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TECDOC No. 1731

Implications for Occupational Radiation Protection of the New Dose Limit for the Lens of the Eye

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IMPLICATIONS FOR OCCUPATIONAL RADIATION PROTECTION OF THE NEW DOSE LIMIT FOR THE LENS OF THE EYE

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IMPLICATIONS FOR OCCUPATIONAL RADIATION PROTECTION OF THE NEW DOSE LIMIT FOR THE LENS OF THE EYE

INTERIM GUIDANCE FOR USE AND COMMENT

INTERNATIONAL ATOMIC ENERGY AGENCY
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FOREWORD

The IAEA Safety Requirements Safety Standards Series No. GSR Part 3 (Interim), Radiation Protection and Safety of Radiation Sources: International Basic Safety Standards, was approved by the IAEA Board of Governors at its meeting in September 2011 and published in November 2011. The equivalent dose limit for the lens of the eye for occupational exposure in planned exposure situations was reduced from 150 mSv per year to 20 mSv per year, averaged over defined periods of five years, with no annual dose in a single year exceeding 50 mSv. This reduction in the dose limit for the lens of the eye follows the recommendation of the International Commission on Radiological Protection (ICRP) in its statement on tissue reactions on 21 April 2011.

At the time when the draft General Safety Requirements (GSR) Part 3 was approved by the Commission on Safety Standards, the Secretariat was asked to develop guidance as early as possible to assist Member States in the observance of the new dose limit.

In the longer term, the guidance provided in this TECDOC will form the basis for the consensus guidance in relation to the new dose limit for the lens of the eye that is to be provided in two safety guides currently being developed, Occupational Radiation Protection and Radiation Safety in the Medical Uses of Ionizing Radiation. It is expected that these will be published in 2015–2016. It is recognized that guidance material is required before the two safety guides are finalized in order to give Member States the opportunity to put appropriate actions in place and to plan for the introduction of the new dose limit for the lens of the eye.

The purpose of the current publication is to provide advice on the implications for occupational radiation protection of the new dose limit for the lens of the eye and to allow comment on detailed recommendations that may be incorporated into the safety guides.

The IAEA wishes to acknowledge the contributions of A. Wrixon (United Kingdom) and R. Behrens (Germany) in the preparation of this publication. The IAEA officer responsible for this publication was T. Boal of the Division of Radiation, Transport and Waste Safety.

EDITORIAL NOTE

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1. INTRODUCTION

1.1 BACKGROUND

The Radiation Protection and Safety of Radiation Sources: International Basic Safety Standards was approved by the Board of Governors of the International Atomic Energy Agency (IAEA) at its meeting in September 2011 and was issued as General Safety Requirements Part 3, GSR Part 3 (Interim) in November 2011[1] [1]. This publication supersedes the previous International Basic Safety Standards issued in 1996 [2].

The requirements in GSR Part 3 (Interim) are governed by the objectives, concepts and principles of the Fundamental Safety Principles [3] and draw upon information derived from the experience of States in applying the requirements of the previous International Basic Safety Standards [2]. They also draw upon the extensive research on the health effects of radiation exposure, in particular the findings of the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) and the Recommendations of the International Commission on Radiological Protection (ICRP). In addition, when the Board of Governors of the IAEA first approved radiation protection and safety measures in March 1960 [4], it was stated that 'The Agency's basic safety standards ... will be based, to the extent possible, on the recommendations of the International Commission on Radiological Protection (ICRP).'

The review and subsequent revision of the previous International Basic Safety Standards was initiated during the development of new ICRP recommendations [5]. These recommendations, finalized in 2007, reiterated ICRP's three general principles of radiation protection, which concern justification of exposure, optimization of protection and application of dose limits. These are also to be found in the Fundamental Safety Principles [3]. The ICRP recommendations also maintained the numerical values of the dose limits found in its earlier recommendations [6] and the previous International Basic Safety Standards [2]. However, ICRP pointed out at the time that the annual equivalent dose limit for the lens of the eye was currently being reviewed by an ICRP Task Group, account being taken of new data on the radiosensitivity of the eye with regard to visual impairment. Since then, ICRP has published its review of recent epidemiological evidence that suggests that there are some deterministic effects[2] of radiation exposure, particularly those with very late manifestation, where threshold doses are or might be lower than previously considered [7]. For the lens of the eye, the threshold in absorbed dose is now considered to be 0.5 Gy and, on that basis, ICRP has revised downwards its recommended dose limit for the lens of the eye. The revised dose limit was subsequently incorporated into GSR Part 3 (Interim) [1].

At the time that GSR Part 3 (Interim) was approved by the Commission on Safety Standards, the IAEA Secretariat was asked to develop guidance as early as possible to assist Member States in the observance of this new dose limit for the lens of the eye. As a first step towards the development of such guidance, the IAEA Secretariat, in October 2012, held a Technical Meeting on 'The New Dose Limit for the Lens of the Eye—Implications and Implementation' as a prelude to the development of a TECDOC in 2013. In the longer term, the interim guidance provided in the TECDOC and experience gained in its application will be used as input to a number of Safety Guides that are currently being revised—on occupational

[1] The jointly sponsored edition of GSR Part 3 will be issued in 2014.

[2] A deterministic effect is a health effect of radiation for which generally a threshold level of dose exists above which the severity of the effect is greater for a higher dose [1]. ICRP now uses the term 'harmful tissue reactions' [5] or simply 'tissue reactions' [7].

radiation protection, and on radiation safety in the medical uses of ionizing radiation. It is expected that these Safety Guides will be published in 2015–2016. The intention is that these Safety Guides will supersede a number of existing Safety Guides [8-13] and Safety Reports [14-16].

1.2 OBJECTIVE

Pending the development of a number of Safety Guides dealing with occupational radiation protection, this TECDOC provides interim guidance on the implications for occupational radiation protection due to the new dose limit for the lens of the eye that is established in the GSR Part 3 (Interim) [1]. It is also intended to provoke discussion that will lead to the establishment of consensus on the guidance that should be given on the matter in the Safety Guides that are currently being drafted.

1.3 SCOPE

This TECDOC provides interim guidance on the implications of the new dose limit for the lens of the eye for occupational radiation protection that is applicable to planned exposure situations. It also provides guidance on the protection of the lens of the eye of emergency workers. It amends the guidance on protection of the lens of the eye given in a number of existing Safety Guides, particularly RS-G-1.1 [8] and RS-G-1.3 [10], but otherwise complements these guides.

