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Eye lens dosimetry

Recommendations No. 17

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General information

These recommendations are the outcome of the work carried out by the SSRPM eye lens task group (WG) aiming to give recommendations on who, when and how eye lens dosimetry should be performed in the medical sector. The group has started its activity in December 2019 and present its results in these recommendations.

Glossary

CT: Computed Tomography
DRF : Dose Reduction Factor
EL: Eye Lens
GCF: Geometrical Correction Factor
MP: Medical Physicist
FOPH: Federal Office of Public Health
OA: Over Apron
RP: Radiation Protection
RPO: Radiological Protection Ordinance
SDO: Swiss Dosimetry Ordinance
SSRMP: Swiss Society of Radiobiology and Medical Physics
WB: Whole Body
WG: Working Group
$H_p(10)$: personal dose equivalent at 10 mm depth
$H_p(0.07)$: personal dose equivalent at 0.07 mm depth
$H_p(3)$: personal dose equivalent at 3 mm depth

Introduction

Radiation exposure can cause eye lens injuries that can result in the loss of function of the eye lens through the formation of lens opacities and cataracts. Recent studies have shown that the previously accepted dose threshold for lens opacification (cataract) was too high. It is still not certain that this is a deterministic effect with a threshold below which no demonstrable effect occurs. Nevertheless, in accordance with the recommendations of the Euratom basic standards and the ICRP, in 2018 the revision of the Swiss Radiological Protection Ordinance (RPO) (1) reduced the eye lens (EL) dose limit for professional workers from 150 to 20 mSv per year. The new limit is a considerable reduction of the previously recommended annual limit of 150 mSv implying a closer surveillance of the EL dose in order to avoid exceeding the new dose limit of 20 mSv. For this purpose, medical physicist (MP) as well as other radiation protection (RP) experts should identify the category of staff requiring a dedicated dosimeter to estimate their EL dose. Moreover, they should determine the attenuation factor provided by the RP means used in order to communicate this value to the federal office of public health (FOPH) and the dosimetry service (Swiss Dosimetry Ordinance SDO, art. 11 paragraph 4 and 5)(2) .

Motivation

Since correct eye lens dosimetry could be a challenging task for hospitals, the FOPH approached the Swiss Society of Radiobiology and Medical Physics (SSRPM) to ask whether it could establish recommendations on this matter. Therefore, a working group (WG) was created within SSRPM, to facilitate and harmonize the task of the RP experts, MP and FOPH.

Main text

These recommendations are the result of this work. It is divided as follows:

1. How and when to measure or estimate the eye lens dose
2. Geometrical correction factor (GCF)
3. Dose reduction factor (DRF) due to the RP means
4. Calibration of personal dosimeters
5. Categories of medical staff that require routine EL monitoring
6. Summary flowchart

For each section, a summary of the main results is presented and a recommendation is given.

In the recommendations, we have defined the different relevant types of dosimeters as follows:

- **WB dosimeter**: refers to a whole-body dosimeter worn at the chest level placed under the apron. This dosimeter measures dose values in terms of personal dose equivalent $H_p(10)$ and $H_p(0.07)$.
- **OA dosimeter**: refers to a dosimeter worn at the chest level placed over the apron. This dosimeter measures dose values in terms of personal dose equivalent $H_p(10)$ and $H_p(0.07)$.

- **EL dosimeter**: specific EL dosimeter that is worn at the eye level under or above the protective equipment (goggles, face mask). This dosimeter is generally capable of measuring dose values in terms of personal dose equivalent $H_p(0.07)$ or $H_p(3)$.

These recommendations concern only staff working with fluoroscopy systems. According to recent publications (3)(4), EL doses in computed tomography (CT)-guided interventions are generally low thus unlikely that the EL dose limit of 20 mSv per year is exceeded by conducting CT-guided interventions solely. For nuclear medicine staff working in general nuclear medicine, including PET/CT, radiopharmacy and cyclotron, the annual EL dose remains well below the limit in agreement with the recent literature (5)(6).

1. How to measure eye lens doses

The most accurate way to measure the eye lens dose is with an EL dosimeter, calibrated for $H_p(3)$ and worn as close as possible to the most exposed eye under the protective means (7). However, there are different ways to determine the EL dose (7), which are compliant with Art 11 of the SDO (2):

1. **EL dosimeter under the protective means:**
   The EL dose can be directly measured with an EL dosimeter, calibrated for the personal dose equivalent $H_p(0.07)$ or $H_p(3)$ worn under the protective means.

2. **Whole body (WB) dosimeter is worn at chest level and no EL protection means (googles,etc.) is used:**
   In this case the EL dose is considered to be equal to the personal dose equivalent $H_p(0.07)$. When two dosimeters are worn, one WB dosimeter and one OA dosimeter, the eye lens dose is equal to the sum of the personal dose equivalent measured with both dosimeters $H_{total}(0.07)$. This also accounts for situations where the person only wears the WB dosimeter without an apron. The SDO(2) does not require a correction factor in this scenario (GCF =1). However, to be even more precise, an individual GCF can be determined.

