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Memorandum

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Abstract
In 2018, the International Radiation Protection Association (IRPA) established its third task group (TG) on the implementation of the eye lens dose limit. To contribute to sharing experience and raising awareness within the radiation protection community about protection of workers in exposure of the lens of the eye, the TG conducted a questionnaire survey and analysed the responses. This paper provides an overview of the results of the questionnaire.

Keywords: IRPA task group, eye lens dose limit, occupational exposure

1. Introduction

The International Commission on Radiological Protection (ICRP) published a Statement on Tissue Reactions in April 2011 with a recommendation that the occupational equivalent dose limit for the lens of the eye be revised (ICRP 2012). This was based on a threshold of 0.5 Gy for induction of vision impairing cataracts in the lens. ICRP recommended that the equivalent dose limit for the lens of the eye, for occupational exposure, be reduced from 150 mSv in a year to 20 mSv per year, averaged over defined periods of 5 yr, with no single year exceeding 50 mSv (ICRP 2012). This recommendation has been included in the IAEA Basic Safety Standards (IAEA 2014) and in the European Union Council Directive (Euratom 2014).

The International Radiation Protection Association (IRPA) established a task group (TG) in 2012 to identify key issues in the implementation of the new eye lens dose limit, and a first survey was launched to provide an international view of IRPA professionals on the impact of the reduction in dose limit for the eye lens in occupational exposure proposed by ICRP (Broughton *et al* 2013, 2015a, 2015b) addressing the implications both for dosimetry and methods of protection. In 2015 a second TG was created to review progress in putting the recommendations from the early report into practice, and to collate practitioner experiences. The second survey was launched (Cantone *et al* 2017) with the aim of collecting views on methods being applied for monitoring dose to the lens, possible critical issues in relation to the dose limits, and progress towards implementation of legislation in the different countries. Based on experiences collated, IRPA published guidance on implementation of eye monitoring and eye protection for workers (IRPA 2017), to provide practical recommendations about when and how eye lens dose should be monitored and on use of protective devices related to exposure levels. IRPA created a third TG in 2018 and launched a new survey in 2019 to contribute further to sharing experiences and raising awareness within the radiation protection (RP) community, about protection of workers in exposure of the lens of the eye. Here we provide a summary of results from the latest questionnaire.

2. The third IRPA survey

2.1. Compilation and distribution of the questionnaire

The survey aimed to promote a wide exchange of experiences at an international level, on the impact of the change in dose limit for the lens of the eye and its implementation with regard to occupational exposure. To that end efforts were made to obtain as large a participation from the RP community worldwide as possible, to determine views and actions taken during the 8 yr since the 2011 ICRP recommendation for revision of the limit.

The TG phase III was compiled based on recommendations and views of nominees from IRPA associated societies (ASs) as representative of different geographical areas: Africa, North

and South America, Asia, Australia and Europe. The TG members comprise the authors of this document, representing different associations and countries with Marie Claire Cantone as Chair and Merce Ginjaume as Vice Chair.

The questionnaire, as a tool to structure the responses based on 27 questions, is not limited to any specific area of radiation practice, and was developed to address four principal topics: (*i*) the implications for monitoring and assessing lens dose and the interpretation of the results; (*ii*) the implications related to the methods of protection being considered by different sectors such as medical, nuclear, and industrial applications, and the different personnel involved; (*iii*) the direct or indirect impact on current practices, in relation to the implementation of the revised limit in the sectors of interest; and (*iv*) the legislative processes being enacted or considered in relation to the dose limit for the lens, and guidelines or documents addressing eye lens monitoring.

The questionnaire was sent to the IRPA ASs in January 2019. Several ASs also circulated the questionnaire to other societies or organisations representing either medical physics or nuclear industry professionals that had expressed their willingness to provide information about approaches in their countries and, also to some other institutions of different countries interested in providing additional information about practices followed based on local knowledge and expertise.

2.2. Analysis of the responses

The TG Phase III has received completed questionnaires from 26 ASs (Argentina, Australia-New Zealand, Belgium, Brazil, Canada, China, Croatia, Eastern Africa, France, German-Swiss, Hungary, Israel, Italy, Japan, South Korea, Netherlands, Nordic Society, Portugal, Romania, Russia, Serbia-Montenegro, Southern Africa, Spain, United Kingdom, Uruguay, United States). In addition, completed answers were received from ten other institutions or organisations (Electric Power Research Institute, EPRI, US; British Institute of Radiology, BIR, UK; Institute of Physics and Engineering in Medicine, IPEM, UK; Thai Medical Physicist Society, Thailand; Malaysian Institute of Physics, Division of Medical Physics, Malaysia; Semmelweis University, Hungary; Greek Atomic Energy Commission, Greece; German Federal Office for Radiation Protection, BfS, Germany; Hospital Italiano Buenos Aires, Argentina; Radiation Protection Experts, Guatemala).

The answers to the survey have been analysed on the basis of participating countries, by taking the following steps:

- merging the answers of six institutions (EPRI, US; Semmelweis University, Hungary; BIR and IPEM, UK; Hospital Buenos, Argentina; BfS, Germany) with the ones provided by the IRPA ASs of the same countries, while the remaining institutions were used to provide data for four additional countries (Thailand, Malaysia, Greece, Guatemala) in the survey;
- splitting up responses from regional societies that presented separate answers for each individual country. This applied to the Nordic Society which presented answers for four countries (Sweden, Norway, Denmark and Finland) and Australia-New Zealand for two countries; and
- for other IRPA regional ASs that provided a single answer for each question, namely East Africa (seven countries), South Africa (three countries), German-Swiss, and Serbia-Montenegro, a single response is taken forward in the analysis in each case.

In practice, the analysis of the survey was performed on the basis of 34 country-related answers, but if all the countries included in the regional societies that were represented by

single responses are considered, this amounts to 44 countries from Africa, North and South America, Asia/Australia, and Europe. In the analysis, results are given in the text relating to numbers of participating countries following different approaches, and information on some practices in individual countries linked to geographical region is given in table 1.

3. Presentation of answers

3.1. Topic 1: implications for dosimetry

Q1. *What is (are) the method(s) used for the assessment of the equivalent dose to the lens of the eye? What methods are used for measuring eye and effective dose by staff involved in medical imaging with x-rays, whose bodies are protected by lead aprons?*

After publication of the ICRP statement in 2011, the definition of the operational quantity, $H_p(3)$, suitable for estimating the equivalent dose to the lens of the eye H_{lens}, and the associated calibration procedure were reviewed in relation to application to occupational dosimetry. This was achieved through the work of ENEA (Gualdrini *et al* 2013) and CEA-LNHB (Daures *et al* 2011) within the frame work of the ORAMED project (Vanhavere *et al* 2012) providing $H_p(3)$ dosemeters for direct measurements that could avoid the use of surrogate quantities.

All but one of the participants gave responses for medical applications, while only six described the perspective for the nuclear industry. Some described general dose monitoring systems in place in their country, while others dealt specifically with eye dosimetry. Twelve countries had access to dosemeters calibrated in terms of $H_{\text{p}}(3)$ and three others were using $H_{\text{p}}(0.07)$ for eye lens dosimetry in x-ray applications.