The interim guidance does not apply to cosmic ray exposure of aircrew[3].

This interim guidance is intended for use by regulatory bodies, licensees and employers in hospitals, general industry and nuclear installations; and management and personnel in such facilities, including radiation protection officers, industrial radiographers, medical physicists, cardiologists, interventional radiologists and other medical specialists and health professionals involved in image guided interventional procedures. It is also intended for use by Member States in the development of consensus on the guidance on protection of the lens of the eye that will be given in the relevant Safety Guides that are currently being drafted.

1.4 STRUCTURE

Section 2 of this TECDOC provides a summary of the relevant biological information relating to the new dose limit for the lens of the eye. Section 3 provides guidance on the workers who might be affected by the change in this dose limit and the actions that should be taken to implement the change. It covers the optimization of protection (including training), monitoring and health surveillance of these workers. Annex I provides a summary of the occupational dose limits for exposure of the lens of the eye. Annex II provides typical values for equivalent dose to the lens of the eye per procedure in interventional radiology. Annex III provides guidance for medical practices where staff might receive significant doses to the lens of the eye.

[3] Exposure to ionizing radiation is inevitable for air crew members and is regarded in GSR Part 3 (Interim) [1] as an existing exposure situation to which the dose limits do not apply. However, due to the homogeneity of the radiation field the dose to the lens of the eyes can be assumed to be quite similar to the effective dose, which is normally of the order of a few millisieverts in a year.

2. THE SCIENTIFIC BASIS FOR THE CHANGE IN THE DOSE LIMIT

For occupational exposure in planned exposure situations, the revised equivalent dose limits for the lens of the eye are 20 mSv in a year, averaged over 5 consecutive years (i.e. 100 mSv in 5 years), and 50 mSv in any single year [1]. These limits replace the previous limit on equivalent dose of 150 mSv in a year [2].

Limits on equivalent dose to the lens of the eye (and extremities and the skin) have been seen as necessary to ensure the avoidance of deterministic effects. The limit on effective dose was not considered to be sufficient for this purpose, particularly in the case of localized radiation exposure.

The previous limit on equivalent dose to the lens of the eye of 150 mSv in a year was based on a dose threshold of 0.5–2 Gy for single acute (or brief) exposure and 5 Gy for protracted exposure for detectable opacities and 5 Gy for single acute (or brief) exposure and 8 Gy following fractionated or prolonged exposure for visual impairment (cataract) [6]. However, some of the earlier epidemiological studies, on which this limit was based may not have had sufficient follow-up to detect either radiation-induced lens changes or visual disability requiring cataract surgery. In addition, better techniques for detecting, quantifying, and documenting early radiation-associated lens changes, as well as better dosimetry, may have been factors that contributed to the more recent findings of radiation-induced cataracts at low exposures.

In ICRP Publication 118 [7], ICRP presented its review of recent epidemiological evidence regarding the induction of deterministic effects and concluded that there were some deterministic effects, particularly those with very late manifestation, where threshold doses were or might have been lower than previously considered. Threshold dose was defined for practical purposes as the dose resulting in 1% incidence of specified tissue or organ reactions (i.e. deterministic effects) [5, 7].

The following reproduces the relevant part of the executive summary from ICRP Publication 118 [7]:

“For cataracts in the lens of the eye induced by acute exposures, recent studies, where formal estimates of threshold doses have been made after long follow-up periods, indicate values of approximately 0.5 Gy with 90–95% confidence intervals including zero dose. This is lower by a factor of 10 than deduced in earlier studies. Those studies generally had short follow-up periods, failed to consider the increasing latency period as dose decreases, did not have sufficient sensitivity to detect early lens changes using the various techniques employed, and had relatively few subjects with doses below a few Gy. For fractionated and protracted exposures, values of approximately 0.5 Gy have been similarly deduced from recent studies. However, the evidence pertaining to the latter exposures mainly refers to opacities rather than cataracts impairing vision because the follow-up times are shorter in those studies. For chronic exposure over several to many years, much of the evidence refers to minor lens opacities. Nonetheless, there is no indication that the threshold accumulated doses are higher in this scenario. These are no established mitigators of lens radiation injury leading to opacities or cataracts, but lens replacement is a well-established surgical procedure.”

The previous judgement that acute doses up to approximately 0.1 Gy produce no functional impairment of tissues was maintained by ICRP [7]. The stochastic risks of radiation-induced cancer and hereditary effects therefore continue to be the principal risks to consider for most

applications of GSR Part 3 (Interim) [1] in occupational situations. However, after acute or accumulated doses of more than 0.5 Gy, the risk of deterministic effects becomes increasingly important for the lens of the eye, at very long times after radiation exposure. There is no indication that protracted delivery of the dose is less damaging than acute exposure.

The dose limits for occupational exposure given in GSR Part 3 (Interim) [1] are reproduced in Annex I.

3. IMPLICATIONS OF THE NEW DOSE LIMIT FOR THE LENS OF THE EYE

The implications of the changes in the dose limit for the lens of the eye given in this section should be read in conjunction with GSR Part 3 (Interim) [1] and the overall guidance for occupational radiation protection given in the currently applicable Safety Guides, particularly RS-G-1.1 [8] and RS-G-1.3 [10]. Only those parts of the guidance that are relevant to the protection of the lens of the eye are amended by this new guidance. The relevant requirements and guidance given in these Safety Standards are only reiterated insofar as it is necessary to give the appropriate context to the amended guidance.

3.1 SAFETY ASSESSMENT

The regulatory body is required to establish and enforce requirements for safety assessment, and the person or organization responsible for a facility or activity that gives rise to radiation risks shall conduct an appropriate safety assessment of this facility or activity (Requirement 13 of Ref. [1]). These assessments should cover all aspects of a practice that are relevant to protection and safety and are required to be conducted at different stages, including the stages of siting, design, manufacture, construction, assembly, commissioning, operation, maintenance and decommissioning (or closure) of facilities or parts thereof, among others things, in order to:

- Identify the ways in which exposures could be incurred;
- Determine the expected magnitudes and likelihood of exposures in normal operation and, to the extent reasonable and practicable, make an assessment of potential exposures;
- Assess the adequacy of the provisions for protection and safety[4].