   $f_L = GCF / 1$

   The eye lens dose is then computed as:

   $H_{eyelens} = H_{under}(0,07) + f_L * H_{over}(0,07)$

3. **WB Dosimeter is worn at chest level and EL protective means is used:**
   The EL dose is considered to be the sum of the personal dose equivalents $H_{under}(0.07)$ and $H_{over}(0.07)$, but where the latter is multiplied by a correction factor f_L. This correction factor takes into account the dose reduction of the protective means (DRF) and the geometrical correction factor which considers the deviation introduced in the results by the fact that the measurement was not performed at the eye level (GCF). According to the SDO(2), the local radiological protection RP expert in agreement with the FOPH should determine individual correction factors f_L.

f_L = GCF / DRF

The eye lens dose is then computed as:

$H_{eyelens} = H_{under}(0,07) + f_L * H_{over}(0,07)$

4. **EL dosimeter over the protective means**
   The EL dose is considered to be equal to the personal dose equivalent $H_p(0,07)$ or $H_p(3)$ multiplied with the correction factor f_L (with GCF = 1).

   f_L = 1/DRF

   The eye lens dose is then computed as:

   $H_{eyelens} = H_p(0,07) * f_L$ or $H_{eyelens} = H_p(3) * f_L$

2. Geometrical correction factor (GCF)

When the EL dose is estimated by an OA dosimeter placed at the chest level, the doses measured by the OA dosimeter should be multiplied by a geometrical correction factor (GCF) (or chest-to-eye conversion factor). To determine the GCF, the group has considered two methods: the first consisted of a review of the literature, the second in analyzing the data from the dosimetry service Dosilab. A correlation between doses measured by the OA dosimeter and the dose measured by the EL dosimeter was sought for the monitored workers.

For the literature review, 58 peer-reviewed papers (published between 2009 and 2019) were analyzed (those papers not specifically metioned in the text have been annexed to these recommendations). The GCF found in the literature range from 0.28 to 1.1. For those papers where the GCF was not explicitly investigated, the authors used a factor equal to 1. Inconsistencies were found in several papers concerning the use of $H_p(0.07)$ vs. $H_p(10)$ for the chest dosimeter. The papers (7), (9), (10) and (11) refer to cases where the OA dosimeter was attached to the collar instead of to the apron, i.e. measuring the region of the neck instead of the chest.

The Dosilab data considered for the analysis came from workers wearing simultaneously OA and EL dosimeters. The EL dosimeter was attached to the temple of the RP glasses and was directly exposed, not protected by RP glasses.

In total 667 relevant data sets with simultaneous OA and EL dosimeters from 33 monitored persons and 11 enterprises were considered from 11.2017 till 10.2020. For the data analysis we considered only measured doses above 10 µSv for each dosimeter and monthly monitoring period.

The ratio EL doses/OA doses correspond to the GCF. The results of the GCF vs. EL doses are shown in Figure 1. The correlation between EL doses and OA doses is shown in Figure 2. Each point in the Figures 1 and 2 corresponds to one data set of simultaneous OA and EL dosimeters for one monitored person and wearing period. The error bars indicate the combined

instrumental, the statistical and the natural background uncertainties (the magnitude dominated by the latter). The grey region in Figure 1 indicates 1σ of the distribution.

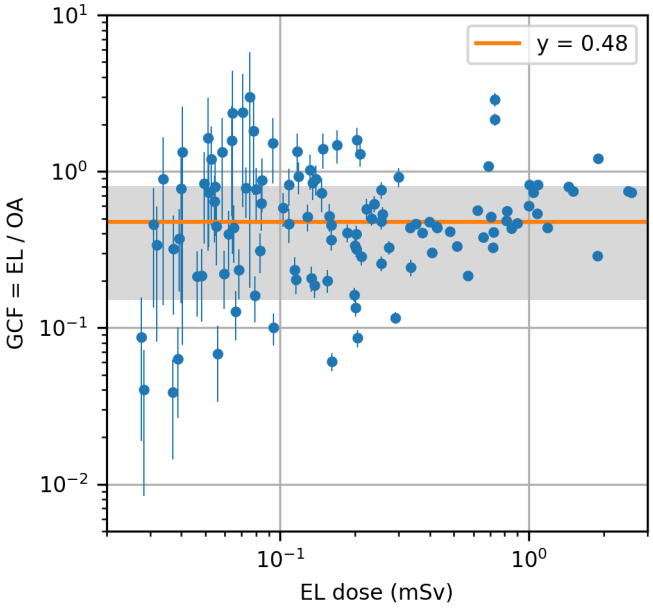


Figure 1. Measured GCF vs. EL dose. The orange line shows the weighted average of the ratios, whereas the grey region represents 1σ of the distribution, i.e. GCF = 0.48±0.33.