Twenty five countries described their current overall dosimetry arrangement for staff in interventional radiology and interventional cardiology revealing a wide variation in practices. Five countries used two dosemeters: one worn under the lead apron and one over the apron at the collar, ten countries used a single dosemeter at the collar, and four countries used one dosemeter under the apron. The remaining six countries used combinations of two of the three alternative approaches, which could be graded based on staff roles or practices. Countries in which a dosemeter was worn at the collar outside the lead apron remarked that this would give an indication of eye dose as well as the radiation level in the environment, but those using a single under apron dosemeter did not have an assessment that could be linked to eye dose or have plans for monitoring eye doses at the present time, although the use of protective eyewear may be considered. It is apparent that other countries carry out dose monitoring, as references were made to collar dosemeters, but the specific approach adopted was not specified. The breakdown of practices in terms of numbers of countries in different parts of the world given in table 1 shows that use of a collar dosemeter, either on its own or with a second dosemeter, has strong support, particularly in the Americas.

Twenty countries stated that members are using or experimenting with dosemeters adjacent to the eye for interventional clinicians, many in conjunction with a collar dosemeter, while five countries reported plans to derive factors to assess eye doses from collar dosemeter results. Two countries indicated plans to implement recommendations made in national guidance (NCS 2018) or international standards (ISO 2015). Decisions about strategies to be adopted were often based on pilot studies and in several of these users expressed a preference for collar dosemeters. The possibility of attaching a dosemeter to lead glasses or integrating one within the frame are also being considered by five countries. Several participants discussed monitoring in nuclear medicine and the majority considered that sufficient information could be obtained from a whole-body dosemeter. Five countries provided information about workers in nuclear power industries, all of whom had carried out investigations into dose levels and

Table 1. Responses from individual countries relating to implementation of eye dose limit.

	Africa[a]	Americas	Asia/ Australasia	Europe
Implications for dosimetry				
Dosemeters calibrated in terms of $H_p(3)$	–	–	2	10
Collar dosemeter worn by interventional staff either as single dosemeter or part of double dosimetry method	–	6(1)	6 (1)	10(5)
Dosemeter positioned adjacent to the eye	–	1	4(1)	15(4)
Pilot studies of eye dose levels undertaken	–	4	5	17
Risk assessment carried out prior to eye dose monitoring	1	1	4	13
Monitoring of interventional clinicians based on role	–	1	2	2
Confirmed intention to adopt 20 mSv dose limit	2	2	6	17
Monitoring suggested for eye doses above 5 or 6 mSv	1	3	3	5
Monitoring suggested for eye doses above 15 mSv	–	–	1	7
Problems in compliance anticipated	1	1	3	12
Training undertaken at local or national level	–	3	6	11
Additional cost foreseen for implementation		3	6	12
Implications for protection				
Regular use of ceiling suspended shielding and eyewear	1	3	4	11
Variable use of ceiling suspended shielding and eyewear	1	3	4	5
Application of ALARA tools in minimising dose	1	1	3	10
Countries highlighting importance of RP training	1	1	1	3
Preparation of legislation and the implications				
Concerns about new system for lens dosimetry	1	1	5	8
No change foreseen in health surveillance	–	3	5	10
Guidelines available about eye dose monitoring	–	2	4	11
ASs heavily involved in preparing legislation	1	5	8	17
Dose limit with averaging over 5 yr allowed	2	2	4	12
Strict 20 mSv per year dose limit being introduced	–	–	–	3
Maintaining 150 mSv per year limit for present		3	3	3
Consideration being given to other tissue reactions	1	2	4	3
Number of countries in survey	2	6	8	18

Figures in brackets denote numbers in which practice only followed at some centres.
[a]Two regional African societies representing ten countries, RP—Radiation Protection.

were developing guidance on personal dosimetry and one indicated that information had been provided on a national website and is freely available to members of the Institute (EPRI 2017).

Q2. *Have there been or is your country involved in pilot studies on lens dosimetry? Please specify details or references and any result of your related experience.*
Studies of staff eye exposure and dosimetry have been undertaken in 26 countries, the majority being for interventional radiologists and cardiologists. A number of European nations were involved in investigations through the ORAMED project, results from which were described in a comprehensive report (Vanhavere *et al* 2012). Other European centres have aimed to establish links between eye doses and patient exposure levels (Antic *et al* 2013, Ciraj-Bjelac *et al* 2016). Extensive studies of exposure of interventional staff have also been undertaken in the Far East (Yokoyama *et al* 2017a, 2017b, 2019, Suzuki *et al* 2018, Kato *et al* 2019), South America (Leyton *et al* 2014, Khoury *et al* 2015) and Australasia (Mclean *et al* 2016), including comparisons between results from dosemeters worn at the collar and adjacent to the eye (Haga *et al* 2017). Studies in nuclear medicine have demonstrated that body dosemeters give an indication of eye dose, but there may be some underestimation (Kubo and Mauricio 2014). Studies at nuclear power plants (NPPs) assessing ocular exposure for reactor workers had been undertaken in six countries (Maeng *et al* 2018), and included accident recovery workers at Fukushima (Hayashida *et al* 2017), and workers in other facilities such as ones dealing with radioactive waste treatment and disposal. Results from a number of studies are available on national nuclear industry websites. Some countries have prepared reports providing overviews of lens exposure in professions throughout their country (Yokoyama *et al* 2019).

Other areas of research are in the performance of eye dosemeters (Clairand *et al* 2016, 2018, Silva *et al* 2018, Bandalo *et al* 2020), phantoms used for dosemeter calibration (Daures *et al* 2009, Gualdrini *et al* 2013, Yoshitomi and Kowatari 2016), and development of detailed models of the human eye for Monte Carlo dosimetry applications (Kim *et al* 2018). Differences in doses between such models were generally less than 5% for photon radiations, but could be up to 80% for low MeV electrons (Han *et al* 2020).

Four countries reported on investigations into the prevalence of lens opacities among interventional cardiologists in South America and Asia through the Retrospective Evaluation of Lens Injuries and Dose (RELID) project surveys in 2010, 2014 and 2017 supported by IAEA (Vano *et al* 2010, Papp *et al* 2017), and other studies of this type have been undertaken, such as (Matsubara *et al* 2017). These have confirmed the occurrence of dose-related progressive lens changes in interventional cardiologists although initial opacities may not cause visual impairment. Linked with this, the EURALOC project has investigated doses received over five decades of interventional cardiology in Europe to assess how these have changed over time (Domienik-Andrzejewska *et al* 2018, Struelens *et al* 2018).

Q3. *For workers, a prospective risk assessment should be performed a priori, taking into consideration also the estimate of the equivalent dose to the lens of the eye that an individual worker is liable to receive. Is it considered, as recommended, to proceed to individual monitoring to compare results with prospective risk assessments?*
Nineteen countries expressed the view that staff would proceed to monitoring eye doses for interventionists based on results of a risk assessment, while a further four would monitor eye dose for all interventional clinicians. However, this tended not to be the practice formally accepted in the Americas (table 1). Responses relating to the nuclear power industry, stated that risk assessments would be carried out and one country stated that prospective risk assessments based on studies of different staff groups within the industry had been commissioned, while another indicated that staff would be monitored during certain procedures known to have

the potential for giving high exposure or when insufficient data were available on potential risks from a particular activity.

