, or the lens of the eye, provided the exposure conditions and the radiation field characteristics (especially the spatial distribution) are taken into account.

The approach of using a single dosemeter worn at the collar of the protective apron potentially provides an option for informing the radiation protection practice. Such a system can provide indications of when dedicated eye dosimetry is required.

When the whole body dosemeter is worn under the protective clothing, its reading strongly underestimates the dose to the unprotected extremities and the lens of the eye and can therefore not be used to provide an indication of the level of these doses.

5.4 Indications from literature data

In the literature, some typical dose values are given for various workplace situations. These can in principle be used to judge if monitoring is needed. When using literature values it should be ensured that the data are truly representative of the current workplace conditions regarding the radiation source (for example, which radionuclides or which high voltage of X-ray tubes is used), the geometry (for example, under or over couch setting in radiology) and types of protective measures (like shielding) that are used. Examples of literature data can be found in Annex C for medical applications.

5.5 Indications from simulations

Numerical simulations can be very powerful and can provide important information on the parameters affecting and influencing the doses in given exposure scenarios. To date, there are no readily available packages that can be easily used to obtain fast evaluations on operator's doses to the skin, the extremities, or the lens of the eye, but general purpose numerical codes (e.g. MCNP, EGS, GEANT, PENELOPE, etc.) can be applied to the particular investigated case. Simulations are often complex and time consuming, depending on the treated case. When using simulations, it is necessary to validate the results with measurements.

5.6 Indications from confirmatory measurements

Another way to determine if individual monitoring is needed is by performing confirmatory measurements with personal dosemeters. Confirmatory measurements are measurements intended to assess the level of doses to the workers in the specific workplace field. These confirmatory

measurements can be used as guidance in determining whether the monitoring level might be reached. Such confirmatory measurements shall fulfil the following requirements:

— the confirmatory measurements shall mimic routine measurements;

— they shall be performed as described in Clause 6;

— the working procedures shall not be changed because of the confirmatory measurements, otherwise the confirmatory measurements need to be restarted;

— the confirmatory measurements shall be performed for a minimum of 3 consecutive periods unless it is to mimic a single work task. The intention is to have a representative sample of the annual doses. If the activities are very irregular (large fluctuations from month to month), longer periods of monitoring are needed. A confirmatory measurement survey lasting a whole year might be needed.

6 Personal dosimetry

6.1 Extremity and skin dosimetry

6.1.1 Locations to monitor

For radiation fields where there is a significant spatial non-uniformity, the doses to the extremities can be of great concern. The skin of the extremities is the limiting organ rather than the extremity itself. An estimate of the equivalent dose to the skin, H_{skin}, is normally a conservative estimate of the equivalent dose to the extremities. Therefore, an extremity dosemeter becomes a skin dosemeter and shall be designed to measure $H_p(0,07)$ and be placed as close as possible to the most exposed part of the skin surface.

The monitoring location needs special consideration. In non-uniform fields, it is often difficult to place one single extremity dosemeter at the most highly exposed part of the skin since this part is not known a priori. In addition, it is not always the hands or fingers that are the most exposed area, also legs or feet as well as unprotected skin can be the most exposed area.

For direct or close handling of radioactive sources, finger-stall dosemeters on the fingertip, or ring dosemeters should be used on the finger which is frequently the most exposed. The monitored hand should be chosen as the most exposed between the left and right one. This can be found by doing some specific tests or using recommendations from the literature. In the case of nuclear medicine,[5] the recommended position is the index finger tip or the base of index finger of the non-dominant hand. The dosemeter should be oriented towards the radiation source.

For nuclear industry fields, interventional radiology, or other similar radiation fields, either a ring dosemeter or a wrist dosemeter worn at the most exposed hand shall be used. The dosemeter shall be oriented towards the radiation field if possible.

For leg monitoring, wrist dosemeters worn at the ankle can be used. The monitored leg shall be chosen as the most exposed between the left and right one. The leg chosen is the closest to the radiation source and/or the least protected. The dosemeter shall be oriented towards the radiation field if possible.

It can be necessary to monitor the doses at different locations using several dosemeters simultaneously (e.g. both hands).