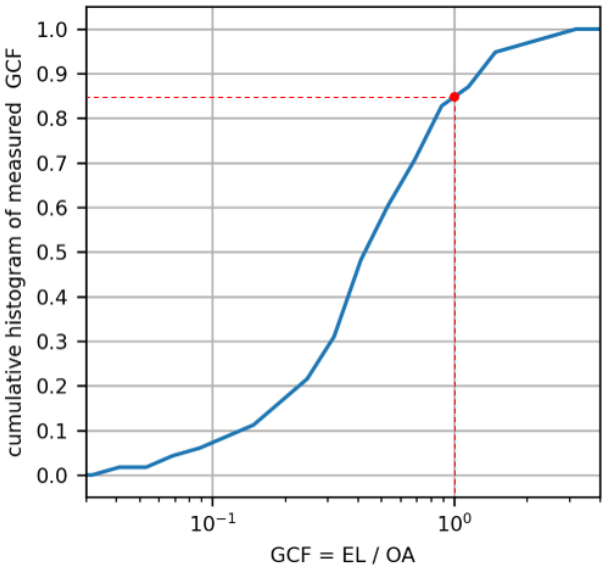


Figure 2. Normalized cumulative histogram of measured GCF, indicating the relative fraction of events with a GCF equal to or below the value on the abscissa. Example (red dot): about 84% of all measured GCF are below 1.

As shown in Figure 1, the GCF was found to have a mean value of 0.48±0.33 indicating that the EL dose values measured close to the eye but above protective means are approximately half of the dose measured by the OA dosimeter, with a broad dispersion of the measured doses.

The relatively broad distribution is due to very different individual working conditions (work place, procedures, approach) and an expected variability in the way the dosimeters are

worn. This may also explain the "outliers" in Fig.1 with GCF>1 and EL>0.5mSv, which are all observed for workers in radiology and cardiology departments, with activities in interventional radiology and/or angiography.

The cumulative histogram in Figure 2 is instructive to directly read the fraction of the EL/OA doses which are below or above a certain value (like e.g. the median of GCF = 0.43). Furthermore, 84% of the EL/OA ratios of all measurements were found to have a value below 1. Therefore, a GCF = 1 represents a conservative value for 84% of the cases considered.

As a consequence this WG recommends the use of a GCF = 1 for the assessment of the eye lens dose in cases the monitoring is based on an OA dosimeter. For a more accurate evaluation of the GCF, measurements should be performed (*An example of measurement protocol is given in the annex)***.**

3. Dose reduction factor (DRF) from the RP means

When an OA dosimeter is worn to estimate EL doses and RP means are used, the estimated EL dose value should be corrected by a DRF corresponding to the protection procured by the RP means. The same is valid when an EL dosimeter is placed over the RP means. This section of the recommendations gives an overview on the existing RP means for the EL and provides a recommendation on their usage and their DRF value for the EL dose.

In general, the RP means for fluoroscopy-guided procedures can be divided into two different groups:

- collective RP equipment, RP means in the stray radiation field near the table and the patient such as: ceiling-suspended shields, table mounted shields and flexible drapes to be put on the patient
- individual RP equipment like glasses or face masks.

The DRF as well as the recommendation of our WG on how to use the protective means is summarized in Table 1. The column indicating the recommended value defined by our WG, if any, refers to a generic conservative best estimate chosen among values in the literature. The determination of DRF for individual RP means is more reliable than a DRF defined for collective RP equipment. Indeed, in the case of collective equipment, its efficacy strongly depends on its correct positioning with respect to the staff. Therefore, this WG will provide, if any, a value of DRF different than 1 only for individual protection equipment.

Table 1. Indication DRF for various protective means

Protective mean	Lead equivalent thickness (mm)	DRF in literature	Recommended DRF value (for personal RP equipment only)	Recommended way to use and comments
Radiation safety glasses	0.3-0.75 *	2.1 (12), 1.4-5.2 (13), 1.5-4.5 (14), 1.7-11.4 (15), 5.9-6.6 (16), 1.1-4.8 (17), 2.0 (18), 5-33 (7)	2**	the glasses should be adapted to the geometry of the face, contact between the nose and cheeks and side shielding are of great importance.
Radiation Safety Masks for eye protection	0.1	4.0 (13), 2-4 (10), 2 (19)	Measurements should be performed	have the benefit of covering a larger area than glasses, thus reducing the exposure to other regions of the head that would make a significant contribution to the dose to the eye lenses from backscatter. Attention should be paid to the mask shape and size
Ceiling-suspended shield	0.5	5.7 (12), 2-7 (10), 2.3 (17), 1.5-33 (7)	1	should be positioned as close to the patient as possible to minimise the gap between shield and source of scattered radiation. The effect strongly depends on its position
Protective drapes	0.25	2-4.5 (14), 1.65 (20), 1.5 (21), 5-25 (7)	1	To be used in procedures where the use of a ceiling-suspended lead shield is not possible – Warning: should never be in the primary beam
Lead cabinet	2.0	28 (22), 68 (23)	1	protect the operator to a high degree

* According to the Swiss ordinance for X-rays (1), annex 2, the minimum lead equivalent thickness for the lead glasses should be 0.5mm

** Radiation safety glasses – wearing lead glasses can be an effective way of protecting the eye lens if ceiling-suspended shields cannot be used. They are most effective when the exposure is frontal or, put

differently, when the operator is looking through the glasses to the scattering object. In these situations DRF's are in the range of 5-8 (13) or even higher (DRF 8-10) as mentioned in (12). In realistic clinical situations taking into account all the possible parameters that could vary, like angulation of the fluoroscopy unit, position of the operator, direction of view, height of operator, or tilting of the operators head due to the position of the monitor, a DRF of 2 may be considered as conservative approach if the glasses are applied effectively. Using Monte-Carlo methods the effects of these parameters on the eye lens dose of the operator is described in (18). An important point is that the glasses are adapted to the geometry of the face, where contact between the nose and cheeks and side shielding are of great importance. The reduction factor of various types of glasses were studied in (12-18). Typical factors in most clinical situations were mentioned to be between 3 and 6 (13).