Q4. *Which level of exposure to the lens of the eye for a worker is proposed in your country as significant (or seen as a constraint) in determining the need for routine monitoring?*
Twenty seven countries had acknowledged the intention of adopting the 20 mSv yr^{-1} limit for the eye including all but one of the European states. Three countries had no plans at the present time to change the 150 mSv yr^{-1} limit. One country had no limit for eye lens dose currently in place, but required all interventional operators to use a double dosimetry arrangement with a collar dosemeter. It was noted that the National Council on Radiation Protection and Measurements (NCRP) has recommended a reduction in the occupational absorbed dose limit to 50 mGy, and stated that any reduction in the dose limit will require a reevaluation of monitoring and protection practices in the country (NCRP 2016, Dauer *et al* 2017).

The dose level at which monitoring will be carried out is variable. Monitoring would be recommended for doses over 5–6 mSv in a year in 12 countries, and nine more would require monitoring if there was a risk of the dose rising above 15 mSv, the limit for a member of the public. Values are not generally set down in regulations, but quoted in guidance or codes of practice or based on recommendations of local RP experts (RPEs). A breakdown of doses used as action levels by countries in different geographical regions is given in table 1. Three countries stated that no recommendation had as yet been made, but many countries are going through a transition period before enforcement of the 20 mSv yr^{-1} limit. Flowcharts have been published to aid the decision process about monitoring that should be undertaken based on dosemeter results (NCS 2018, Martin *et al* 2019).

Q5. *Are there any foreseen problems in achieving compliance in the wearing of eye dosemeters by different occupational groups and if so, what strategies are recommended to overcome these problems?*
Seventeen countries anticipated that as the 20 mSv yr^{-1} dose limit is introduced, there would be poor compliance in wearing dosemeters by interventional staff because of deficiencies in the RP culture. A number of responders thought that many interventional clinicians were not convinced of the need to monitor eye doses or that it was necessary to use additional protective devices which could hinder performance of the procedures. Fewer problems in compliance were foreseen in the Americas where collar dosemeters were worn (table 1). Four countries stated that wearers of eye dosemeters were not content with the current design of head band versions, which they found uncomfortable or unsightly. While some found dosemeters attached to lead glasses improved compliance, others considered that they interfered with vision or gave problems by becoming detached. Training in dosemeter use and auditing compliance in wearing dosemeters were seen as necessary to ensure that systems operated correctly.

Other problems that were highlighted were a lack of dosimetry services able to provide $H_p(3)$ dosemeters in a few countries and difficulties in calibration or accreditation of dosimetry services. Four countries saw the likelihood of the new dose limit being exceeded as a potential problem, with doses between 20 mSv y^{-1} and 50 mSv y^{-1} being recorded for interventional clinicians (e.g. Grande *et al* 2018), while another reported that doses to over 2200 medical staff exceeded the proposed 20 mSv limit in 2017 (Chiyoda Tecnology 2018, Nagase Landauer 2018). Other problems identified from the use of additional dosemeters were an increased likelihood of dosemeters being lost and the mixing up of under and over apron dosemeters that could lead to substantial overestimates of effective dose for those using a double dosemeter regime.

Q6. *In your country, are there any experiences in the evaluation of dose to the lens of the eye, in relation to possible contamination of the individuals because of handling of radioactive contaminated components or unsealed radioactive sources?*
Three countries have carried out some work on doses to the eye from contamination or had in the past. One described incidents involving ^{201}Tl, ^{18}F and ^{99m}Tc, based on which methods have been proposed for evaluation of dose equivalent factors per unit activity for several radionuclides used in nuclear medicine based on Monte-Carlo simulations (Huet *et al* 2013). Another reported an increase in dose to the lens of the eye due to contamination of the hands among workers in nuclear medicine hot laboratories, but had not found any increase in eye doses to cyclotron service engineers from handling parts contaminated with radioactivity. A third had initiated a project to investigate eye dose assessment techniques for nuclear medicine workers, including modelling of biological effects and strategies for reduction of risks during administration of ^{90}Y therapy and radiopharmaceuticals for positron emission tomography, as previous measurements had shown eye lens dose values above the proposed 20 mSv y^{-1} limit.

Q7. *Do you foresee any changes in workers' dose recording associated with eye lens monitoring? Are there any particular issues in the case of itinerant workers ('outside workers'—i.e. people who work at more than one location)?*
Seven countries foresaw the need for changes in methods for recording eye doses. The majority of the changes related to setting up of systems to record $H_p(3)$, and of new systems to sum doses. Ten countries stated that when an individual worked for several employers, each was required to issue a separate dosemeter. This could lead to issues in sharing dose information between employers and summing sets of eye dose measurements and four countries saw this as a potential problem. However, practices vary both between and within individual countries, and sometimes each worker might have a single dosemeter, based on the approach adopted by the local RPE. One country commented that the period for which itinerant workers practice is sometimes short and so RP service personnel may not be aware that dosemeters need to be provided until it is too late, because of deficiencies in communication. Several countries declared that they had few itinerant workers and so did not expect any issue and at least one did not monitor itinerant workers for eye dose. Eight countries indicated that they had centralised dose registries, five of which included eye dose measurements.

Q8. *Has there been any additional education and training introduced and performed in your country, in relation to eye dosimetry. If so, for which professional groups and with reference to which situations and working activities, has specific training been developed?*
Nineteen countries reported that there had been some education and training (ET) of staff about the implications for eye protection and dose monitoring relating to the new eye dose limit, and two others stated that training would be given once the dose limit had been introduced in national regulations. Twelve countries indicated that some training had been given at a national level, primarily through seminars held at conferences, which could be arranged by professional societies, regulators, or dosimetry companies, and 12 said that training was being given by local experts in individual centres.

Q9. *What cost implications are foreseen for additional dosimetry in relation to monitoring for the lens of the eye equivalent dose? Consider in term of different areas such as medical applications (including radiology, interventional radiology and cardiology, nuclear medicine, etc), nuclear applications and industrial applications in general.*

Table 2. Dosemeters developed for monitoring the dose to the lens of the eye.

Country	Organisation developing dosemeter	Dosemeter name	Dosemeter type[a]
Belgium	SCK-CEN, Chyuda Techno dosimetry services		TLD
China	CIRP—China Institute of Radiation Protection		
France	IRSN Institute for Radiological Protection and Nuclear Safety	DOSIRIS	TLD
USA/Europe	LANDAUER	VISION®	TLD
		nanoDot	OSL
Switzerland	DOSILAB	dosiEYE	TLD
Germany	Dosimetrics		OSL
Sweden	Gammadata	EYE-D	TLD
Russia	St Petersburg Research Inst. Of Radiation Hygene	MKD-A	TLD
Thailand	TINT—Thailand Institute of Nuclear Technology	nanoDot	OSL

[a]TLD: thermoluminescent dosemeter; OSL: optically stimulated luminescence.

Twenty one countries foresaw additional costs, primarily from the issue of more dosemeters. The majority identified interventional radiologists and cardiologists as the groups requiring these, but indicated that the likely numbers involved would not be large. Smaller countries expected to have to monitor fewer than 200 individuals and predicted annual costs for dosemeters would be between €2000 and €30 000, while larger countries predicted that it might be €300 000–€600 000. In one country the national dosimetry laboratory had developed its own dosemeter for measurement of $H_p(3)$, so the long term cost to users would be less than for purchasing from abroad, allowing more monitoring to be undertaken. Eight countries foresaw that there would be additional costs in either putting a new dosimetry system in place to measure $H_p(3)$ or determining methods for obtaining the measurement from existing dosimetry data, and one stated that if they set up their own system for eye dosimetry this might require an initial outlay of €120 000.

