TECHNICAL INFORMATION SHEETS:

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EYE LENS:
REGULATORYLIMITS,MEASUREMENT,DOSIMETRYANDMEDICALSURVEILLANCE

The lens of the eye is radiosensitive tissue that can be affected by ionising radiation. It develops opacities, which can go on to become cataracts. As a result of various epidemiological studies[1,2,3] the International Commission on Radiological Protection (ICRP) has proposed a revised exposure limit for the eye lens[4], which in some work situations may lead to a significant change in radiological protection practices around monitoring the risk of eye lens exposures.

In this sheet, we begin by explaining the official limits and the measurement quantities. We then describe various exposure situations and the operating principles and performance of several dosemeters, together with their wearing conditions, before going on to describe the possibilities for indirect monitoring of the dose delivered to the lens and procedures for dosimetric and medical surveillance.

1 - REGULATORY LIMITS AND MEASUREMENT QUANTITIES.

In 2010, ICRP recommended that the occupational exposure limit be reduced for the lens of the eye to 20 mSv per year on average over a five-year period, with a maximum of 50 mSv in any one year[4] (as opposed to the previous 150 mSv over 12 consecutive months). Decree 2018- 437 of January 18, 2018 [5] reiterates this recommendation (article R4451-6), stating that the limit is 20 mSv over twelve consecutive months. This limit came into force on July 1, 2023.
The limit is expressed in terms of equivalent dose to the lens – H_{lens}[6]. As this quantity cannot be measured, it is estimated via two operational quantities[7,8,9], the first being directional dose equivalent at 3 mm depth – $H'(3)$ – for area monitoring, and the second being individual dose equivalent at 3 mm depth – $H_p(3)$. The depth of 3 mm was selected as it corresponds to the depth at which the part of the lens considered to be sensitive to ionising radiation is located. In order to study the energy deposited in the tissue without using an anthropomorphic phantom, the operational quantities are set using simplified phantom shapes. For example, for $H_p(3)$, a 20 cm diameter right circular cylinder made of ICRU (soft) tissue material is used and for $H'(3)$ the ICRU 30 cm diameter sphere[10,11,12,13].

2- SITUATIONS ENTAILING LENS EXPOSURE HAZARDS.

The table below gives some examples of lens exposure situations by occupational sector (industry, medical). The exposure risk situations and the sources mentioned for these sectors can also be found in research facilities. This is not intended to be an exhaustive list, but is designed to draw attention to situations we might not necessarily think about and to stimulate an examination of exposure risk according to the work place. The table illustrates the fact that all types of ionising radiations – neutrons, photons and electrons – can entail exposure of the lens. In some circumstances, these exposure situations can lead to dose equivalents close to or even in excess of the exposure limit laid down by Directive 2013/59/Euratom.

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Technical Information Sheets:

Eye lens:

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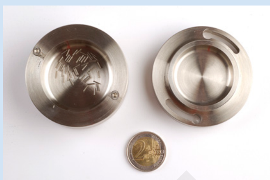
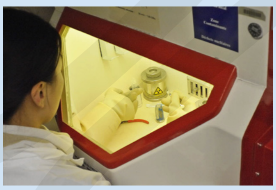
OCCUPATION	Ionising radiation source	Exposure risk situation / example / diagram/photo
INDUSTRIAL	Pu, Am, Beta emitters ...	 Glove box work and related maintenance[14]
	^{60}Co and ^{58}Co (primarily activation products)	- Nuclear facility modification works (e.g. work on steam generators, work on vessel closure thermocouples, welding on hot spot). The radiation sources tend to lead to greater exposure of the head than the chest (body/lens ratio close to 1.5). - Dismantling operations (e.g. waste sorting or waste package filling). Job hazard assessments usually reveal body/lens ratios close to 1. - Changing targets; maintenance works on accelerators or cyclotrons, etc.
	Thorium released by grinding, via abrasives containing white corundum and zircon.	Jewellery industry: diamonds can be artificially irradiated to change their colour. Stones such as diamonds, topaz, etc. can also be contaminated during cutting (with abrasives containing white corundum (alumina) and zircon, which release thorium during grinding). Examining stones using magnifying instruments can therefore lead to a lens exposure risk.
	^{137}Cs, ^{252}Cf	Use of gauge such as humidity meters (soil water content), etc.
MEDICAL	X-rays < 50 kV	Contact X-ray therapy (treatment of eyelids, skin, rectum)[15].
	X-rays: 50 <HV< 150 kV	 Interventional radiology and cardiology [16,17]: Angiography, cardiac angioplasty, radiofrequency ablation, pacemaker implantation, embolization. Endovascular surgery for angiomas and stroke, stent fitting, vertebroplasty. Veterinary and human radiology: holding patients during procedures.
	^{125}I, ^{137}Cs, ^{192}Ir	 Brachytherapy for prostate and eye tumours; repair work on brachytherapy source afterloader[18].
	^{99m}Tc, ^{18}F, ^{131}I, ^{90}Y ...	 Nuclear medicine: preparation and injection of radioactive tracers[19]; for example for PET scan investigations (in both humans and animals).

Photo: PF.Grosjean/CEA - IRSN

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3 - HOW PERSONAL DOSEMETERS SPECIFICALLY FOR THE EYE LENS SHOULD BE WORN.

A personal dosemeter should be worn as close as possible to the target organ, either as close as possible to the most exposed lens [20,21,22,23,24], or with dual measurement for both lenses, to avoid under-estimated exposure readings. A personal dosemeter that is to be worn near the eye lens must be calibrated against a phantom that replicates the dosemeter wearing situation. The phantom which best replicates the head is the 20 cm diameter right circle cylinder filled with water with PMMA[1] walls[11,12]. The dosemeter will be worn over or under personal protective equipment (PPE) depending on the model. If the dosemeter housing has a built-in shield equivalent to the required PPE shield, it can be worn over the PPE. If not, it must be worn under it. It must also be noted that for dosemeters not worn in contact with the skin, the backing material must be of a thickness with equivalent reflectance to the skull.