Correct application of shielding materials is essential to ensure their efficacy. The consistent application of a combination of a personal and collective RP equipment could eliminate the need for restrictions on workload of interventional radiologists and cardiologists. Lead glasses of wraparound design or with large front lenses *and* side shielding provide a reasonable level of protection.

The WG recommends to apply a conservative DRF of 2 for clinicians wearing lead glasses consistently. Nevertheless, if a more detailed value of EL dose assessment is needed, i.e. when EL doses are approaching 15 mSv, local measurements to determine the DRF for specific lead glasses could be performed *(an example of measurement protocol is given in the annex)*.

4. Calibration of dosimeters

The WG has also addressed the calibration of dosimeters for photons in the energy range up to 100 keV in the context of the measurement of the personal EL dose either by a specific EL dosimeter or by an OA dosimeter. We also tackle the influence of the calibration phantom and of the RP means (apron and glasses) on the dosimeter calibration and measurement results.

Concerning the calibration, according to the international standards (24)(25), a personal EL dosimeter should be calibrated in terms of $H_p(3)$ on a cylinder phantom.

The Swiss legislation about EL dosimeter calibration follows the international recommendations. The quantities $H_p(0.07)$ and $H_p(3)$, if calibrated on the cylinder phantom, are adequate for measuring the personal EL dose. Art. 23, para. 2 of the SDO (2) leaves the choice of the calibration phantom to the surveillance authorities. Nowadays, however, mainly personal WB dosimeters are used to assess the EL dose without any specific calibration applied even though the dosimeter is dedicated to the measurement of the EL dose.

Response of OA dosimeters is different in the presence of RP means. Indeed, OA dosimeters are worn over a lead apron but are calibrated without shielding, thus considering the influence of backscatter radiation, a passive dosimeter worn over a lead apron is likely to underestimate the personal equivalent dose by up to 40% (26). For lead free aprons, the underestimation is lower, in the order of 10%, but may differ for each apron.

Although dedicated dosimeter calibration for the usage over the apron is possible, we do not recommend it for routine personal dosimetry due to the dependence of the calibration factor on apron type, material and attenuation as well as on the radiation type and energy. Moreover, specific EL dosimeters combined with protective glasses are likely to yield a more precise measurement of the EL dose.

5. When to measure eye lens dose

According to the IRPA Guidance 2017 (27), the annual EL dose cut-off of 6 mSv should be used to determine the professionals that need to be regularly monitored for EL exposure.

The IRPA cut-off applies for individuals. Distinct from such a dose-based individual approach is the role-based group-oriented approach, where the professional role is taken as indication for the adequate dosimetry monitoring. Based on the former approach, we here aimed at nevertheless giving recommendations at the scale of groups of professionals even if a huge asymmetry in the dose distribution is often found (see section 5). Using the 90th percentile is a conservative way to consider RP of EL, stating that if more than 10% of individuals in one group (same workplace and function) receive doses over the threshold, then the whole group will follow the same monitoring. A possible group-based approach is described towards the end of this work.

Table 2 provides a summary of recommendations of the group on when and how medical staff is required to have EL monitoring.

Table 2. Recommendations for routine EL monitoring

Annual estimated EL dose* for a group of professionals	Routine EL monitoring	dosimeter to estimate **EL dose**	Position of dosimeter
below 6 mSv	Not mandatory	--	--
between 6 mSv and 15 mSv	mandatory	OA dosimeter or EL dosimeter	OA dosimeter: at the chest (**above** the lead apron) EL dosimeter: near the most exposed eye **below** the radiation protection means
above 15 mSv	mandatory	EL dosimeter	EL dosimeter: near the most exposed eye **below** the radiation protection means

**dose estimated without considering any correction factors (neither geometrical nor for the use of RP means)*

6. Categories of medical staff that require routine EL DOSE monitoring

EL dosimetry measurements were gathered and analyzed to provide a list of medical professional groups that should be monitored for EL dose with an OA dosimeter and to identify for whom, or above which dose level a specific EL dosimeter should be used. Moreover, to

complement the measurement analysis, an extensive review of the existing literature concerning EL dose measurements in different countries was performed.

Measurements were performed in the following centers: Hôpitaux Universitaires de Genève (HUG), Centre Hospitalier Universitaire Vaudois (CHUV), Universitätsspital Basel (USB), Inselspital, Sion hospital and Hirslanden clinics, representing a good variety of university hospitals, regional and private clinics in the French- and German-speaking parts of Switzerland.