Four countries did not expect any additional cost in their countries, because the current monitoring systems for interventional staff included a collar dosemeter outside the protection, and this was considered to provide the necessary information on eye dose levels. Two countries indicated that there could be a need to increase monitoring if regulators implemented a new dose limit, but did not think that was planned in the near future. Three countries anticipated that additional eye protection would need to be purchased and some that had already changed their monitoring arrangements said the new monitoring results had identified a need for additional protection.

Q10. *Are you aware of the development of any small dosemeters suitable for monitoring dose to the lens of the eye in your country?*

Twelve countries were aware of the development of new dosemeters to measure eye doses, some within their own countries and one gave a reference to work undertaken with a dosemeter integrated in protective glasses (Hoedlmoser *et al* 2019). The dosimetry services or organisations that developed the dosemeters are listed in table 2.

3.2. Topic 2: implications for methods of protection

As with responses for the Topic 1 group of questions, most answers refer to methods of protection for medical applications, particularly in interventional radiology and cardiology, and to a lesser extent in nuclear medicine. Only seven countries described the perspective for industrial radiography or the nuclear industry.

Q11. *What types of procedures and equipment are used in order to reduce the dose to the eye and how is the effectiveness of the protection evaluated in the different areas?*
The most common protection means reported in order to reduce the dose to the eye in interventional procedures are ceiling suspended shields and lead glasses. Nineteen countries stated that such protection devices are used on a regular basis, while 13 countries indicated variable use, depending on the end-users. Two countries also mentioned rotation among workers to distribute tasks. In nuclear medicine, together with the use of lead glasses for some specific tasks, one country indicated work in hot cells and another country the use of automatic injection systems to reduce doses. One project has shown a reduction in eye lens doses from use of remote handling devices, such as a robotic angiography arm for interventional procedures and an automatic injector in nuclear medicine. Only four countries provide an answer for the case of NPPs. Three of them mentioned the use of polymethyl methacrylate (PMMA) or lead protective glasses or full-face masks, in particular, when exposed to beta radiation. One country referred to exposures in the field of industrial radiography, and stated that in this case work is done in well-shielded enclosures and thus no specific eye protection is needed.

In addition to the above mentioned equipment, 15 countries reported application of the ALARA principle, combining reduction of time, increasing distance and using shielding as the basic means for dose reduction, and seven countries indicated the importance of training.

As regards evaluation of the effectiveness of the protection only ten countries reported that they measure the efficiency of the protection. In general, the effectiveness of protection is assessed by dosimetric monitoring, two countries reported the use of active personal dosemeters for this purpose, and four countries stated it is the responsibility of the organisation employing the staff or their RP Officer (RPO). Several countries referred to published guidelines (ISTISAN 2015, EPRI 2017, Compagnone *et al* 2018) and presentations in scientific meetings about the effectiveness of the protective devices. For example, ISTISAN (2015) highlighted that, in the choice of eyeglasses, lead equivalence, weight, attenuation, and model all play decisive roles. The design of the glasses and the shape of the face play a fundamental role, because of the 'unprotected' spaces between the glasses, the temple, the cheek and the nose, as well as the position of the head in the scatter field (Mao *et al* 2019) and the responses are summarised in the section on protection in table 1.

Q12. *What methods have been developed to ensure that the use of protective equipment is optimised in the practice? Do you consider that the design of protective eyewear currently available has been optimised?*
In general, there are no formal methods in place to verify the effectiveness of protective methods. Among the most frequent systems for the optimisation of the use of protective equipment nine countries mentioned monitoring, although only in one of them is monitoring a requirement. Eight countries ensure optimisation of use of protection following written recommendations, while five refer to appropriate training. Nine countries have been involved in specific studies to optimise the use or the design of lead glasses, and five countries refer to regulator audits as a final verification of the optimisation of practices.

Nineteen countries did not have any comment regarding the design of protective eyewear. Only three countries considered that the new protective eyewear is correctly optimised. The other 12 responders highlighted several limitations. The major problems are related to the design: weight (2 out of 12 responders) and ergonomics (6), in particular fitting over the nose and the ears. A more ergonomic and aesthetic design would be preferred. Problems with the field of view, and loss of clarity because of fogging (6) are also described. Two countries referred to the cost, in particular if the worker needs eye prescription lenses. Four countries pointed out the need to have standard protocols for verification of the attenuation of the glasses. The main aspects reported to ensure appropriate protection were inclusion of lateral shielding and the closeness of the fit between the glasses and the facial contours of the individual.

Q13. *Is the reduction of equivalent dose from personal protective equipment (e.g. glasses, aprons) taken into account in the designation/classification of workers and their needs for dosimetry in your country? If not, is only the equivalent dose level outside the personal protective equipment considered?*

Among the 31 countries that responded, 12 would consider the dose under the protection in the classification of workers, five would take into account the dose without the protection and the remaining 14 indicated that there is no unique criterion within the country. Three countries reported that there correction factors are available to estimate the dose reduction from personal protective equipment but that they cannot be used to determine whether workers require classification. Several countries mentioned the difficulty in knowing, in practice, the dose to the eyes beneath protective eyewear.

Only eight countries answered the question on the criteria required for eye lens dosimetry. From those, four said that they do not have criteria yet to require eye lens dosimetry. From the other four, one indicated that eye lens dosimetry is required for category A workers,[1] two indicated that it is based on the dosemeter reading irrespective of the fact that it is protected or unprotected, and one stated that eye lens monitoring is required when (unprotected) $H_{\mathrm{p}}(3)$ is above 2 mSv. One country indicated that in NPPs, the attenuation factor provided by some personal protective equipment is taken into consideration, and $H_{\mathrm{p}}(10)$ is the only dose considered both for whole-body and lens of eye. The answers received highlighted a wide range of practices as regards the classification of workers when protective equipment is used.

Q14. *In the use of protective personal equipment, such as lead glasses, it could be difficult to find an adequate position for the dosemeter, in order to ensure that the dose equivalent measured by the dosemeter is the same as that to the eye lens. What consideration has been given to this?*

The answers to this question are related to the dosimetric system used in the country for the assessment of eye lens exposure and the reported dose information in Q1 and Q13 and the approaches are variable. Five countries propose to put the dosemeter outside the protection and then apply a correction factor. Eleven countries recommend situating the dosemeter adjacent to the eye: four outside the protection, three covered by the protection, and four at the convenience and comfort of the user. In these cases, the use of a correction factor depends on the RPO. Four countries use a collar dosemeter for the assessment of eye dose irrespective of the use or not of protection and one country suggest situating the dosemeter over the left shoulder. Based on

[1] The European Council Directive 2013/59/EURATOM classifies exposed workers in two categories for the purposes of monitoring and surveillance. Category A exposed workers are workers liable to receive an effective dose greater than 6 mSv per year or an equivalent dose greater than 15 mSv per year for the lens of the eye or greater than 150 mSv per year for skin and extremities. Category B workers are exposed workers who are not classified as category A.

research studies, one country recommends as the best position for the dosemeter, the middle of the eyes, attached to glasses. Finally, 13 countries responded that they do not have guidelines on the position of eye dosemeters, although five of them have pilot studies in progress to decide on the recommended approach.