The dosemeter shall be worn under protective clothing, especially inside gloves, if such clothing is worn. The dosemeter can also be worn outside the protective clothing, but under an appropriate thickness of material that approximates the type and thickness of the protective clothing. This protects the dosemeter from perspiration, permits easier removal, and gives an accurate measurement of the skin dose.

6.1.2 Types of dosemeters

Skin and extremity doses shall be estimated by measuring the operational quantity $H_p(0,07)$.

The dosemeters used for extremity monitoring are generally based on passive techniques and made of thermoluminescent (TL) materials, although, detectors based on other methods, such as film badges, optically-stimulated luminescence (OSL) and radiophoto luminescence (RPL) can also be used. The dosemeter shall be appropriate for the radiation fields to be monitored.

Two types of passive dosemeter design are available for fingers: rings, worn at the thumb, index, middle or ring finger, and finger-stalls, pulled on at either the index, middle or ring finger with the detector located at the finger tip. For wrists, the dosemeter is attached with a strap and thus can also be used for forearms and ankles.

Loose detectors are generally used to perform measurements at locations for which ring or wrist dosemeters are not adapted (e.g. at the finger tips, on the palm of the hand), or in case the dose levels to measure are expected below the routine dosemeters' thresholds. They can be used in test measurements to establish dose levels related to specific tasks, identify the position where the maximum dose is received and define appropriate correction factors to the dose measured at the monitored position. Many whole body dosemeters are also capable of measuring skin doses through $H_p(0,07)$. In principle these dosemeters can also be used to measure the skin dose on different parts of the body.

Electronic devices, e.g. made of small silicon probe(s) wire-connected with a command and reading box are available. These systems offer the advantage of a direct reading of the dose, which is useful for training and optimization purposes. Active dosemeters can be helpful in some cases to determine the expected dose (see Clause 5). However, their suitability in pulsed radiation fields should be verified if they are to be used in such fields, e.g. in the vicinity of pulsed X-ray tubes as often used in the medical sector. Performance requirements for the measurement in pulsed radiation fields are provided in Annex A.

6.1.3 Technical specifications of dosemeters

The technical specifications for extremity dosimetry systems measuring the quantity $H_p(0,07)$ shall be as defined in IEC 62387 for passive dosemeters and IEC 61526 for active dosemeters. Further details are provided in Annex A.

6.1.4 Application of correction factors

Depending on the exposure situation, common extremity monitoring positions, such as the base of the fingers or the wrist, often underestimate the maximum dose. To estimate the maximum skin dose from a routine dosemeter, a correction factor, for the specific routine monitoring position, shall be established and employed. This value could be determined independently for each worker by individual measurements for a short trial period. If for practical reasons, these measurements are not possible, existing correction factors can be employed considering the routine monitoring position.

For nuclear medicine, ICRP Publication 106[6] recommends placing the routine dosemeter on the base of the middle finger with the detector positioned on the palm side when the tip cannot be used. In this case, a correction factor of 3 (6 if the dosemeter faces the back) can be applied to get the value at the tip of the finger. Recently published values[7] for nuclear medicine recommend a mean factor of 6 between the location of the maximum dose and the measured value at the base of the index finger of the non-dominant hand.

The application of correction factors can be subordinate to national legislations.

6.2 Monitoring of the lens of the eye

6.2.1 Locations to monitor

The positioning of the dosemeter for the lens of the eye is important to have a good estimate of the dose to the lens of the eye.

The dosemeter for the lens of the eye shall be worn as close as possible to the eye, if possible in contact with the skin, and facing towards the radiation source. In case of usage in interventional radiology, the side closest to the X-ray tube shall be chosen.