Participants (numbers listed in Table 3 and 4) were equipped with an OA dosimeter and were instructed to wear it rigorously during the measurement period. Measurement periods differed from one hospital to the other, ranging from 1 to 12 months, results were linearly extrapolated to estimate the annual EL dose. The values of $H_p(0.07)$ measured by the OA dosimeter were used to estimate the EL dose if no protection means were used, on a workplace assuming a typical workload. The doses obtained were neither corrected by the position of the dosimeter (no GCF applied), nor for the use of RP glasses, nor for a calibration accounting to their position above a protective apron.

Measurements were performed for different interventional procedures and different healthcare professionals:

i) Nursing staff (Nurse): the group includes all nurses and assisting personnel
ii) Medical radiation technologists (MRT)
iii) Physicians (MD): the group includes both first and second operators since their position in relation to the patient may change during the procedure.

Interventional procedure categories are given with respect to the hospital departments that provided data. It is important to note that the analysis is based on interventional procedure categories and not on the specialization of each physician, as different specialties may perform the same type of procedure (for example, pain management procedures may be performed by orthopedists and anesthesiologists).

The annual EL dose estimations in mSv according to the profession are shown in Figure 3. The highest maximum values were found for the medical doctors and the lowest for the technologists. In general, the estimation of the EL doses to the medical doctors can reach or even exceed the 20 mSv/year. For the other two categories, the EL dose estimates are well below the limit (except for a single case).

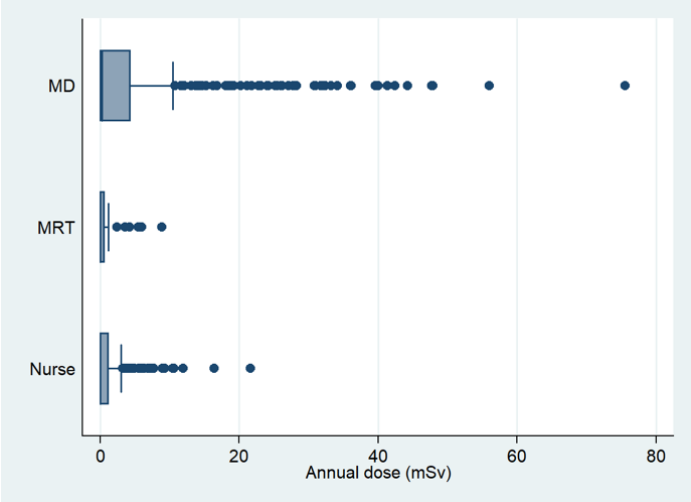


Figure 3: Annual eye lens dose estimations in mSv for different healthcare professionals in Switzerland. Boxes represent 1st, median and 3rd quartiles values. The whisker represents maximum non extreme values (Q3+1.5*(Q1-Q3)), and the dots are outliers.

The estimated annual dose values are presented in Table 3, for nursing and radiation technologists combined and in Table 4 for physicians performing different interventional procedures.

Table 3: Descriptive statistics (number of sample (N), minimum (min), maximum (max) and percentiles) of annual EL dose estimations in mSv for nursing staff and MRT participating in interventional procedures given in the first column

Interventional procedure	N	Min	25th	50th	75th	90th	95th	Max	Monitoring
Anesthesiology*	57	0.0	0.0	0.0	0.6	**1.2**	2.4	6.9	
Angiology	10	0.0	0.0	0.0	0.5	**0.7**	0.8	0.8	
Electrophysiology	26	0.0	0.0	0.1	0.6	**2.4**	4.9	10.6	
Gastroenterology	44	0.0	0.0	0.2	1.2	**3.6**	4.8	7.2	
Interventional cardiology	163	0.0	0.0	0.7	2.5	**4.2**	7.4	21.6	Not mandatory
Interventional radiology	110	0.0	0.0	0.0	0.0	**1.8**	3.6	25.2	
Operating theatre**	23	0.0	0.0	0.0	0.0	**0.2**	0.6	1.9	
Urology	20	0.0	0.0	0.0	0.0	**0.8**	1.6	2.1	
Vascular surgery	14	0.0	0.2	0.8	1.2	**3.3**	3.5	3.5	

** The term "Anesthesiology" refers to the staff that sedates the patient*

***The term "Operating theatre" was used for different procedures performed in the operating theatre (neurosurgery, orthopedics, pain management procedures, visceral surgery)*

Table 4: Descriptive statistics (number of sample (N), minimum (min), maximum (max) and percentiles) of annual EL dose estimations in mSv for MD performing interventional procedures given in first column