As indicated in Safety Guide RS-G-1.1 [8], the prior radiological evaluation and safety assessment is the first step towards the definition of a radiation protection programme for a practice or facility[5]. Such programmes may relate to all phases of a practice or the lifetime of a facility, i.e. from design through commissioning and operation to decommissioning. Consideration of protection of the lens of the eye should be given at all of these stages.

The principal parties (e.g. employers, registrants and licensees) are required to promote and maintain a safety culture (Ref. [1], para. 2.51). One of the identified mechanisms for doing this is by 'encouraging the participation of workers and their representatives and other relevant persons in the development and implementation of policies, rules and procedures dealing with protection and safety'. It therefore follows that existing radiation protection programmes, particularly for the operational phase, should be updated as necessary, in conjunction with the workers involved and their representatives. The updating of the radiation

[4] These requirements are expressed somewhat differently in the context of operations in RS-G-1.1 [8] as follows: 'The prior radiological evaluation should include, for all aspects of operations:
(a) An identification of the sources of routine and reasonably foreseeable potential exposures;
(b) A realistic estimate of the relevant doses and probabilities;
(c) An identification of the radiological protection measures needed to meet the optimization principle.'

[5] It is noted that Requirement 24 of GSR Part 3 (Interim) [1] requires the establishment and maintenance of organizational, procedural and technical arrangements for the designation of controlled areas and supervised areas, for local rules and for monitoring of the workplace, in a radiation protection programme for occupational exposure.

protection programmes should be on the basis of the guidance given in the following paragraphs.

Each registrant or licensee should therefore review the safety assessment to:

- Identify if any workers might receive a significant dose to the lens of the eye (e.g. of the order of a few mSv in a year), in particular, those for whom the dose limit for the lens of the eye will be more restrictive than the limit on effective dose, e.g. due to localised exposure or exposure with weakly penetrating radiation such as beta particles and or photons of low energies;

- Ensure that equipment and installations are designed such that protection is optimized with due account being taken of the exposure of the lens of the eye;

- Establish operational procedures, as necessary, to ensure that protection is optimized with due account being taken of the exposure of the lens of the eye;

- Require the use of personal protective equipment by workers when the design of equipment and installations and the operational procedures are not sufficient to ensure that protection is optimized with due account being taken of the exposure of the lens of the eye.

In reviewing the safety assessment, registrants and licensees should take account of any generic safety assessments that may be available in the literature—to identify the groups of workers at risk and the doses that they might receive.

3.2 WORKERS FOR WHOM EXPOSURE OF THE LENS OF THE EYE MIGHT BE IMPORTANT

Three categories of workers who might routinely receive significant doses to the lens of the eye need to be considered:

- Those exposed to a relatively uniform whole-body (penetrating) radiation field;

- Those exposed to highly non-uniform radiation fields in which the lens of the eye may be preferentially exposed;

- Those exposed to weakly penetrating radiation, such as beta particles or photons of low energies (below about 15 keV), significantly contributing to the dose to the lens of the eye but not to the effective dose.

Workers exposed solely to alpha particles or other high-LET radiation need not be considered in view of their limited range in tissue. It is recognized that neutron exposure is unlikely to be the most significant contributor to eye dose, but it is likely to be the most complex to assess.

For the first category of workers, if the protection measures result in the field becoming non-uniform, for example, through the use of shielding that reduces the dose (or the probability of a dose being received) to the trunk of the body, but not the head, should specific consideration of the protection of, including monitoring of the dose to, the lens of the eye be necessary. This situation is covered by the second category of worker.

Workers in the second category include the following:

- Those whose trunks may be shielded but not the head;
- Those whose heads are close to a source of penetrating radiation;
- Those who are exposed to beta radiation.

These three groups overlap substantially. The intention is simply to indicate the types of situation to which attention may need to be paid.

The third category of workers covers the rather seldom case where the workers receive a more or less homogeneous exposure to weakly penetrating radiation. This category may be to some degree of theoretical nature but is mentioned here for the sake of completeness.

In the past when the dose limit for the lens of the eye was 150 mSv in a year, routine monitoring of the dose to the lens was rare. With the introduction of the new dose limits, the number of workers requiring specific monitoring of the dose to the lens of the eye is likely to increase. The following provides some examples of where monitoring should be considered, but these examples should not be regarded as comprehensive.

Medical workers

The largest groups of such workers potentially affected by the reduction in the dose limit for the lens of the eye are in the medical sector [17]. These include:

- Staff working in close proximity to patients in fluoroscopy guided interventional procedures;
- Staff carrying out some tasks in nuclear medicine such as preparation of sources/radiopharmaceuticals, PET/CT, particularly if beta-radiation sources are used;
- Staff involved in manual brachytherapy;
- Staff involved in CT-guided interventional procedures, including biopsies;
- Staff working with cyclotrons.

In its Publication 113 [18], ICRP noted that there was evidence of a risk of lens opacity among those working in cardiac catheterization laboratories where radiation protection had not been optimized. It specifically noted that risks to the lens of the eye should be considered in interventional radiology and interventional cardiology. In Publication 120 [19], ICRP further noted that surveys of cardiologists and support staff working in catheterization laboratories had found a high percentage of lens opacities attributable to occupational radiation exposure when radiological protection tools had not been used properly and radiation protection principles have been ignored. There have been reports of radiation-induced cataract in interventionalists who have received equivalent doses to the lens of the eye approaching the annual limit of 150 mSv over a number of years [20, 21, 22, 23, 24, 25]. Several surveys of cardiologists and support staff working in catheterization laboratories, in Latin America and Asia, have found a high prevalence of lens opacities of the type associated with occupational radiation exposure [21, 26].

Padovani et al. [27] have reported that approximately 10% of a sample of over 200 interventional cardiologists received estimated doses to the lens of the eye exceeding the new dose limit, based on either over-apron or lens specific dosimeters. Examples of the typical values for the equivalent dose to the lens of the eye for various interventional procedures are provided in Annex II. Recommendations emphasizing the need for optimization of protection measures with respect to the lens of the eye for interventional cardiology, prepared by the IAEA Working Group on Interventional Cardiology (WGIC) in the Information System on Occupational Exposure in medicine, Industry and Research (ISEMIR) project are presented in Annex III. An indication of typical doses to the lens of the eye of operators involved in interventional radiology and cardiology procedures can also be found in the ORAMED project report [28].