When using protective lead glasses or face masks, the dosemeter shall be worn preferably behind them. This is often not very practical, and a dosemeter on the outside or next to the lead glasses can be chosen. In this case, some correction factors should be applied (see 6.2.4). It can also be an option to cover the front of the dosemeter with a filter that mimics the attenuation by the lead glasses. It shall be realized that some types of lead glasses do not offer adequate protection for oblique angles. In those cases, covering the dosemeter with a filter can lead to underestimation, and this method is not recommended. Requirements to protective eyewear are given in IEC 61331-3.[8]

In practical situations, eye lens dosemeters are often placed in various positions: above the eyes, at the forehead, at the side of the head, between the eyes.[9][10][11][12]

Some studies suggest estimating the dose to the lens of the eye from a well-placed dosemeter at collar level[17][18] or from the reading of the whole body dosemeter.[9] Although this might be acceptable in homogenous fields with higher energy radiation, this is in general not recommended in other fields. For example, for interventional radiology, different correction factors have been published to convert collar doses (above the lead apron) to doses to the lens of the eye for interventional procedures. Such correction factors are very dependent on the type of procedure, personal habits, the exact place of the above apron dosemeters and the protection measures taken,[15] so they cannot be applied to all routine cases.

The application of correction factors can be subordinated to national legislations.

6.2.2 Types of dosemeters

Doses to the lens of the eye shall be estimated by measuring the operational quantity $H_p(3)$. Dosemeters designed to measure $H_p(3)$ were very rare in the past, but recently specifically designed $H_p(3)$ dosemeters became available on the market.

If the radiation field is well known in advance, $H_p(3)$ monitoring can be performed by the use of dosemeters type tested and calibrated in terms of other quantities, i.e. $H_p(0,07)$ and $H_p(10)$ as, in many cases, they can provide an adequate estimate of the dose to the lens of the eye (depending on the radiation field). Technical specifications of dosemeters are provided in Annex A. Guidance on which type of dosemeter should be used, depending on the radiation field, is provided in Annex B.

The dosemeters used for monitoring the lens of the eye are generally based on passive techniques and made of thermoluminescent (TL) materials, although, detectors based on other methods, such as film badges, optically-stimulated luminescence (OSL) and radiophoto luminescence (RPL) can also be used.

Electronic devices, e.g. made of small silicon probe(s) can be used if they are optimized in terms of $H_p(3)$ with respect to energy and angular dependence or if the quantity they are optimised for provides an adequate estimate of the dose to the lens of the eye in the prevailing radiation field (see Annex B). These systems offer the advantage of a direct reading of the dose, which is useful for training and optimization purposes. However, their suitability in pulsed radiation fields shall be confirmed if they are to be used in such fields, e.g. in the vicinity of pulsed X-ray tubes as often used in the medical sector. Performance requirements for the measurement in pulsed radiation fields are provided in Annex A.

6.2.3 Technical specifications of dosemeters

The technical specifications for dosimetry systems for the lens of the eye measuring the quantity $H_p(3)$ shall be as defined in IEC 62387 for passive dosemeters. For active dosemeters, currently no International Standard is available for the quantity $H_p(3)$ but IEC 61526 can be applied accordingly by adopting the radiological requirement from IEC 62387. Further details are provided in Annex A.

6.2.4 Application of correction factors

If the dosemeter for the lens of the eye is not worn optimally (not close to the lens of the eye or behind shielding like e.g. lead glasses), then appropriate correction factors shall be applied. These factors shall normally be determined by means of measurements, possibly accompanied by numerical simulations.

For interventional clinicians, a correction factor for eye doses should only be applied if the clinician is conscientious in wearing protective eyewear. Correction factors to be used when the dosemeter is not

worn under the protective shielding determined through local assessment should be conservative and are likely to be in the range of 0,2 to 0,3. If no facility or expertise is available to assess protection, then a correction factor of 0,5 can be applied, provided the lenses contain the equivalent of 0,5 mm of lead and the frames include protection.

7 Interpretation and management of the results

7.1 Analyses of results

When it follows from Clauses 4 and 5 that individual monitoring (Clause 6) is not needed, the results of characterizing the fields and the working conditions (Clause 4) as well as assessments of dose levels (Clause 5) shall be documented (as required in local procedures).

The dose results from monitoring of the skin, the extremities, and the lens of the eye shall be treated in a similar way as the dose results from the whole body monitoring.

— The results shall be evaluated after each monitoring period.

— In the framework of optimization, dose constraints and reference levels shall be established per monitoring period. The measurement results should initiate follow up actions when needed. The annual results should be compared to the legal dose limits.