Interventional procedure	N	Min	25th	50th	75th	90th	95th	Max	Monitoring
Anesthesiology*	54	0.0	0.0	0.0	0.3	**2.4**	2.4	4.8	Not mandatory
Angiology	16	0.0	3.3	5.7	13.7	**21.1**	27.8	27.8	Mandatory, recommended with specific EL dosimeter
Electrophysiology	25	0.0	0.0	0.1	0.6	**2.3**	4.4	4.8	Not mandatory
Gastroenterology	20	0.0	0.0	1.4	3.6	**7.1**	8.4	9.6	Mandatory
Interventional cardiology	151	0.0	0.0	1.4	10.4	**31.0**	39.6	47.9	Mandatory, recommended with specific EL dosimeter
Interventional radiology	99	0.0	0.0	0.0	2.4	**6.6**	8.3	75.5	Mandatory
Neurosurgery**	9	0.0	0.0	0.0	0.2	**25.2**	25.2	25.2	Recommended
Orthopedics	12	0.0	0.0	0.2	2.7	**7.4**	8.1	8.1	Mandatory
Pain management**	2	0.0	0.0	8.1	16.2	**16.2**	16.2	16.2	Recommended
Pulmonology**	2	0.0	0.0	1.0	2.1	**2.1**	2.1	2.1	Not mandatory
Urology	37	0.0	0.0	0.0	1.2	**1.7**	8.4	8.4	Not mandatory
Vascular surgery	35	0.0	0.6	4.8	16.8	**26.2**	34.1	36	Mandatory, recommended with specific EL dosimeter
Visceral surgery**	2	0.0	0.0	0.0	0.0	**0.0**	0.0	0.0	Not mandatory

** The term "Anesthesiology" refers to the staff that sedates the patient and not to interventional procedures*

*** Low numbers of participants in this study*

In absence of the correction factor (i.e. f_L =1), the group decided following a conservative approach for radiation protection to use **the 90th percentile value of EL doses for each specialty and profession in order to identify the groups that need to be monitored for EL exposure**. Nevertheless, for those categories where the maximum or 95th percentile of EL dose values are close or even higher than the cut-off of 6 mSv (urology), we strongly recommend to perform measurements in order to determine the need of routine EL monitoring.

Considering the above, routine EL monitoring is not mandatory for none of the nursing staff or technicians. However, we strongly recommend to perform confirming measurements for

nurses/technicians working in fields where the maximum or 95th percentile of EL dose values are close or even higher than the cut-off of 6 mSv, i.e. interventional cardiology.

From the analysis of the physician data we derive that for the following procedures EL monitoring is mandatory (see Table 4) either with an OA or an EL dosimeter for physicians performing:

- Angiology procedures
- Gastroenterology
- Interventional cardiology
- Interventional radiology
- Orthopedics
- Vascular surgery.

For some of the above-mentioned procedures, the 90th percentile of the estimated value is higher than the annual EL dose cut-off of 15 mSv. For these procedures, more accurate dose estimations are needed than simple monitoring, following the rules fixed by the WG summarized in Table 2, we recommend that a specific EL dosimeter should be worn. The procedures concerned are:

- Angiology procedures
- Interventional cardiology
- Vascular surgery

Nevertheless, it cannot be excluded that in a particular hospital/clinic, higher EL dose values may be observed for other procedures, indicating the need to monitor eye lens exposure using a specific EL dosimeter.

The number of specialists performing neurosurgery, pain management procedures, and visceral surgery was low, therefore no firm conclusions could be drawn for these areas of work. High EL exposures cannot be excluded (for instance, neurosurgery) implying that routine EL dose monitoring might be required for those categories too.

The WG has also reviewed the literature dealing with the group of professionals that should be monitored. There is a broad range of statements and proposals. Interventional radiologists and cardiologists are usually mentioned as a group for EL monitoring. There are actually three main criteria that are considered: position/role around the patient (such as main operator, second operator,…), clinic, and dose. While the first two criteria are covered by the so-called role-based approach, the last criterion is reflected by the dose-based individual approach, both introduced in section 5. The recommendation of this WG is to primarily use the dose-based criterion, since it encompasses the other two criteria. However, once the dose-based criterion has been evaluated for a given working group, the conclusion may be generalized to other working groups with similar roles and tasks.

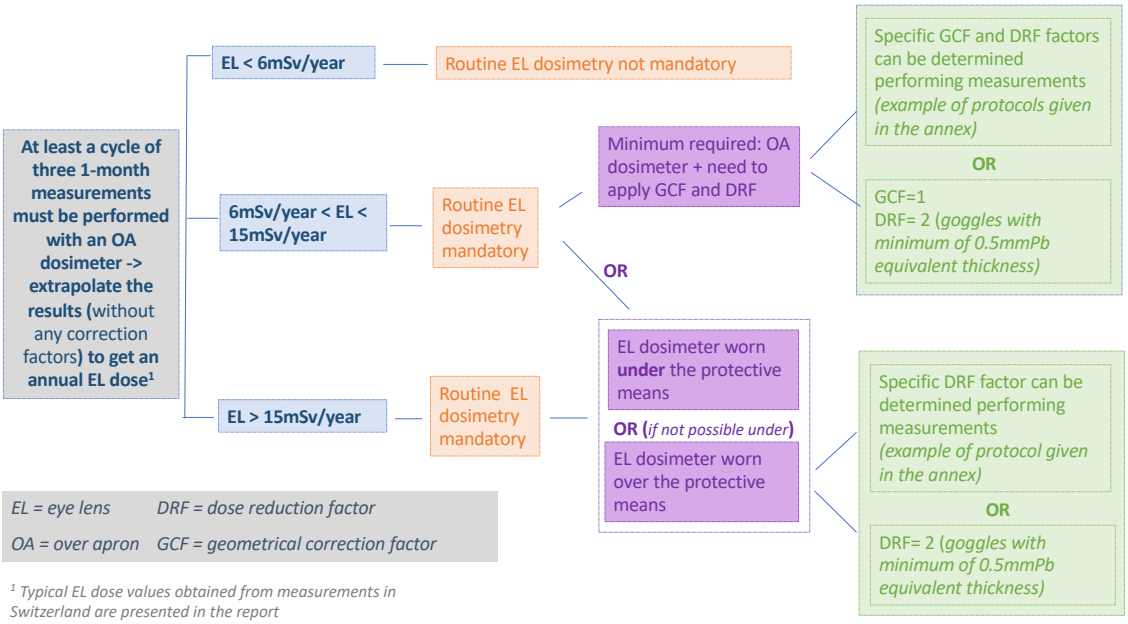
When considering the dose criterion, the levels that require routine EL dose monitoring vary in different papers: some consider that EL dose should be monitored when it exceeds 15 mSv per year, others if the annual dose at the chest level above the apron is above 6 mSv and others if the annual EL dose can reach 1/3 of the annual limit.