One country referred to developments in methods to measure the dose under protective eyewear (Hoedlmoser *et al* 2019, Bandalo *et al* 2020), while three countries report they follow national or international guidelines (ISO 2015, NCS 2018) and adopt different solutions depending on the workplaces and the risk assessment. Recent research suggests that current dosimetry methods used with protective eyewear may significantly underestimate the dose received by the eye lens (Silva *et al* 2020).

Q15. *What procedures are in place to ensure that there is a good level of quality of protection, for the individual workers?*
Most countries reported having put in place several procedures to ensure that there is a good level of quality of protection for individual workers. The most frequent answer, cited by 24 countries, is following the ALARA principle through regular audits from regulators (16 times) and internal RP surveys. Individual monitoring is mentioned by 14 countries, while training is cited five times and risk assessment and guidelines three times. One country indicated that national legislation establishes *investigation levels*, and whenever a dose reaches this level the employee must be informed officially and a report sent to the authority concerned describing causes and a potential strategy for optimisation.

Q16. *What are the cost implications related to the introduction of adequate procedures and equipment for protection to reduce the equivalent dose to the lens of the eye?*
Among the 27 answers to this question, six countries indicated they do not have an estimate yet of the cost. Twelve countries believed that it would only imply minor changes, seven stated that it would represent a reasonably acceptable increase considering the benefits, while one claimed it would mean high costs and another a very high cost. As regards what would imply major expenses, nine countries mentioned eye lens protection, seven dosimetry, three training and two additional shielding.

3.3. Topic 3: wider implications of implementing the revised limit

Q17. *What are the concerns or acquired experiences in implementation of the reduced exposure limits to the lens of the eye in terms of revised dosimetry and methods of protection?*
Twenty-four countries responded to the question expressing concerns about aspects of dosimetry and the foreseen increase in cost related to the new dose limit. Comments from 15 countries pertained to the need for methods for determining dose to the lens of the eye to be based on measurements suitable for different working environments and appropriate for the given task. It is evident that there is concern by regulatory authorities and institutions regarding:

- whether evaluation of lens doses is made properly;
- the balance between optimisation for effective dose and equivalent dose to the lens;
- the approaches for dose measurement when protective eyewear is worn.

Difficulties are recognised in wearing dosemeters, for instance ergonomic problems, when workers in the nuclear industry are using a protective mask. Moreover, the availability of eye lens dosemeters, calibration facilities, and processes for their approval are reported as a general concern. Seven countries reported concerns about additional costs related to dosemeters and protective devices. Additional ET for exposed workers will be needed to ensure proper use

of dosemeters and protection, especially with the introduction of new protective devices, and this will require provision of funds and dedicated time. Dose measurement is indicated for the large number of workers, for example in hospitals, who are unlikely to receive high doses, but must nevertheless be considered for monitoring and this will incur further costs.

Five countries identified clinicians undertaking interventional procedures in the medical field, as a group from which individuals might exceed the lens dose limit. Some suggested that a restriction, defining a maximum number of procedures to be performed by each exposed worker might be introduced. Others proposed mandating the wearing of lead glasses, which was not an accepted practice in interventional radiology in their countries, but staff members who have never worn glasses might find difficulty in adjusting to this. Feedback suggests that over time lead glasses had become part of the 'standard kit' in some centres, before the official implementation of the dose limit for the lens. Assessment of lens dose has been offered to volunteer workers in other centres and actions to reduce exposure implemented for those receiving high doses, and this approach has contributed to an increase in communication and raised awareness of staff members.

Q18. *Are there any potential long-term issues which may have an impact on working activities on a more permanent basis?*

Issues regarding the impact of the revised limit on long term working activities did not attract much attention, with 18 countries answering 'no' or not giving an answer. Sixteen countries provided some analysis of issues the RP community is facing, accompanied by various suggestions. Four countries expressed concern about a lack of education for physicians, who are not specialised radiologists, but are using radiological equipment every day and education is a priority for this group in order to avoid possible over-exposure to the lens of the eye in interventional procedures, with potential long-term health issues. Continuous attention to RP education is suggested, in view of the turnover of workers, and more cooperation and sharing of experience between countries is required. However, due to the shortage of staff and busy workloads among this group, they are the least likely to attend training and update courses that are provided. Moreover, the perception that cataract surgery is a highly successful routine procedure, could reduce the concern for prevention and control of worker radiation exposure.

The importance in defining a recognised approach for quantification of lens changes correlated with work-related radiation exposure, was raised by five countries and a number of proposals were made. The predominant type of opacity induced by radiation exposure is a posterior subcapsular defect, but the clouding of the lens during chronic irradiation can have characteristics in common with those in non-exposed individuals. Legal cases regarding cataracts developed after high doses to the lens of the eye in workers are possible, but there is dubiety since cataracts can originate from other causes, such as old age and high sun exposure dependent on country and lifestyle. How to distinguish an occupational disease, such as cataract, from the corresponding natural disease is a problem still seeking a solution.

The implementation of protective measures was highlighted by four countries, as it is recognised that for some workers regular use of protective measures is restricted by physical disturbance, as in the case of lead aprons or lead glasses. Many workers find wearing lead glasses an irritation. Dosemeters worn adjacent to the eye can also have an impact on comfort and safety. Moreover, workers assume that having dose monitors is all that is required and do not take steps to ensure they are worn in the correct position to record a true eye lens dose. More rigid verification of dose optimisation systems with strict measures for protection of the eyes during work activities was proposed, e.g. in interventional procedures, especially for operators with high workloads. Three countries highlighted the need for development of

standardised and accepted phantoms/models for performing lens of the eye dosimetry calibration and validation, although recommended versions are available (Gualdrini *et al* 2011, ISO 2015). One country brought attention to the need for proper management of resources, dedicating efforts to reduce the costs to as low a level as feasible.

Q19. *Are there any implemented or foreseen changes in the health surveillance of the workers? Consider for example the question of eye examinations before starting radiation work, and in particular the case of workers who may have already accumulated a dose higher than the threshold of 500 mGy, and the associated costs.*
Eighteen countries responded that no changes in the health surveillance of workers were expected or foreseen or at least they did not know of any, while four countries anticipated there might be changes. The responses from the other 12 countries can be summarised as follows: the medical examination of workers including an examination of the eye lens, was already mandatory before the lowering of the eye dose limit; each worker receives a physical examination before radiation work every year in his/her career and their individual radiation exposure is recorded; pre-employment examinations or ones relating to work restrictions are performed by the occupational physician with the RPE for each individual. In many European countries the workers are classified as category A and B (Directive 2013/59), and responses may be different relating to the two groups as follows: both categories undergo examinations before starting radiation work which includes examination of the eye lens; category A workers undergo annual medical exams and the examination of the eye lens should be included; category B workers do not have an annual eye examination, but they have an exit examination after ceasing radiation work; in one case, for category A the eye lens examination is at least a biannual exam; in another case an eye examination is recommended at termination of employment, and is independent of the worker's classification; the use of slit-lamp examinations is reported for eye examinations of potentially highly exposed workers in some responses. Examinations will be performed more frequently with the new dose limit for the eye lens, both in preventive and periodic surveillance, and with the increase in numbers of classified A workers, the costs will rise.