Workers in nuclear facilities

The main workers affected by the proposed dose limit for the lens of the eye in the nuclear sector are thought to be [29]:

- Those using glove boxes;
- Those working on decommissioning of nuclear facilities;
- Those handling plutonium or depleted uranium.

Other workers

The only other group of workers so far identified is industrial radiographers. The IAEA Working Group on Industrial Radiography (WGIR), established under the ISEMIR project, has reported on the current practice of occupational radiation protection in industrial radiography [30]. Thirty-three regulatory bodies provided annual effective dose data for industrial radiographers for the year 2009. The average annual effective dose for nearly 18 000 monitored industrial radiographers was 2.9 mSv, with a reported maximum annual dose of 158 mSv. The reported doses for the majority of industrial radiographers (86%) was less than 5 mSv in 2009, nearly 350 industrial radiographers (2%) received an effective dose greater than 20 mSv, and nearly 50 radiographers (0.3%) received a dose greater than 50 mSv.

WGIR did not request regulatory bodies, industrial radiographers or companies carrying out NDT on the availability of equivalent dose to the lens of the eye. As industrial radiographers work in a relatively homogenous radiation field, separate monitoring of the dose to the lens of the eye has not normally been considered necessary.

Accidental exposures

Workers in a number of industries are at risk of elevated doses to the lens of the eye from accidental exposures.

In industrial radiography, Le Heron et al. [30] has reported that 82 (approximately 20%) of the 432 industrial radiographers from 31 countries who responded to the WGIR questionnaire stated that they had an accident, near miss or deviation with respect to radiation in the previous 5 years. Eleven accidents had resulted in individual exposures greater than the annual dose limit were reported by the employer (non-destructive testing (NDT) company) to the regulatory body. When accidents occur, the radiation field at the radiographer's position

may not be homogenous, and the reading of the whole body individual dosimeter worn by the worker may no longer be a surrogate for the dose received by the lens of the eye.

In nuclear medicine departments, staff may receive significant doses to the lens of the eye due to incidental ocular contamination with radiopharmaceuticals during their preparation.

3.3 OPTIMIZATION OF PROTECTION

The balancing of the costs involved in reducing the detriment caused by radiation exposure against the benefit accrued has long been part of the process of optimizing protection and safety [31]. As a consequence, the focus has been on reducing the effective dose caused by a particular practice, rather than the equivalent dose to particular organs. The main concern with doses to particular organs was to ensure that they remained below the relevant equivalent dose limit in order to prevent the induction of deterministic effects.

The concept of optimization of protection and safety is now regarded more generally, being defined 'the process of determining what level of protection and safety would result in the magnitude of individual doses, the number of individuals (workers and members of the public) subject to exposure and the likelihood of exposure being as low as reasonably achievable, economic and social factors being taken into account' [1]. The implication is that all doses, whether effective or equivalent, should be kept as low as reasonably achievable[6]. This is not unreasonable in the context of the equivalent dose to the lens of the eye because, although the dose limit is based on the assumption that radiation-induced cataracts are deterministic in nature, there is a strengthening argument that such effects may, after all, be governed by stochastic processes and there may be no dose threshold [7]. The evidence comes from the observed dose–risk relationship for cataract induction at higher doses, which do not rise as steeply as in the typical case for deterministic effects [32, 33, 34].

Employers, registrants and licensees are required to minimize the need to rely on administrative controls and personal protective equipment for protection and safety by providing well engineered controls and satisfactory working conditions, in accordance with the following hierarchy of preventive measures:

- Engineered controls;
- Administrative controls;
- Personal protective equipment (Ref. [1], para. 3.93).

It should be noted that the optimization of protection of workers can sometimes lead to increased exposure of other workers or members of the public or, in the medical field, increased exposure of patients or a reduction in the efficacy of the clinical procedure. Such impacts should be taken into account in determining the appropriate arrangements to be used, particularly in establishing the administrative controls and the use of personal protective equipment. In particular, the arrangements for the protection of staff should take account of the exposure of other workers, members of the public, and the patient, and the clinical outcome, as appropriate.

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[6] Even so, limiting the effective dose is more important than limiting the dose equivalent to the lens of the eye because induction of cancer should be considered as a more serious consequence of radiation exposure than induction of cataracts.

Engineered controls

In general, the optimization of protection with due account being taken of the exposure of the lens of the eye should be considered first and foremost at the design stage of equipment and installations, when some degree of flexibility is still available. As noted in RS-G-1.1, the prior radiological evaluation or safety assessment "will help to determine what can be achieved at the design stage to establish satisfactory working conditions through the use of engineered features" (Ref. [8], para. 5.6). One example of such engineered features given in RS-G-1.1 [8] is the provision of shielding being part of the installation, e.g. a lead glass shield[7], which is important in the context of protection of the lens of the eye. Guidance on the shielding against diagnostic medical X rays is being developed by the International Electrotechnical Commission (IEC) [35, 36].

Administrative controls

If the design of equipment and the workplace is not sufficient to achieve an optimized level of protection with due account being taken of the exposure of the lens of the eye, then consideration should be given to the establishment of operational procedures and restrictions (administrative controls). These should be expressed in written local rules and procedures, prepared in consultation with workers or through their representatives.

Where specific measures are required to control exposure of the lens of the eye in normal operations or to limit the likelihood and magnitude of exposures in anticipated operational occurrences and accident conditions, controlled areas should be designated. Any area that is not already designated as a controlled area but in which the occupational exposure conditions need to be kept under review, even though specific measures for protection and safety are not normally needed, should be designated as a supervised area. All of these matters constitute part of the radiation protection programme, which should be communicated to the affected workers.

Personal protective equipment

If the above measures are not sufficient to achieve an appropriate level of protection and safety, the use of personal protective equipment may be necessary. In particular, consideration should be given to protecting the lens of the eye using the appropriate protective glasses. Glasses made of Perspex may be sufficient when the exposure is predominantly due to beta radiation. Account however should be taken of any bremsstrahlung generated by high-energy beta radiation. When the exposure is predominantly due to penetrating radiation (gamma or X rays) consideration should be given to the use of protective glasses containing lead.