7.2 Optimization

The application of the ALARA principle is important also for doses to the skin, the extremities, and the lens of the eye. The radiation protection measures shall be optimized to limit these doses. This can be done by introducing dose constraints and reference levels. If the doses are close to the dose limits, more detailed studies to better estimate the operational quantities, in addition to individual monitoring, are recommended. The radiation protection measures shall be reviewed and improved, when possible, or the workload shared between more workers.

Detailed guidelines on how radiation protection can be optimized is beyond the scope of this International Standard.

7.3 Registration and documentation

The skin, extremity and doses to the lens of the eye have to be recorded according to national regulations and monitored with respect to the dose limits.

8 Special cases

8.1 Contamination

8.1.1 General

The monitoring requirements given in the previous clauses are not applicable in the case of contamination on the body. Also they might not be applicable in the case of a person working where the air is contaminated. Additionally, corrections of the measured dose might need to be made if a dosemeter is contaminated. Therefore, recommendations are given in this Clause for estimation of the dose in these special cases.

The estimated doses from these special cases might need to be formally recorded, depending on national regulations or local procedures. The use of routine hygienic measures such as wearing gloves and protective clothing, limits skin contamination.[6] Nevertheless, contamination cannot be completely avoided in the case of accidental spills or cross-contamination. The best way to limit cross-contamination is to frequently measure contamination during and after a manipulation by means of a contamination monitor.

In cases of skin contamination with radioactive substances, immediate and rapid decontamination measures are of higher priority than an exact evaluation of skin activity and dose.

8.1.2 Estimation of dose to the skin or the lens of the eye from contamination

A skin or eye contamination in the working environment is unlikely to be recorded by a personal dosemeter but can be detected by the routine use of contamination monitors including exit monitoring.

In accordance with national regulations, the evaluation of the dose due to radionuclides deposited on the skin or close to the lens of the eye might be necessary only when a threshold in terms of dose to the skin or the lens of the eye might be exceeded. In that case, the following recommendations apply.

To evaluate the contribution of the contamination to the skin dose or to the dose to the lens of the eye, an on-site investigation shall be performed to localize and identify the contamination and then quantify its activity.[16] Characteristics (size and position) and activity values for radionuclides on the skin or the eye as well as the duration of the contamination are necessary for the dose assessment. When contamination is on the skin, there is a proportional relationship (for a given radionuclide) between instrumentation count rate and skin dose rate for contamination averaged over a small area (1 cm^2 or less). Thus evaluations where the dose is low can be done without knowing the individual radionuclide activities. For higher doses, though, it is important to determine the radionuclide activities.

The identification of the radionuclides involved is necessary when a dose assessment has to be provided due to regulatory issues. It can also be useful, in particular as feedback, when the worker does not know when the contamination had occurred (e.g. the worker has manipulated several different radionuclides). Identification can be done by different means. Several instruments are available on the market for radio nuclide identification, for example by means of gamma (or beta) spectrometry.

Localization can be determined more or less precisely (depending on its actual size and on the accuracy required) with a contamination monitor, which shall be available in any location where unsealed sources or contaminated components are handled, e.g. nuclear medicine departments, nuclear installations and nuclear research establishments.

Quantification of skin dose can be performed in different ways. Radiation protection and medical departments can have established specific guides defining validated procedures in case of skin or eye external contamination. Different measurement devices (like a NaI spectrometer) exist to determine the spectra and the activity of each radionuclide in the source, which can be used for the calculation of the dose rate to the skin. The dose rates per unit of activity over 1 cm^2 can be calculated by several methods: the use of the data from Reference[17] a calculation with the deterministic code like VARSKIN[18] and a Monte Carlo simulation code of radiation transport, e.g. Reference.[19]

To estimate the total cumulated dose, the total exposure time has to be estimated.

Quantification of the dose to the lens of the eye can be performed in a similar way as for the skin dose.

Further information is given in Annex D.

8.1.3 Estimation of dose to the skin or to the eye lens from hot particles

Hot particles are localized aggregations of radioactive atoms that give rise to an inhomogeneous distribution of radionuclides.[20] These particles can deliver highly non-uniform, localized absorbed dose distributions when in contact with the skin or the eye.[21]

ICRP has given specific recommendations on the doses from hot particles (ICRP 59[22]). Different depths and thresholds are recommended for different effects.