The general recommendation from our WG is that measurements should be performed wearing an OA dosimeter over a time period sufficient to be a representative

sample of the clinical activities (usually three months) for MD, nurses and MRT working with fluoroscopy. The results should be extrapolated to estimate the annual EL doses (without considering any correction factor). The decision whether an EL dosimeter is mandatory or not and the type of dosimeter to be used should be made according to the instructions in Table 2. For further input, the results of the measurements presented in Table 3 and 4 represent typical values obtained in Switzerland and can be used to identify relevant areas of work.

7. Summary flowchart

The above-mentioned recommendations are summarized in the flowchart below.



When the conditions or activity changes (for example: new procedures are performed, new fluoroscopic devices are installed,…) or the measured doses change, we recommend to repeat the measurements with an OA dosimeter for at least three 1 month period measurements.

Legal Supplement[1]: according Art. 9 of the SDO (2), a second dosimeter (OA dosimeter) is compulsory for radiation exposed personnel in interventional radiology staying close to the patient during the procedure in order to better estimate the effective dose.

[1] Although effective dose dosimetry not being part of this recommendation, be aware that OA dosimetry remains mandatory for mentioned group.

References

(1) Swiss Radiological Protection Ordinance (814.501), 26 April 2017.
(2) Swiss dosimetry ordinance (814.501.43) 26 April 2017.
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Annex 1: List of publications used for the review of the GCF

List of papers considered I the literature review:

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Annex 2: Description of two measurement setups to determine the different correction factors for specific working conditions under real conditions.

Method 1: Determination of an individual GCF, DRF and f_L with dedicated dosimeters

According to our recommendations, the individual geometrical correction factor (GCF) and the dose reduction factor (DRF) should be experimentally determined when the annual EL dose is likely to exceed 6 mSv. If the individual EL dose is unknown, the OA dose should be used as an indicator to decide whether dedicated measurements are necessary. Assuming the GCF to be ranging between 0.5 – 1.0 (Section 2), **an average monthly OA dose between 0.5 to 1 mSv should be considered as a lower threshold for determining the individual GCF and DRF.**

When dedicated measurements are required, they should be closely supervised by a medical physicist or radiation protection officer, who prepares the dosimeters and positions them adequately to cover the following measuring points:

- Position 1 (P1): Close to the OA dosimeter (worn on the chest)
- Position 2 (P2): Close to the more exposed eye, under the protective equipment
- Position 3 (P3): Close to the more exposed eye, over the protective equipment

The most exposed eye is usually the one close to the patient or radiation source. If the region of highest exposure is unknown, it is recommended to use additional dosimeters positioned close to the second eye and another between the eyes, if applicable underneath the protective equipment. The highest dose value should be retained as conservative measure of the EL exposure.

The duration of the measurements should be chosen such that a cumulated EL dose of approximately 0.5 mSv per measurement is achieved under representative working conditions, but should not exceed 60 days. Measurements should be repeated at least twice and the average EL dose should be used as a reference dose value.

The correction factors are then calculated as follows:

a) GCF = average $H_p(0.07)$ or $H_p(3)$ in P3 / average $H_p(0.07)$ in P 1
b) DRF = average $H_p(0.07)$ or $H_p(3)$ in P3 / average $H_p(0.07)$ or $H_p(3)$ in P 2
c) f_L = GCF / DRF = average $H_p(0.07)$ or $H_p(3)$ in P 2 / average $H_p(0.07)$ or $H_p(3)$ in P 1

The factor f_L and its uncertainty (k=2) must be transmitted to the FOPH for approval. If approved, the FOPH informs the individual dosimetry service in charge.