Q20. *Are there any circumstances in which you foresee (or you have experience of) specific claims for compensation in relation to the change of eye lens exposure limits for workers?*
Eighteen countries either answered no or that they had no data available, and a further ten stated that they were unaware of any specific claims for compensation and disputes, but recognised that the change in the dose limit may result in claims in the future. The most likely claimants were seen as those carrying out medical procedures involving x-ray fluoroscopy who had developed a cataract that might potentially be eligible. Six countries reported their views and experiences in more detail. The comments made included: that regulations recently issued on restriction of dose to the eye lens had no implication for exposures received in the past; that the criteria defined for attributing cataracts to radiation exposure will need to be revised when the new dose limit is implemented; that from evaluations and measurements performed so far, it is unlikely that workers have received doses to the lens of the eye near or above the dose limit; while there was one report about a complaint from two young workers that developed cataracts, but for whom there were no records of eye lens doses.

Q21. *What are the issues to be considered in relation to exposures for the lens of the eye for the patients undergoing medical diagnosis and treatment, and for the public? In case of patients, consider, for example, interventional radiology, fluoroscopically guided procedures, head CT and other medical exposures.*

Twenty-seven countries reported considerations relating to patients undergoing medical diagnosis and treatments at different levels, and these are summarised under three headings: 1, justification, optimisation and informed consent; 2, recommendations and examples; 3, research both ongoing and needed in the future. Responses of participants related to one point, two, or all points.

- Ten countries made the point that patients are not subject to dose limits and the main attention is given to justification and optimisation, and a dose to the eye lens should be according to the principle of keeping doses as low as reasonably practicable (ALARP). The most important issue in optimisation is maintaining adequate image quality, while balancing this against lowering eye lens doses where and when appropriate. Benefit and risk have to be explained to the patient in relation to informed consent. For procedures in which there is a risk of the eyes receiving a high dose, this should be communicated to the patient before the start of the procedure.
- Eight countries made specific points, as follows. There is a need to encourage manufactures to pay more attention to reducing doses delivered to the lens, and bring down the cost of special eye shields for the lens of the eye. When a patient has several head computed tomography (CT) examinations methods for reducing eye lens dose, such as gantry angulation, should be used when possible to avoid direct irradiation of the eye. National guidelines are produced for protection of the patient relating to the eye, thyroid and breast, and more education should be given to staff to encourage reduction of patient lens dose and avoid unnecessary eye exposure in CT. The employment of qualified, properly trained staff aids in selection of exposure factors to improve the optimisation of both diagnostic and therapeutic procedures. Attention should be given in interventional radiology to reduction of dose to the eye lens, in particular for procedures on paediatric patients. There should be systems for notification or follow-up of a patient if there is a risk that the dose to the lens has exceeded an agreed level (Jaschke *et al* 2020), in cases of long and/or multiple interventional procedures. For radiotherapy procedures, where the eye lens is an organ-at-risk it must be considered in therapy planning; and direct irradiation of the eyes should be avoided when possible.
- Seven countries provided comments about research needs. Even if there is no legislation regarding patients' eye lens dose monitoring, studies and research are required on the development of eye dosimetry and eye protection for patients, with particular attention to possible lead glass shielding. Research on patient dose measurement during neuro-interventional radiology and head CT to evaluate patient eye lens dose is being undertaken in some universities and hospitals. It is often almost impossible to implement any sort of protection for a patient's eyes, since this would affect the quality of the image. For example, the use of bismuth eye shielding during a CT scan, can reduce eye dose, but the images are affected by scattered photons and scanning artefacts.

Only two countries responded to the question of doses to the general public. No special issues or scenarios of high lens dose are identified and members of the public are considered to be unlikely to receive doses to the lens above 15 mSv yr^{-1}.

Q22. *Are there any additional matters regarding the equivalent dose to the lens of the eye that you wish to bring to the attention of the Task Group?*
Sixteen countries had other matters that they wished to raise, and the areas included were recognition of the needs for raising the awareness of workers through ET and practical approaches and provision of criteria and guidance relating to compliance with the new lens dose limit (Cornacchia *et al* 2019). Responses of nine countries were mainly dedicated to ET,

highlighting the difficulties due to lack of defined, approved and comprehensive procedures. A better awareness of workers was needed to achieve better lens dose management, use of personal protective equipment, and compliance in wearing lens dosemeters. Defining a list of minimum requirements for ET of staff who could be exposed to high lens doses was proposed to address this. Decisions need to be made involving dosimetry laboratories about the necessity for measuring $H_p(3)$, whether and under what circumstances other surrogate quantities could be employed as $H_p(0.07)$ for work from x-rays and $H_p(10)$ for nuclear medicine staff using Tc-99m, and certification and calibration of personal dosemeters in the practice. Cases have been reported of workers who are afraid of wearing eye dosemeters in case the dose exceeds the limit.

Seven countries, stressed the need for clear management criteria for dose compliance, during implementation of the new lens dose limit. There was support for establishment of clear criteria for when a lens dosemeter should be worn adjacent to the eye recording $H_p(3)$. The lifetime radiation dose to the lens of the eye should be kept below 500 mGy to limit the risk of effects, and this level would be reached after 25 yr of work receiving doses close to the level of the lens dose limit. Thus, for workers receiving annual doses near the limit, investigations could be launched to verify if these are related to particular activities and are justified, and whether the ALARA approach is being applied. Other topics requiring further study and discussion are aspects of age dependence of cataract and consideration of individual radiosensitivity. More sharing of information from studies undertaken during the periods of transition or phases of implementation in different countries in both the nuclear and medical sectors would be useful.

Specific guidance is needed on implementation and standard procedures for performance tests of eye dosemeters and criteria for accreditation of dosemeters. The phantoms from ICRP Publication 110 (ICRP 2009) have recently been converted into mesh-type reference computational phantoms (Kim *et al* 2018) and are available for adult, male and female, and some paediatric ages. These could be used in simulations to provide doses to the lens for a range of radiations, exposure scenarios, and dosemeter positions. ICRP Publication 139 (ICRP 2018), on occupational protection in interventional procedures, has proposed use of a dosemeter at collar level over the apron, worn on the side adjacent to the irradiated volume of the patient for providing an estimation of dose to the lens for staff in the interventional room other than the operator carrying out the procedure. EURADOS has organised an intercomparison for extremity and eye lens dosemeters, directed to single monitoring services mainly in Europe. IRPA Guidance is also cited, but it is recognised that there is a need for regulators to proceed with preparation or indorsement of guidance.