If conventional industrial safety glasses are to be used, for example, to protect against beta-radiation exposure, then they should be evaluated for their shielding properties beforehand. Similarly, protective glasses containing lead should also be evaluated before use in protecting against penetrating radiation. Protective glasses containing lead may well be adequate for protecting against low-energy X rays, but totally inadequate for protecting against higher-energy gamma radiation. Methods for such evaluations for X rays have been developed by the International Electrotechnical Commission (IEC) [36].

[7] In some practices, two ceiling suspended screens should be considered [37].

The radiation attenuation factor of the eyeglass lenses is not an adequate descriptor on its own of the effectiveness of the eyewear in reducing radiation exposure [19]. The area covered by the lenses should also be considered. Glasses should be fitted with side shields and should fit properly [19, 34, 38]. The specific conditions at the workstations, i.e. the radiation fields, the exposure and the incidence of the radiation with respect to the lens of the eye, should be analysed. The IEC provides further guidelines for the design of such personal protective equipment [39].

Care should be taken to ensure that the use of personal protective equipment, such as protective glasses, does not unduly impede operation or lead to a significant increase in the effective dose (Ref. [1], para. 3.95(e)).

Review of safety assessment, radiation protection programme and efficacy of equipment

The safety assessment, amended to take into account the new dose limit for the lens of the eye, is required to be kept under review to ensure that the technical specifications or conditions of use continue to be met (Ref. [1], para. 3.35). Furthermore, the radiation protection programme, including the local rules and procedures and the use of personal protective equipment should be kept under review and amended, as appropriate, to ensure that the protection of workers (and patients, where necessary) is optimized.

The performance of protection equipment, such as protective glasses, should be checked at appropriate intervals to ensure that the necessary level of protection is being maintained.

Information, instruction and training

The regulatory body is required to establish or adopt regulations and guides for protection and safety and establish a system to ensure their implementation (Requirement 3 of Ref. [1]). The regulatory body is required among other things to include in the regulatory system provision of information to, and consultation with, parties affected by its decisions. It should therefore ensure that the new information on the biological effects of radiation exposure of the lens of the eye and the consequential changes in the regulatory requirements and guides are appropriately disseminated to employers, registrants and licensees.

Employers, registrants and licensees are required to provide workers with adequate information, instruction and training for protection and safety (Requirement 26 of Ref. [1]). Further, employers, in cooperation with registrants and licensees, are required to provide workers with adequate information on health risks due to their occupational exposure (Ref. [1], para. 3.10). Thus, employers, in cooperation with registrants and licensees, should provide this new information and the associated regulatory requirements and guides to those workers who might be affected. They should also keep these workers informed on any relevant changes to the radiation protection programme, local rules, operating procedures, etc. Those requiring this information, and, as appropriate, training, include:

- Qualified experts;
- Radiation protection officers;
- Medical physicists;

- Workers (including medical doctors, nurses, etc.) who may be at risk of receiving significant doses to the lens of the eye;

- Equipment service engineers.

Guidance on the topics that should be covered in a training programme is given in RS-G-1.1 (Ref. [8], para. 5.95). In the context of the protection of the lens of the eye, the following points are made:

- Training of workers should cover how to protect themselves and others who may be affected by their work from exposure to radiation. In particular, in the medical area, training should be linked to training on the protection of the patient;

- Training should cover where to wear dosimeters to estimate the doses to the lens of the eye (see next subsection);

- Training should cover what type of personal protective equipment (protective glasses, ceiling suspended screens and other shielding) should be used and its effectiveness and when and how to use it;

- Training of staff undertaking interventional fluoroscopy should cover the effect of orientation of the radiation field on the exposure of the lens of the eye.

3.4 MONITORING OF DOSES TO THE LENS OF THE EYE DUE TO EXTERNAL RADIATION

The most accurate method for monitoring the equivalent dose to the lens of the eye, H_{lens}, is to measure the personal dose equivalent at 3 mm depth, $H_p(3)$, with a dosimeter worn as close as possible to the eye and calibrated on a phantom representative of the head. As this procedure may be impractical, other methods may be used such as evaluating $H_p(3)$ through $H_p(10)$ or $H_p(0,07)$ both measured with dosimeters worn on the trunk or an $H_p(0,07)$ dosimeter worn near the eyes, or monitors for measuring $H'(0.07)$, $H'(3)$ or $H^*(10)$.

Performance requirements for monitors and dosimeters

In order to ensure an appropriate individual monitoring, the monitors and/or dosimeters should comply with internationally agreed performance requirements. At present, dosimeters designed for $H_p(3)$ are not broadly available and monitors and dosimeters for other quantities may be used. These requirements are stated in standards of the International Electrotechnical Commission (IEC) and the International Organization for Standardization (ISO). Table 1 provides an overview of these standards.

If an extremity dosimeter passes a type test in terms of $H_p(3)$ it can be calibrated accordingly. Another way is to modify a dosimeter for $H_p(0.07)$ to directly measure $H_p(3)$. An example for this is published [40]. In such a case, even though the dosimeter may need improvement in performance, the dosimetric performance for the lens of the eye dose assessment is then straightforward: $H_p(3)$ response is known and the estimate of the dose to the lens of the eye is directly estimated without taking into account the workplace radiation field information (i.e. energy and angle of incidence). However, only if information on the workplace radiation fields are available, dosimeters type tested and calibrated in terms of $H_p(0.07)$ or $H_p(10)$ can be used in order to estimate a conservative value for $H_p(3)$. In such a case, one should know

that the accuracy of the measurement is then lower and those measured dose values, which lead to a dose to the lens of the eye close to the limit should be carefully considered.

In contrast to passive dosimeters, 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 [41] [42] [43]. The performance tests with respect to pulsed radiation for electronic monitors and dosimeters published by IEC [44] should be used in addition to the standards given in Table 1. The term 'pulsed radiation' is defined in a technical specification from ISO [45].

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 quantity air kerma, K_a, 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 [46] and ICRP Publication 74 [47], nor are they available in the literature.