A hot particle exposure in the working environment is unlikely to be recorded by a personal dosemeter but can be detected by the routine use of contamination monitors including exit monitors.

Hot particles consisting of pure beta emitters, e.g. Sr-89 and Sr-90/Y-90, are difficult to find and identify due to the short range of the beta particles. The existence of such particles shall be identified through other methods e.g. radio nuclide measurements on reactor cooling water. Hot particles consisting

of pure alpha emitters are outside the scope of this International Standard as alpha particles do not penetrate 0,07 mm of skin.

In the event of observing a localized radioactive contamination of the skin, the eye, or clothing, every effort shall be made to retrieve the activity for subsequent investigation. It is important to record details of the exposure such as body site, clothing/shielding, likely duration of exposure, etc.

The dose to 1 cm^2 of skin at a depth of 0,07 mm can be evaluated by direct measurement using techniques such as thermoluminescence dosimetry, extrapolation ionization chamber, exo-electron dosimetry or radiochromic dye films. Calculations of skin dose can also be made using tabulated beta or photon dose distributions or PC-based codes (e.g. VARSKIN,[18] Monte Carlo codes) but this requires information on the particle characteristics, composition, and activity (usually obtained by gamma spectrometry and supplemented by some assumptions regarding the presence of pure beta emitters).

Quantification of the dose to the lens of the eye can be performed in a similar way as for the skin dose.

8.1.4 Estimation of dose to the skin or to the lens of the eye from contamination on protective clothing

The contamination on protective clothing (e.g. gloves) irradiates the skin and contributes to the skin dose. Its contribution to the skin dose should be quantified. After quantification, if its value is higher than the dosemeter reading, it shall be registered as the skin dose value obtained for the monitoring period. When the contamination is homogenous across the protective clothing or located directly at the dosemeter position, the dosemeter reading already takes into account the contribution.

The contamination on protective clothing close to the eye (e.g. lead glasses, plastic glasses, face masks) irradiates the eye and contributes to the dose to the lens of the eye. Its contribution to the eye lens dose should be quantified. After quantification, if its value is higher than the dosemeter reading, it should be registered as the eye lens dose value obtained for the measurement period. When the contamination is homogenous across the protective clothing or located directly at the dosemeter position, the dosemeter reading already takes into account the contribution.

8.2 Estimation of dose from exposure to radioactivity in the air

Radionuclides in the air in the working environment lead to exposure of the personnel. This leads to exposure of the skin and/or the lens of the eye, as well as an internal dose in case of intake or an external effective dose in case they are also gamma emitters. Only assessment of the skin dose and the dose to the lens of the eye are in the scope of this International Standard.

The directional dose-equivalent rate, $H'(0,07)$ caused by radioactive contamination in room air is to be calculated, if necessary, from the radionuclide composition and "concentration" (expressed in terms of activity per volume unit, or derived air concentration, DAC) or should be determined by a measurement of the directional dose-equivalent rate (thin thermoluminescent dosemeters; thin walled ionization chamber). If relevant, the skin dose shall be calculated from the results taking the exposure period into consideration. Dosemeters measuring $H_p(0,07)$ provide in most cases the requested dose value (see 6.1).

Depending on the energy and type of the emitted radiation and the attenuation in protective clothing, e.g. protective eye wear, the dose to the lens of the eye from contaminated air might need to be estimated. The information given in 6.2 is useful when this estimation of dose is performed. Dosemeters measuring $H_p(3)$ provide in most cases the requested dose value (see 6.2). The use of dosemeters measuring other quantities than $H_p(3)$ can be appropriate as well (see Annex B for details).

8.3 Need to correct estimated doses due to contamination of dosemeters

If an individual dosemeter is contaminated, the dosemeter reading is larger than the true dose to the respective individual. If the time the dosemeter has been contaminated, the activity and position of the contamination is known, this excessive reading of the dosemeter can be determined.

National regulations and/or local procedures should be followed when and if corrections of the dose, $H_p(0,07)$ or $H_p(3)$, to the individual should be performed.