3.4. Topic 4: legislation and other general aspects

Q23. *Are there, in your country, guidelines or documents, addressing eye lens monitoring related to the new equivalent dose limit for workers? (Please, if affirmative, indicate references for the documents and/or the corresponding weblinks).*

Half of the countries in the survey had issued guidelines addressing aspects of eye lens monitoring (IRSN Rapport 2013, CNSC 2016). Among the documents, already produced and made available for the RP community, there are: a factsheet launched by an association, to inform industrial users of the changes, including advice on monitoring and the use of protective equipment (ARPANSA 2015); publications, in the form of documents and articles, by members of a dedicated Working Group from an association, reporting operational indications in interventional radiology procedures with a focus on optimisation (Compagnone *et al* 2018); an ongoing web area of frequently asked questions, with particular attention paid to changes in the equivalent dose limit for the lens and research on eye dose monitoring; recommendations

provided by four associations are dedicated to good practice for different groups of workers in view of the new limit for the lens, including guidelines for implementation of medical surveillance, and in some cases, direct distribution of the documents to monitored workers (SFRP 2016); a guidance document produced by one association stresses the principle of keeping staff doses ALARP through the hierarchy of control measures; articles and documents, prepared by a dedicated member of an association, on monitoring giving an updated view about the use of an indirect evaluation of $H_p(3)$, through $H_p(10)$, to avoid underestimations (Bordy 2018). Other countries report that guidelines are under preparation, e.g. on dose criteria in various departments in the medical field for management purposes, on instruction about wearing eye lens dosemeters and dissemination of results from studies communicated through active ET processes. Other guidelines provided practical advice for workers, including e.g. indications about how and when to wear the eye lens dosemeters (e.g. Martin *et al* 2019) and how to use protective devices distributed to workers.

Q24. *What is or was the involvement of your Association with governmental or regulatory advisory bodies regarding consultation and preparation for updated legislation, at national level, about radiation protection?*

Thirty-one countries reported having a significant and/or deep involvement with regulatory bodies in preparing updated legislation. For some countries the response to the survey represented the voice of the regulatory bodies, while for others it represented the view of practitioners in the society. For the majority of countries the level of involvement included: collaborating with and providing information directly to national regulatory bodies for preparing updated legislation; involvement of expert members in committees of national radiation councils, ministries of health or nuclear regulatory authorities in the regulatory preparation phase and in preparation of the final version of the regulations, implementing the new International Basic Safety Standards (BSS) (IAEA 2014); involvement in aspects of research on RP, as in occupational exposure dose evaluation criteria, in specific situations including e.g. interventional procedures; actively maintaining an open discussion and commenting on the legislation prior to approval. Some countries reported their involvement as being mainly in: providing recommendations and comments on drafts of the new legislation, and responding to national consultation; inviting members of regulatory bodies to meetings and technical congresses; contributing in the preparation of guidance documents and circulating them for comments, and also increasing the attention and involvement of RPEs; and organising training and lectures discussing and explaining new recommendations, their implications, and the manner of implementation.

Q25. *What changes have been made or are being considered in the legislative processes related to the new limits for the lens of the eye in your country?*

Twenty nine countries reported an active level of consideration for legislative processes, while five stated there had been no consideration of the new lens dose limits or legislative process. Nineteen countries reported that new limits for the equivalent dose to the lens of the eye are being implemented through various national approaches, including: publication of specific national norms, through approved codes of practice and guidance in national ionising radiation regulations, or ministerial regulations on RP; update of the radiation safety act and national atomic energy commission standard for RP incorporated in an ordinance with publication in a national gazette; a code for RP in planned exposure situations, and governmental decrees comprising equivalent licensing, reporting and notification in inspection systems; and national legislation for implementation, e.g. of European BSS including relevant information and training requirements. The national documents relate mainly to 2018, but in some cases

go back to 2015. Ten countries reported a continuous dialogue among the parties involved as the legislative process moving towards implementation of the new limit, and considering e.g. the intention to update the national dose registry.

Q26. *How is the equivalent dose limit to be enforced in your country? Is a strict annual dose limit of 20 mSv to be imposed, or is the limit to be taken as averaged over a period of 5 years with any single year not exceeding 50 mSv, or is a different dose limit to be used for the lens of the eye?*
Thirty-two countries answered this question, including some in which implementation was already in progress; legislation and implementation were in the elaboration phase, and; others who had not yet started the active phase. Sixteen countries reported an approach based on a limit of 20 mSv yr^{-1} together with the average over a period of 5 yr, not exceeding 50 mSv in any single year. Four countries adopted a limit averaged over a period of 5 yr with no single year exceeding 50 mSv, while three countries had imposed a strict annual dose limit of 20 mSv. Nine countries reported the intention to keep the 150 mSv yr^{-1} limit, or maintain it while the new limit is being considered, but with no agreement yet to implement. One country reported that this matter was outside its mandate, and another that no consideration was being given to changing the limit.

Q27. *Are you analysing and taking into consideration the wider issue of tissue reactions and in particular the case of circulatory disease, because of recent evidence of higher incidences of injury occurring at lower doses than had been reported previously?*
The wider issue of tissue reactions is not receiving much attention, with 16 countries either answering 'no', or skipping the answer, and eight stating that the issue is not being considered at the moment. Ten countries acknowledged the issue, but different aspects and actions are being considered in different areas, with the main interest being in the medical field.

Pilot studies are reported considering tissues reactions, e.g. in optimising, with increased attention to the delivery of radiation therapy. Responses give indications about: setting up research studies at an academic level; discussions initiated at the level of national commissions of RP; ongoing optimisation in exposure of patients and staff members; monitoring and recording of patient doses in interventional radiology and cardiology procedures and dose alert systems; managing skin dose in interventional procedures in daily practice, and the availability and implementation of a protocol of prophylaxis for skin syndrome; and ongoing research on potential radiation effects in the circulatory system that might occur at the low doses and dose rates of interest for occupational and public exposure.

4. Summary of key points

As a summary, the key points derived from the answers received are highlighted below.

4.1. Direct implication in dosimetry and protection

A third of the countries are aware of the development of new dosemeters for measuring eye doses and $H_p(3)$ dosemeters were available for a third. However, there is a wide variation in dosemeter arrangements for interventional staff, the main exposed group. Options being used include one dosemeter worn under the lead apron and one either over the apron at the collar or adjacent to the eye; a single dosemeter at the collar outside the apron; and a single dosemeter under the lead apron, and there may be graded systems with a combination

of different approaches. Variations in trends in different continents were apparent (table 1). Almost two thirds of the countries were carrying out tests of dosemeters worn adjacent to the eye or integrated into the frame of lead glasses, but compliance in wearing head dosemeters is seen as an issue.

Dose levels at which routine monitoring would be considered are variable, ranging from 5–6 to 15 mSv per year, and this would often also be on the basis of local RPE recommendations. In nuclear medicine the body dosemeter was considered to give sufficient information on eye dose by most countries. More than half of the countries would use risk assessment as the basis for proceeding to monitoring eye doses for interventional staff. This would also be the approach in the nuclear power industry, for which a number of countries have guidance available on national or institute websites.

Ceiling suspended shields and lead glasses are used on a regular basis by more than half of countries during interventional procedures. While in NPPs, lead or PMMA glasses or full-face masks, are used in particular for beta radiation. A third of countries reported measurements of effectiveness of protection through dosimetry monitoring, but no formal methods for verifying the effectiveness of protection have emerged. The need to develop standard protocols for verification of the protection provided by glasses is well recognised.

4.2. Pilot studies

Pilot studies are being carried out into methods for assessing the dose to the lens of the eye. The majority are in the medical field, addressing interventional radiology and cardiology, with some in nuclear medicine and the nuclear power industry. Some pilot studies involving cooperation between different countries, e.g. the European RP research platforms, are being used to evaluate dosimetry methods. Examples of studies being undertaken include comparisons between results from dosemeters worn at the collar and adjacent to the eye during interventional procedure and the evaluation of eye doses from body dosemeters in nuclear medicine.