TABLE 1. OVERVIEW OF INTERNATIONAL STANDARDS FOR MONITORS AND DOSIMETERS

Type of radiation	**Area monitors**		**Individual dosimeters**	
	active	**passive**	**active**	**passive**
Photon and beta particles	IEC 60846-1 [48] $H'(0.07)$ and $H^*(10)$	IEC 62387 [49] $H'(0.07)$ and $H^*(10)$	IEC 61526 [50] $H_p(0.07)$ and $H_p(10)$	IEC 62387 [49] $H_p(0.07)$, $H_p(3)$, and $H_p(10)$
Neutron	IEC 61005 [51] $H^*(10)$	---		ISO 21909 [52] $H_p(10)$

Estimation of dose levels prior to routine monitoring

Prior to undertaking routine individual monitoring, the dose to the lens of the eye in a workplace field situation should be estimated in order to determine which method, if any, and which interval of routine monitoring, should be used. Routine monitoring of the dose to the lens of the eye should be undertaken if the provisional estimation indicates that the annual equivalent dose to the lens is likely to exceed a dose of the order of 5 mSv.

The doses may be estimated by one or more of the following methods:

- Workplace monitoring;
- Use of literature data;
- Use of simulations;
- Use of confirmatory measurements, i.e. individual monitoring for a limited time.

Workplace monitoring

In work situations with radiation fields that are predictable over a long period (at least for several months) and with well-established procedures, it is possible to estimate the doses which workers will receive using workplace monitoring at relevant locations. As no area monitors for $H'(3)$ are currently available, special care should be taken in the choice of the measuring instrument. Tables 3 and 4 give guidance on how to choose the appropriate dosimeter and quantity (H_p should be replaced by H' in these tables if ambient dosimetry is being considered). The location of measurement should be representative of the conditions under which individuals will be exposed.

The estimation of dose should be repeated if the working conditions or workload change significantly such that the estimation is no longer valid.

Use of literature data

Some information on dose may be given in the literature for various workplace situations [53]. These can, in principle, be used to judge if monitoring is needed. The data should properly reflect the workplace conditions regarding the radiation source (e.g. the radionuclides or the voltage of the X ray tubes) and the geometry (e.g. under- or over-couch setting in radiology). Examples of data taken from the literature can be found in Annex II.

Use of simulations

Numerical simulations can be very powerful and can be used to obtain important information on the parameters that influence the doses that would be received in given exposure scenarios [28, 54]. There are no readily available packages that can be used to obtain a rapid estimation of the dose to the lens of the eye of the operator, but general purpose numerical codes [55, 56, 57] can be applied to the particular situation. Simulations are often complex and time consuming, depending on the situation. The results from the use of simulations should be verified by sample measurements.

Use of confirmatory measurements, i.e. individual monitoring for a limited time

Another way to determine if individual monitoring is needed is by performing confirmatory measurements with individual dosimeters. Such confirmatory measurements should:

- Mimic routine measurements and be performed as described in the next subsection;
- Be performed for a minimum of three consecutive periods. The intention is to have a representative sample of the annual doses. Special care should be taken choosing the dosimeter as it should be appropriate for the type of radiation present. If the work activities are very irregular (large fluctuations from month to month), longer periods of monitoring are needed. In some cases, confirmatory measurements for a whole year might be needed.

Routine monitoring

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 within this

TECDOC. 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 its 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 2 to 4. 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, in line with the recommendation in the Safety Guide RS-G-1.1 (Ref. [8], para. 5.64), but only in those cases where the total dose to the lens of the eye is estimated to exceed 5 mSv. In a mixed radiation field, more than one dosimeter may be necessary (see Table 5).

Dosimeters 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 dosimeters 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. 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 2 to 4, guidance is given for the cases when dosimeters type tested and calibrated in terms of $H_p(0.07)$ or $H_p(10)$ can be used and indicate the cases when dosimeters 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 dosimeters are in use, one under the apron (on the chest) and one over the apron (near the collar). Tables 2 to 4 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 3 deals with photon radiation. It should be noted that if extremity dosimeters for the quantity $H_p(0.07)$ are used instead of dosimeters for the quantity $H_p(3)$, the dosimeters should:

- Either be type tested and calibrated on an appropriate phantom (as is the case for whole body dosimeters 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 dosimeters which do not have thick material on the back wall of the dosimeter. For example, a back wall made of plastic of about 1 to 3 mm thickness could be appropriate [58].

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), dosimeters for the quantity $H_p(3)$ should be used (see Tables 4 and 5). As such dosimeters 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 dosimeters for the quantity $H_p(10)$) was suggested for the quantity $H_p(3)$ [59]. Recently, a cylinder phantom has been suggested [60, 61, 62]. 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) [63]. 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 2. DOSES DUE TO NEUTRONS

<table>
<tr><th>Impact factor</th><th colspan="2">Comment</th></tr>
<tr><td>A
(Energy and angle)</td><td colspan="2">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 [64]. Therefore, neutron dosimetry of the lens of the eye may become necessary in some workplace situations [64], however, this needs further investigation.</td></tr>
<tr><td rowspan="2">B
(Geometry)</td><td colspan="2">Are homogeneous radiation fields present?</td></tr>
<tr><td>If yes
↓
Monitoring on the trunk may be used.</td><td>If no
↓
Monitoring near the eyes is necessary.</td></tr>
<tr><td>C
(Protective equipment)</td><td colspan="2">Any personal protective equipment in use may not adequately protect from neutron radiation.</td></tr>
</table>

TABLE 3. 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
↓
$H_p(0.07)$ may be used but not $H_p(10)$
(see Fig. 6 in Ref. [65] and Fig. 1 in Ref. [66])</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 $H_p(10)$ may be used
(see Fig. 1 in Ref. [66])</td><td>If no
↓
$H_p(0.07)$ may be used but not $H_p(10)$
(see Fig. 1 in Ref. [66])</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 may 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 below the protective equipment or below 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 below 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 4. DOSES DUE TO BETA RADIATION

<table>
<tr><th>Impact factor</th><th colspan="2">Comment</th></tr>
<tr><td rowspan="2">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 dosimeter placed near the eyes. However, it may not be needed if a thick enough shield is used, see impact factor C.</td></tr>
<tr><td rowspan="2">C
(Protective equipment)</td><td colspan="2">Is protective equipment such as shields and glasses that are thick enough to absorb the beta radiation in use?</td></tr>
<tr><td>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.</td><td>If not used
⬇
$H_p(3)$ is the only appropriate quantity.</td></tr>
</table>

TABLE 5. GUIDANCE ON THE CHOICE OF DOSIMETERS NECESSARY TO MONITOR THE DOSE TO THE LENS OF THE EYE IN MIXED RADIATION FIELDS[8] REGARDING THE TYPE AND POSITION OF DOSIMETERS TABLES 2 TO 4 APPLY.