When estimations are to be made of the excess dose due to contamination it is possible to approximate the contamination as a 1 cm^2 contaminated area and use tabulated data. Also Table D.2, Annex D gives factors that can be used in such cases. A correction for attenuation in the dosemeter casing is needed when estimating the dose from contamination on the outside of the dosemeter.

Annex A
(normative)

Technical specifications of dosemeters

The following text and Table A.1 were adopted from the IAEA TecDoc No. 1731 "Implications for occupational radiation protection of the new dose limit for the lens of the eye", (slightly modified and updated) by permission.[27] The scope of the IAEA TecDoc also covers neutron radiation while this International Standard only covers photon and beta radiation. Therefore, this Annex contains information regarding neutron radiation although this is not the case in the rest of this International Standard.

In order to ensure an appropriate individual monitoring, the monitors and/or dosemeters should comply with internationally agreed-upon performance requirements. These requirements are stated in standards of the International Electrotechnical Commission (IEC) and the International Organization for Standardization (ISO). Table A.1 provides an overview of these standards.

In contrast to passive dosemeters, active ones (especially electronic devices mainly designed for radiation protection purposes) can have poor performance in pulsed radiation fields, such as are present for example in interventional radiology.[24][25][26] The performance tests with respect to pulsed radiation for electronic monitors and dosemeters published in IEC 62743[27] should be used in addition to the standards given in Table A.1. The term "pulsed radiation" shall be as defined in ISO/TS 18090-1.

No standards are currently available for area monitors measuring the directional dose equivalent at a depth of 3 mm, $H'(3)$. For photons and neutrons, conversion coefficients from the basic quantities air kerma, K_a, or fluence, Φ, to $H'(3)$ have not been internationally agreed on and are therefore not included in publications of the International Commission on Radiation Units and Measurements (ICRU) or the International Commission on Radiological Protection (ICRP) such as ICRU Report 57[28] and ICRP Publication 74,[29] nor are they available in the literature.

Table A.1 — Overview of International Standards for monitors and dosemeters

Type of radiation	Area monitors		Individual dosemeters	
	Active	Passive	Active	Passive
Photon and beta particles	IEC 60846-1 $H'(0,07)$ and $H^*(10)$	IEC 62387 $H'(0,07)$ and $H^*(10)$	IEC 61526 $H_p(0,07)$ and $H_p(10)$	IEC 62387 $H_p(0,07)$, $H_p(3)$, and $H_p(10)$
Neutron	IEC 61005[30] $H^*(10)$	—		ISO 21909-1[31] $H_p(10)$

Annex B
(informative)

Monitoring the dose to the lens of the eye

B.1 General

The following text and tables were adopted from the IAEA TecDoc No. 1731[32] "Implications for occupational radiation protection of the new dose limit for the lens of the eye" (slightly modified and updated) by permission. The scope of the IAEA TecDoc also covers neutron radiation while this International Standard only covers photon and beta radiation. Therefore, this Annex contains information regarding neutron radiation although this is not the case in the rest of this International Standard.

The method to monitor the dose to the lens of the eye mainly depends on the type of radiation to which the worker is exposed: neutron, photon, and beta radiation are covered. For each type of radiation, there are three main impact factors that should be taken into account in monitoring the dose to the lens of the eye:

— A Energy and angle of incident radiation;

— B Geometry of the radiation field (may change during the monitoring period);

— C Usage of personal protective equipment or thick enough shields and their correct use.

For each of the three types of radiation, a separate table dealing with each of these impact factors is provided giving guidance on monitoring the dose to the lens of the eye (see Tables B.1 to B.3). The lines A to C should be read in logical order, i.e. apply at first impact factor A, then B, and finally C. By so doing, all possible cases are covered.

Often, the worker is exposed to more than one type of radiation. Monitoring should therefore be undertaken for all types of radiation contributing more than about 1 mSv in a year, but only in those cases where the total dose to the lens of the eye is estimated to exceed 3/10th of the limit. In a mixed radiation field, more than one dosemeter can be necessary.