Dosimeters should be acquired from an approved dosimetry service. If the EL dose accumulated during not more than 60 days is approximately 0.5 mSv, standard procedures for natural background correction are expected to be sufficiently precise and no additional control dosimeters are required. Recommended dosimeter types and technologies are:

1. High sensitivity LiF : Mg, Cu, P thermoluminescent (TL) detectors (Harshaw TLD-100H, RadPro MCP-N), in sealed water tight plastic bags: Individual TLD pellets of size 4.5 x 4.5 x 0.9 mm^3, calibrated in terms of $H_p(0.07)$ and easily attachable to a person. Estimated uncertainty (k=2) in the determination of the factors (a)-(c) is approximately 20%.

2. $Li_2B_4O_7$: Cu TL detectors (Panasonic UD-807) are encapsulated in a water tight and disinfectable holder and are therefore larger in size (Ø14 x 6 mm). To ensures a well defined position for reproducible measurement and traceability, the detector holder is designed as part of a bayonet coupling, the counter part of which is integrated in the protection means (or supplied as an adapter). Uncertainty (k=2) on factor assessment is approximately 20%. Alternatively, the detector can be clipped to any convenient position, which, however, may rise subsequent questions about the actually measured radiation field.

The uncertainty calculations for the factors (a)-(c) presume that

- the dosimeters are synchronously prepared, worn and measured in order to ensure consistent background subtraction,
- the same dosimeter technology is used to minimize material dependent effects,
- at least 0.5 mSv is accumulated on each dosimeter during less than 60 days,
- detector positions are particularly well defined and supervised in positions 2 and 3.

The two materials suggested above are nearly tissue equivalent which makes them suitable for eye lens and extremity dosimetry.

As an outlook, an alternative passive dosimetry technology is optically stimulated luminescence (OSL) based on BeO, which is superior to TL detectors in terms of instrumental uncertainty. Furthermore, BeO detectors show an even lower energy dependence in the relevant medical x-ray range. That allows to further reduce the measurement uncertainty. BeO based OSL detectors are in preparation for approval in Switzerland within the next 1-2 years.

Detector materials with strong energy dependence (e.g. Al_2O_3:C) are not advised for this purpose.

Method 2: determination of f_L using EL and OA dosimeters for a given professional

The person consistently wears an EL and an OA dosimeter for 2-3 months. The EL dosimeter must be worn under the protective equipment as close as possible to the more exposed eye. OA and EL doses are then compared to determine the correction factor f_L.

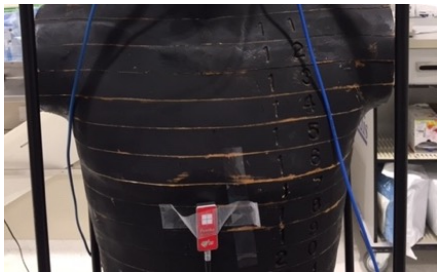
The limitations of this method are the long measuring time and possible loss of data usability if the two dosimeters are not reliably worn simultaneously.

Method 3: determination of DRF using an anthropomorphic phantom

Description of measurement setup for determination of lead glass attenuation factor for face masks or goggles using fluoroscopy units.

Typical setup at fluoroscopy unit (i.e. in cardiology):

- detector position: LAO 30°
- distance patient – operator's eyes: 1 m
- Phantom representing the medical staff
- Dosimeters on the eye's surface



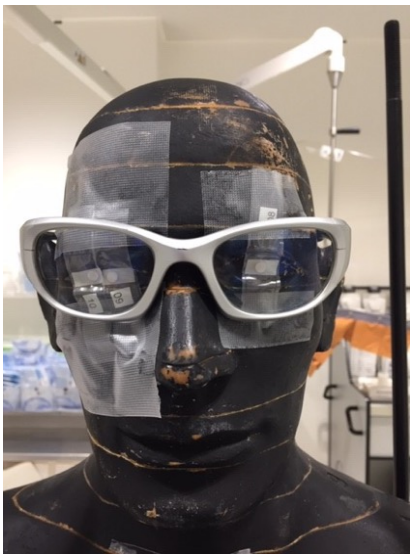


Figure 4. Representation of the scenario used for the measurement of the DRF when using googles or RP face mask.

An anthropomorphic phantom which mimics the operator should be placed looking straight to the screen. The direct distance between the phantom eyes to the patient is about 1 m. Unless different angulations of the detector are used in clinical practice, one should choose the 'worst case' angulation geometry. This corresponds to the angulation which causes the highest dose scattered to the operator. This angulation is known as "LAO" (Left-anterior-oblique projection) applied e.g. in cardiology.

The patient is simulated using a phantom on the table near to the detector. The operator is positioned just at the side of the table, around 80 cm caudal with respect to the tube.

The dosimeters are fixed directly on the surface of the phantom representing the operator at the eyes position. Two sets of measurements should be performed, one with protective means and one without protective means. The factor for the attenuation should then be taken as the ratio of the measurement values performed with and without the protective equipment. For each measurement, the dose area product (DAP) value should be the same. If this is not possible, the measured doses at the eye lens position should be normalized by the DAP value before calculating the attenuation.

In case that passive dosimeters are used on the operator and to ensure that enough dose is cumulated, a dosimeter with a direct reading (i.e. APD, RadCal,….) placed at the chest level should be used simultaneously.

The limitation of the method is clearly that it represents a single static scenario.