Radiation in the field			**Necessary types of dosimeters**
Neutron	**Photon**	**Beta above 0.7 MeV**	
x [1]			One $H_p(10)$-dosimeter for neutrons
	x		One $H_p(0.07)$- and/or one $H_p(10)$-dosimeter for photons
		x	One $H_p(3)$-dosimeter for beta radiation
x	x		One $H_p(10)$-dosimeter for neutrons and one $H_p(0.07)$- and/or one $H_p(10)$-dosimeter for photons
x [1]		x	One $H_p(10)$-dosimeter for neutrons and one $H_p(3)$-dosimeter for beta radiation
	x	x	One $H_p(3)$-dosimeter for photons and beta radiation
x	x	x	One $H_p(10)$-dosimeter for neutrons and one $H_p(3)$-dosimeter for photons and beta radiation

[1] It is noted that neutron radiation is almost always accompanied by photon radiation but the possibility of neutron radiation alone is listed here for the sake of completeness.

[8] In addition, further dosimeters may be necessary to monitor the effective dose and/or the dose to the skin.

3.5 HEALTH SURVEILLANCE

Programmes for worker's health surveillance are required to be:

- Based on the general principles of occupational health;
- Designed to assess the initial fitness and continuing fitness of workers for their intended tasks (Ref. [1], para. 3.108).

The Safety Guide RS-G-1.1 (Ref. [8], para. 7.2) states that further objectives are to provide a baseline of information that can be used in the case of accidental exposure to a particular hazardous agent or occupational disease and for specific counselling of workers with respect to any radiological risks to which they are or might be subjected, and to support the management of overexposed workers.

RS-G-1.1 (Ref. [8], para. 7.5) states that 'there should be examinations before radiation work commences and periodic reviews thereafter.' It goes on to state that the initial examination should be used to identify those workers who have a condition that might necessitate particular precautions during work. It notes that it should be rare for the radiation component of the working environment to significantly influence the decision about the fitness of a worker to undertake work with radiation, or to influence the general conditions of service. As far as the periodic reviews are concerned, it states that they should focus on confirming that no clinical condition which could prejudice the health of the worker has developed while working with radiation.

As the dose threshold on which the dose limit for the lens of the eye is based is 0.5 Gy, the following points are made:

- An eye examination need not be undertaken prior to starting radiation work, except for the purposes of determining the fitness of the worker for the intended task;
- Workers who have not received doses to the lens of the eye of more than 20 mSv in a year on average over their working lives, need not be subject to any additional medical examination beyond what is required by the above general principles of occupational health;
- Workers who have already received accumulated doses to the lens of the eye of more 0.5 Gy or who, even if now subject to the new dose limit, may, after a few more years, accumulate doses in excess of this level may need to be subject to regular visual tests. This is related to the ability of the workers to carry out the intended tasks (e.g. in interventional radiology) and should not be regarded as a radiation protection measure as such.

Although the risk of visual impairment at accumulated doses of somewhat above 0.5 Gy are considered to be small, nevertheless, such health effects should be identified and appropriately monitored to determine their evolution with time. Even if opacities are detected in a worker, this should not be regarded as a reason for removing that worker from working with radiation, provided that worker is fit to undertake the job (i.e. his/her vision has not been impaired to the extent that he/she is no longer able to do the work appropriately). Employers should ensure that workers who could receive accumulated doses of 0.5 Gy or higher have been informed in advance of the associated health risks and are monitored.

3.6 EXPOSURE OF EMERGENCY WORKERS

GSR Part 3 (Interim) requires that response organizations and employers ensure that no emergency worker is subject to an exposure in an emergency in excess of 50 mSv other than:

(a) For the purposes of saving life or preventing serious injury;

(b) When undertaking actions to prevent severe deterministic effects and actions to prevent the development of catastrophic conditions that could significantly affect people and the environment; or

(c) When undertaking actions to avert a large collective dose.' (Ref. [1], para. 4.15)

In these exceptional circumstances, response organizations and employers are required to make all reasonable efforts to keep doses ($H_p(10)$) to emergency workers below 500 mSv in the case of the first two actions, and below 100 mSv in the third action (Table IV-2 of Ref. [1], and identical with Table 4 of Ref. [67]).

$H_p(10)$ also represents $H_p(3)$, except in the case of exposure to beta radiation with a maximum energy above about 0.7 MeV or to photon radiation with a mean energy below about 40 keV (see Tables 3 and 4). In these latter cases, a restriction on $H_p(10)$ is not sufficient for protection of the lens of the eye.

Where emergency workers are likely to be exposed to significant levels of beta radiation or low energy photon radiation, shielding of the eye (e.g. with glasses made from low Z material) should be used to reduce the doses to the lens of the eye, at least below 500 mSv (for (a) and (b) above) or 100 mSv (for (c) above), depending on the circumstances.

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ANNEX I.
DOSE LIMITS FOR OCCUPATIONAL EXPOSURE IN PLANNED EXPOSURE SITUATIONS[9]

For occupational exposure of workers over the age of 18 years, the dose limits are:

(a) An effective dose of 20 mSv per year averaged over five consecutive years[10] (100 mSv in 5 years), and of 50 mSv in any single year;

(b) An equivalent dose 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;

(c) An equivalent dose to the extremities (hands and feet) or the skin[11] of 500 mSv in a year.

Additional restrictions apply to occupational exposure for a female worker who has notified pregnancy or is breast-feeding.

For occupational exposure of apprentices of 16 to 18 years of age who are being trained for employment involving radiation and for exposure of students of age 16 to 18 who use sources in the course of their studies, the dose limits are:

(a) An effective dose of 6 mSv in a year;

(b) An equivalent dose to the lens of the eye of 20 mSv in a year;

(c) An equivalent dose to the extremities (hands and feet) or the skin[11] of 150 mSv in a year.