4.3. Dose recording

There may be issues regarding individuals working for different employers. Some countries require separate dosemeters and this could lead to problems in sharing dose information and summing of eye dose measurements. However, practices vary even within individual countries, and sometimes itinerant workers each have a single dosemeter, based on the approach adopted by the local RPE.

4.4. Exposure of the eye lens in patients and public

The primary concern for patients undergoing examinations involving radiation is maintaining adequate image quality for diagnosis, while keeping lens doses as low as practicable. National guidelines are produced for protection of the patient relating to the eye, thyroid and breast. There is awareness of the need for minimising doses to the eye lens in interventional radiology procedures, in particular for paediatric patients, and for organising systems for notifying occurrence of cataracts following long and/or multiple interventional procedures. Doses to the eye lens are considered in planning radiotherapy treatments. No special issues or scenarios of high lens dose were identified for the public, who are considered to be unlikely to receive doses to the lens above the 15 mSv yr^{-1} limit.

4.5. Health surveillance

In most countries the medical examination of workers, including an eye lens examination, is already mandatory. Category A workers have annual examinations, which should include examination of the eye lenses every 1 or 2 yr and at termination of employment. Category B workers do not have annual examinations, but may have an exit examination after ceasing radiation work. Half of the countries consider there will be no changes in the health surveillance of workers, while others think eye examinations will be performed more frequently with the new dose limit, both for the purpose of prevention and periodic surveillance, and because of a foreseen increase in numbers of type A workers.

4.6. Legislative processes status with regard to the new dose limits for the lens

The great majority of countries reported an active level of involvement of ASs in the legislative processes related to the new dose limits for the eye lens. Different levels of participation were described, such as open discussion with pertinent authorities, ministries and organisations representing the view of practitioners or provision of comments on draft legislation. Most countries have or are intending to adopt the ICRP recommendation of an equivalent dose limit for the lens of the eye for workers of 20 mSv yr^{-1} averaged over a period of 5 yr with no single year exceeding 50 mSv. Three European countries have established a stricter regulation, with an annual dose limit of 20 mSv, but in about one third of the countries the limit of 150 mSv yr^{-1} is still in place. Many countries reported the preparation of codes of practice, guidance documents, standards, factsheets, or information on websites relating to RP and dose monitoring requirements for the eyes. The majority of these have been prepared by or in collaboration with members of the RP community.

4.7. The wider issue of tissue reactions

Only one third of the countries acknowledged any steps to address the wider issue of tissue reactions. The main interest is in medical interventional procedures, with research into approaches to monitoring, recording, and managing patient skin doses and implementation of protocols for prophylaxis in cases of skin injury. Research on potential circulatory radiation effects that could occur at low dose and dose rate is being considered (ICRP 2012).

4.8. Costs

There is general concern about additional costs and time required to implement new dosimetry and protection methods particularly in interventional procedures. This will require significant amounts of additional training of staff. There could also be costs related to improving designs of protective eyewear where attention is needed to provision of proper protection, ergonomics for proper fitting, and requirements for prescription glasses. In addition, medical examinations of workers will be performed more frequently in some countries linked to a foreseen increase in numbers of category A workers.

4.9. Education and training (ET)

A major effort is required in ET in RP to disseminate information on dose criteria and ensure proper use of dosimetry and protection, following the introduction of changes in both monitoring and protective equipment. ET are recognised as a priority for workers in interventional

procedures, and it is reported that, due to shortage of staff and busy workloads among these groups, they are less likely to attend training and update courses. The training will need to be ongoing in view of the turnover of workers, and require periodic auditing of compliance to ensure application of the ALARA principle. About half of the countries reported training initiatives at a local or national level, through seminars and conferences by professional societies, dosimetry companies, and local experts.

5. Recommendations

A number of recommendations were made by the participants in the survey, relating to doses to the eye lens, related health effects, and decisions about the definition of proper practices in protection and dosimetry. A series of recommendations relating to the requirements developed from the survey results are given here for the different stakeholders.

5.1. Regulatory aspects (for consideration by regulators)

- Prepare or proceed with endorsement of guidance relating to compliance with the new national dose limit for the eye lens, as recommended by ICRP.
- Prepare specific guidance on implementation of standard procedures for performance tests of eye dosemeters and criteria for accreditation of dosemeters.
- Provide clear information about certification and calibration of personal dosemeters in practice.
- Make clear decisions, with involvement of dosimetry laboratories and users, about the necessity for measuring $H_{\mathrm{p}}(3)$, and consider under which circumstances other quantities could be employed.

5.2. Dose reduction and protection (for consideration by groups identified)

5.2.1. Workers and management

- Implement clear, well-defined, and comprehensive procedures governing all aspects of protection.
- Implement more rigid verification of dose optimisation arrangements with strict measures for protection of the eyes during work activities, e.g. in interventional procedures and especially for operators with high workloads.
- Raise awareness among workers of need to manage lens dose through use of personal protective equipment, and to comply with local instructions for wearing lens dosemeters.
- Provide more ET for raising awareness of workers concerning both protection of staff members and reduction of patient eye dose.

5.2.2. Manufacturers of protective equipment

- Pay attention to optimising the design of protective eyewear both to reduce doses delivered to the lens, and make lead glasses more comfortable to wear.

5.2.3. Needs for the patient

- Benefit and risk have to be explained to the patient in case of procedures with potentially high dose to the eyes, before starting the procedure and in relation to informed consent.

- Continue research into developing eye dosimetry and protection of patients' eyes, e.g. in neuro-interventional radiology and head CT.

5.3. Sharing experiences

- Encourage sharing of information from studies undertaken during periods of transition and implementation of changes in different countries in both the nuclear and medical sectors.
- Promote and stress the need for clear management criteria for dose compliance and continuous sharing of information during implementation of the new dose limit.
- Promote cooperation and sharing of information in investigations for workers receiving annual doses to the eye near the limit, to evaluate if it relates to particular justified exposure activities, and determine whether ALARA approach is being applied.
- Disseminate the new ISO and IEC standards for performing lens of the eye dosimetry calibration and validation (ISO 2019, IEC 2020).

5.4. Research

- Continue development of improved eye dosimetry calibration and validation methods.

5.5. Education and training (ET)

- Define a list of minimum requirements for ET of staff who could be exposed to high lens doses.
- Discuss difficulties related to possible lack of defined, or approved comprehensive procedures.
- Implement continuous ET on all aspects of dosimetry and protection for staff members, and relating to patients, where relevant, for updating professionals on the evolution of systems and advice.
- Take steps to ensure that, despite high workloads, time is made available for staff members to participate in ET activities on topics that concern their own or patients' RP.

6. Conclusions

Since the publication, in 2011, of the ICRP recommendation for a reduction in the equivalent dose limit for the lens of the eyes for workers, IRPA has organised three surveys to collate the practitioners' experiences and concerns related to its implementation.

The third IRPA questionnaire highlights that the introduction of a 20 mSv dose limit for the eye is well underway in the majority of countries. However, not all countries are intending to adopt the limit in the foreseeable future. Compared with the previous surveys, there has been a significant amount of work carried out relating to practical implementation. But national and international guidelines are available and in place in half of the countries surveyed. There is, by at large, agreement that training and education is crucial to ensure an appropriate use of protections and increase awareness. It is necessary to continue monitoring these developments to facilitate sharing of experiences and assisting authorities still determining the appropriate route for implementation in their countries.

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