Dosemeters should be type tested and calibrated in terms of $H_p(3)$ using an appropriate phantom. If the radiation field is well known, $H_p(3)$ can be estimated by the use of dosemeters type tested and calibrated in terms of other quantities, i.e. $H_p(0,07)$ and $H_p(10)$ as, in many cases, they can provide an adequate estimate of the dose to the lens of the eye (depending on the radiation field). However, in such a case, the qualified expert should be aware that the accuracy of the estimation of the dose to the lens of the eye is lower and the uncertainty of the dose to lens of the eye measurement is likely to increase. In the Tables B.1 to B.3, guidance is given for the cases when dosemeters type tested and calibrated in terms of $H_p(0,07)$ or $H_p(10)$ can be used and indicate the cases when dosemeters type tested and calibrated in terms of $H_p(3)$ have to be used. However, one should be aware that the radiation workplace fields are not always known in advance.

It is noted that in some situations, at least two dosemeters are in use, one under the apron (on the chest) and one over the apron (near the collar). Tables B.1 to B.3 should be taken into account when determining the dose to the lens of the eye from the indication of the one near the collar.

Table B.2 deals with photon radiation. It should be noted that if extremity dosemeters for the quantity $H_p(0,07)$ are used instead of dosemeters for the quantity $H_p(3)$, the dosemeters should:

— either be type tested and calibrated on an appropriate phantom (as is the case for whole body dosemeters for the quantity $H_p(10)$);

— or correctly detect the radiation scattered back from the body (i.e. the head). This is usually the case for extremity dosemeters which do not have thick material on the back wall of the dosemeter. For example, a back wall made of plastic of about 1 mm to 3 mm thickness could be appropriate.[33]

For exposure to a mixed photon/beta radiation field where the maximum beta energy is above 0,7 MeV, and the eyes of the worker cannot be shielded from the beta radiation (although this should usually be possible using glasses made of transparent plastic with a thickness of a few mm), dosemeters for the quantity $H_p(3)$ should be used (see Table B.3). As such dosemeters usually detect both photon and beta radiation, they should be type tested and calibrated using the same method, i.e. for the same quantity and on the same calibration phantom. In the past, the slab phantom (as used for whole body dosemeters for the quantity $H_p(10)$) was suggested for the quantity $H_p(3)$.[34] Recently, a cylinder phantom has been suggested.[35][36][37] Investigations show that using the new cylinder phantom instead of the well-established slab phantom does not significantly improve the quality of measurements except for high incidence angles (larger than 75°: at 90° only the cylindrical phantom can be used for type testing).[38] Therefore, in the absence of a cylindrical phantom, it is recommended that the slab phantom for angles of incidence up to 75° should be used because of its availability and historical use in calibration laboratories.

Table B.1 — Doses due to neutrons

Impact factor	Comment	
A (Energy and angle)	For certain energies and angles of incidence of neutrons, whole body monitoring is not likely to be conservative with respect to dose to the lens of the eye.[39] Therefore, neutron dosimetry of the lens of the eye can become necessary in some workplace situations,[39] however, this needs further investigation.	
B (Geometry)	Are homogeneous radiation fields present?	
	If yes ↓ Monitoring on the trunk can be used.	If no ↓ Monitoring near the eyes is necessary.
C (Protective equipment)	Any personal protective equipment in use cannot adequately protect from neutron radiation.	

Table B.2 — Doses due to photon radiation

<table>
<tr><th>Impact factor</th><th colspan="3">Comment</th></tr>
<tr><td rowspan="3">A
(Energy and angle)</td><td colspan="3">Is the mean photon energy below about 40 keV?</td></tr>
<tr><td>If yes
↓
$H_p(0,07)$ can be used instead of $H_p(3)$ but not $H_p(10)$
(see Reference,[40] Figure 6 and Reference,[41] Figure 1)</td><td colspan="2">If no
↓
Is the radiation coming mainly from the front or is the person moving in the radiation field?</td></tr>
<tr><td>If yes
↓
$H_p(0,07)$ or $H_p(10)$ can be used instead of $H_p(3)$
(see Reference,[41] Figure 1)</td><td>If no
↓
$H_p(0,07)$ can be used instead of $H_p(3)$ but not $H_p(10)$
(see Reference,[41] Figure 1)</td></tr>
<tr><td rowspan="2">B
(Geometry)</td><td colspan="3">Are homogeneous radiation fields present?</td></tr>
<tr><td>If yes
↓
Monitoring on the trunk can be used.</td><td colspan="2">If no
↓
Monitoring near the eyes is necessary.</td></tr>
<tr><td rowspan="2">C
(Protective equipment)</td><td colspan="3">Is protective equipment such as lead glasses, ceiling, table shields, and lateral suspended shields in use?</td></tr>
<tr><td>If used for the eye
↓
Monitoring near the eyes and behind the protective equipment or behind an equivalent layer of material is necessary. Otherwise, appropriate correction factors to take the shielding into account should be applied.</td><td colspan="2">If used for the trunk (e.g. a lead apron)
↓
Monitoring behind the shielding underestimates the dose to the lens of the eye as the eye is not covered by the trunk shielding.
↓
Separate monitoring near the eyes is necessary.</td></tr>
</table>