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[9] The dose limits are taken from Schedule III of GSR Part 3 [1].

[10] The start of the averaging period shall be coincident with the first day of the relevant annual period after the date of entry into force of these Standards, with no retrospective averaging.

[11] 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. The dose to the skin also contributes to the effective dose, this contribution being the average dose to the entire skin multiplied by the tissue weighting factor for the skin.

ANNEX II.
TYPICAL VALUES OF EQUIVALENT DOSE TO THE LENS OF THE EYE PER PROCEDURE IN INTERVENTIONAL RADIOLOGY.

Typical values for equivalent dose to the lens of the eye per procedure in interventional radiology are presented in Table II-1. The results in Table II-1 show that the doses to the lens of the eye vary considerably. The doses depend on the use of protective tools and applied working practice, including examination technique and distance from the isocentre. The doses to the lens of the eye per procedure range from 10 μSv to few mSv. The highest values are related to the over-couch X-ray tube geometry and the absence of ceiling suspended screens and glasses.

TABLE II-1. TYPICAL EYE LENS DOSES PER PROCEDURE FOR VARIOUS X-RAY PROCEDURES

Procedure	Eye dose (mSv)	Remark
Hepatic chemoembolization[12] [1]	0.27-2.1 (range)	Unshielded
	0.016-0.064 (range)	Shielded
Iliac angioplasty[12] [1]	0.25-2.2 (range)	Unshielded
	0.015-0.066 (range)	Shielded
Neuroembolization (head, spine)[12] [1]	1.4-11 (range)	Unshielded
	0.083-0.34 (range)	Shielded
Pulmonary angiography [1]	0.19-1.5 (range)	Unshielded
	0.011-0.045 (range)	Shielded
TIPS creation [1]	0.41-3.7 (range)	Unshielded
	0.025-0.11 (range)	Shielded
Cerebral angiography (CA)		
[2]	0.046 (mean)	Unshielded
[2]	0.025 (mean)	Shielded
[3]	0.014 (mean)	Shielded
[4]	0.013 (mean)	Shielded
Endovascular aneurysm repair (EVAR) [5]	0.010 (mean)	Unshielded
Urology [6]	0.026 (mean)	Unshielded
Orthopedic[13] [7]	0.05	Unshielded

[12] Doses estimated using phantoms simulating patients.

Procedure	Eye dose (mSv)	Remark
Hysterosalpingography (HSG) [8]	0.14 (mean)	Unshielded
Endoscopic retrograde cholangiopancreatography (ERCP)		
[9]	0.094 (mean)	Under-couch X-ray tube
[10]	0.55 (mean) 2.8 (maximum)	Over-couch X-ray tube

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ANNEX III.
GUIDANCE FOR MEDICAL PRACTICES WHERE STAFF WORK IN CLOSE PROXIMITY TO PATIENTS IN IMAGE GUIDED INTERVENTIONAL PROCEDURES

Recommendations of the Working Group on Interventional Cardiology on occupational doses to the lens of the eye in Interventional Cardiology[14]

ICRP published in April 2011 a statement that for the lens of the eye the threshold for tissue reactions is now considered to be 0.5 Gy. As a result, ICRP recommended a new occupational dose limit for the lens of the eye of 20 mSv in a year. This recommendation has been incorporated into the interim version of the International Basic Safety Standards of the IAEA, published in November 2011.

The new lower limit has important implications for some areas of occupational exposure, including interventional cardiology, emphasizing the need for optimization of protection measures with respect to the lens of the eye.

The nature of interventional cardiology is that if no protective measures for the eyes are used in an interventional cardiology laboratory, personnel with a typical workload would receive doses to the lens of the eye that would greatly exceed the dose limit, and over time could result in lens opacities.

Conversely, if the interventional cardiology equipment is performing correctly, procedure protocols have been optimized and protective tools for the eyes are being used, then the dose to the lens of the eye would be less than the dose limit, and likely to be a few mSv per year for a typical workload.

Results from ISEMIR surveys suggest that the use of protective tools and personal dosimeters are uneven, the quality of occupational dose monitoring is poor, and as a consequence knowledge about actual doses is limited. This has implications for the professionals, hospital or clinic management, and regulatory bodies.

WGIC of ISEMIR recommends that:

- Training in radiation protection for all interventional cardiology personnel should include methods for reducing doses to the lens of the eyes, with practical exercises or demonstrations. Active dosimeters should be used in training.
- Interventional cardiology professionals working close to the patient must use a ceiling suspended protective screen, positioned appropriately. If the use of such screens is not feasible with a given procedure, lead glasses with side shields must be worn.
- Protective measures for interventional cardiology professionals working more distant from the irradiated volume of the patient should be specified by the local expert in radiation protection (e.g. radiation protection officer, medical physicist).
- Interventional cardiology professionals must always wear their personal dosimeters, following their local rules.

[14] Can be downloaded from: http://www-ns.iaea.org/tech-areas/communication-networks/norp/documents/recommendations-doses-eye-lens.pdf

- Hospital management must perform continual reviews of personnel occupational eye doses.
- Personal dosimetry monitoring protocols must include assessment of the dose to the lens of the eye.
- Elements of a monitoring protocol should include the following:
    - The use of double dosimetry (over-apron at neck level and under-apron at chest/waist level);
    - The use of ambient dosimeters (such as at the C-arm) in identifying the lack of compliance in wearing personal dosimeters and to help to estimate occupational doses when personal dosimeters have not been used;
    - The use of active dosimeters to identify means for improving radiation protection practice[15].
- Improved methodologies to assess lens doses need to be developed, including when lead glasses are worn.
- Industry should pursue the development of computational technologies (not requiring dosimeters), with personnel position sensing, to assess personnel doses, including eye doses.
- Manufacturers of interventional cardiology equipment should design their systems so that it is possible to provide a second ceiling suspended screen to afford protection for situations where personnel are working on both sides of the table.
- National dose registers should include records for lens of the eye dose assessments. Such records should include the occupation and function of the individual to enable identification of areas of concern.
- The ISEMIR International Data Base, under development, will be a useful tool for each interventional cardiology facility and regulatory bodies in benchmarking occupational eye doses in interventional cardiology in the future, and participation is recommended.

[15] Care should be exercised in pulsed radiation fields, see section on monitoring of doses to the lens of the eye.

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