Table B.3 — Doses due to beta radiation

<table>
<tr><th>Impact factor</th><th colspan="2">Comment</th></tr>
<tr><td rowspan="3">A
(Energy and angle)</td><td colspan="2">Is the maximum beta energy above about 0,7 MeV?</td></tr>
<tr><td>If no
↓
No monitoring due to beta radiation is necessary as it does not penetrate to the lens of the eye.</td><td>If yes
↓
Monitoring is necessary as described in lines B and C.</td></tr>
<tr><td>B
(Geometry)</td><td colspan="2">As beta radiation fields are usually rather inhomogeneous, monitoring of the dose to the lens of the eye is necessary with the dosemeter placed near the eyes. However, it cannot be needed if a thick enough shield is used, see impact factor C.</td></tr>
</table>

Table B.3 *(continued)*

Impact factor	Comment	
C (Protective equipment)	Is protective equipment such as shields and glasses that are thick enough to absorb the beta radiation in use?	
	If used for the eye ↓ Consider "photon radiation" as the beta radiation is completely absorbed in the shielding; however, bremsstrahlung has to be taken into account — the contributions from both that produced outside and that produced inside the shielding.	If not used ↓ $H_p(3)$ is the only appropriate quantity.

Annex C
(informative)

Special considerations in the medical sector

C.1 General

In the literature, some dose values are given for various medical workplace situations. These can in principle be used to judge if monitoring is needed. When using values from the literature, one has to make sure that the data really represent the current workplace conditions regarding the radiation source (for example, which radionuclides or which set-up of X-ray tubes is used), the geometry (for example, under or over couch setting in radiology) and types of radiation protection measures (like shielding) that are used. Examples of literature data can be found here for medical applications.

Updated data can also be found at the homepage of the IAEA: https://rpop.iaea.org/RPOP/RPoP/Content/InformationFor/HealthProfessionals/6_OtherClinicalSpecialities/radiation-cataract/Radiation-and_cataract.htm#top.

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Annex D
(informative)

Special considerations in nuclear power plants

D.1 General

A high percentage of beta radiation has to be expected especially during maintenance work, in nuclear power plants. Also irradiation by low energy photons might need to be considered and special rules need to be respected and particular protection procedures are required for external exposure to this radiation.

Exposures of persons to beta radiation and low energy photons are mainly caused by unshielded open radioactive sources. This type of exposure can occur, in particular, in connection with contamination. Nuclear installations can involve large-area contamination with locally different nuclide composition, which can vary with time. In addition the activity per unit area can assume high values. Particular attention has to be paid to work performed on heavily contaminated parts at close proximity. This requires special rules and procedures for the nuclear power plants, some of which can be applicable to the handling of radioactive sources in other disciplines.

The components on which contamination can occur are, as a rule, known from operational experience. If a high gamma ambient dose equivalent rate is measured on closed components (e.g. pumps, steam generator), a high percentage of weakly penetrating radiation has to be expected when the component is opened.

D.2 Effect of protective clothing

The dose rate to the skin from low penetrating radiation decreases quickly with distance and shielding. Attenuation in air as well as attenuation in protective clothing might lead to low doses to the skin although the dose rate at the surface of a contaminated component is high.

Figure D.1 and Table D.1 can be used when the effect of protective clothing needs to be considered.