4 - DOSEMETERS FOR DIRECT MEASUREMENT OF $H_p(3)$.

Several dosimetry services are available, enabling direct measurement of $H_p(3)$ for photons and electrons. Without being exhaustive, the websites listed in the following table present some dosimeter designs as they are known at the date of publication of this data sheet. All these devices are based on thermos-luminescent detectors. They come either inside an elastic headband or inside housing that can be fitted to the arms of goggles or onto a visor or headband. In most cases, the detector has a filter. The shape and material used for the filter ensure that the dosemeter meets standard EN CEI 62387 2015 or higher[2] [25]. The dosimetry services provide information about these features on their websites and advertising brochures. They generally cover the following energy ranges:

- for photons: a range from several tens of keV to energy approximately equal to that of ^{60}Co photons;
- for electrons, down to 700 keV.

The dose equivalent range covered is usually 0.1 mSv to 10 Sv.
The dosemeter should be chosen depending on the work place it will be used for, in terms of the range of angle, energy and dose equivalent respectively.
The web addresses of the manufacturers and distributors we are aware of to date are given below. These provide the additional information needed to choose the most appropriate dosemeter for the specific exposure risk situation.

1-PMMA = Polymethyl methacrylate.
2-It is worth noting that another standard, ISO 12794 [26,27], is currently being withdrawn.

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The web addresses of the manufacturers and distributors we are aware of to date of the publication of this note are given below. These provide addresses and the additional information needed to choose the most appropriate dosemeter for the specific exposure risk situation.

Later in this information sheet, we will look at other possible procedures for estimating *Hp*(3), for example using whole body dosimetry[3].

MANUFACTURER / DISTRIBUTOR	WEBSITE
Dosimeter EYE-D ™ (Radcard) [28]	www.radpro-int.com / assets / eye-d.pdf
UK rotundascitech company	http://www.rotundascitech.com/EyeDosimetry.html
Public Health England (PHE)	http://www.phe.org.uk
DOSIRIS (IRSN)	http://dosimetre.irsn.fr/fr-fr/Documents/Fiches%20produits / IRSN_Fiche_dosimetre_Cristallin.pdf
Landauer	http://www.landauer-fr.com/lentreprise/actualites.html
DosiEYE (Dosilab)	http://www.dosilab.fr

5 - PERSONAL PROTECTIVE EQUIPMENT.

As mentioned in paragraph 2 of this sheet, various work situations can lead to eye lens exposure hazards, whether the ionising radiation consists of neutrons, photons or electrons. Depending on the outcome of the risk assessment, and after the collective protective equipment has been put in place, it may be necessary to add personal protective equipment (PPE). However, PPE cannot meet all needs, especially in the case of exposure risks due to neutrons and high-energy photons. PPE basically covers situations involving electrons and low-energy photons. The equipment may take the form of radiation protection cabins or ceiling-suspended lead-equivalent personal shields up to 2 mm thick. However, there are operational constraints with this type of equipment and it cannot always be used. In these situations, other means of protection are available[29,30], such as lead-equivalent acrylic goggles or visors (sometimes used by people who wear glasses), for which lateral protection is needed. The lead equivalent material can be up to 0.5 mm thick. It is worth noting that there are three specific advantages to the cabins and shields: they provide a higher level of mitigation; they protect the head and torso and their weight is not supported by the operator, which reduces the potential for musculoskeletal problems. Information about the risks associated with exposure of the eye lens and about when and how personal protective equipment should be worn must be included in the work place training.

6 - FACTORS TO CONSIDER WHEN CHOOSING BETWEEN DIRECT AND INDIRECT $H_p(3)$ MEASUREMENT IN THE CASE OF PHOTON AND ELECTRON RADIATION [31].

The most accurate way of determining $H_p(3)$ is to use a dosemeter that will measure it directly; in other words one that is worn as close as possible to the eye lens. Since wearing dosemeters in this way can be restrictive depending on the work place, estimating $H_p(3)$ indirectly via a different personal dosimeter, for example one worn on the torso, may be an acceptable alternative. This indirect method is included in the ISO 15382 standard [31b]....

3-e.g. Arevabadge

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In these situations, it is useful to decide on an objective criterion for choosing between direct $H_p(3)$ measurement and indirect $H_p(3)$ estimation based on a reading of $H_p(10)$ taken at the torso, to which a conversion factor is then applied in order to obtain the $H_p(3)$ value.

When determining the conversion factor, the fact that the radiation field is not the same between the eye and the torso must be taken into consideration, in addition to the conversion between $H_p(3)$ and $H_p(10)$. The conversion factor is obtained during the work place study, which will establish the ratio, R, so that: R = $H_p(3)$ / $H_p(10)$.

The criterion must take into consideration the accuracy of the readings. By taking into account the annual eye lens exposure limits suggested in the European directive (20 mSv or 50 mSv in any given year) and the expanded uncertainty for the $H_p(10)$ reading, it is possible to establish maximum values of measured $H_p(10)$ – $H_p(10)_{max20}$ or $H_p(10)_{max50}$. This would mean that if the $H_p(10)$ reading is lower than the maximum values, it can be considered with a 95%, 99.8% or 99.99% confidence level (depending on the coverage factor chosen for $H_p(10)$ uncertainty) that the $H_p(3)$ value calculated from the $H_p(10)$ value would not result in a value below the $H_p(3)$ limit being stated while the limit would have been exceeded according to a direct reading.

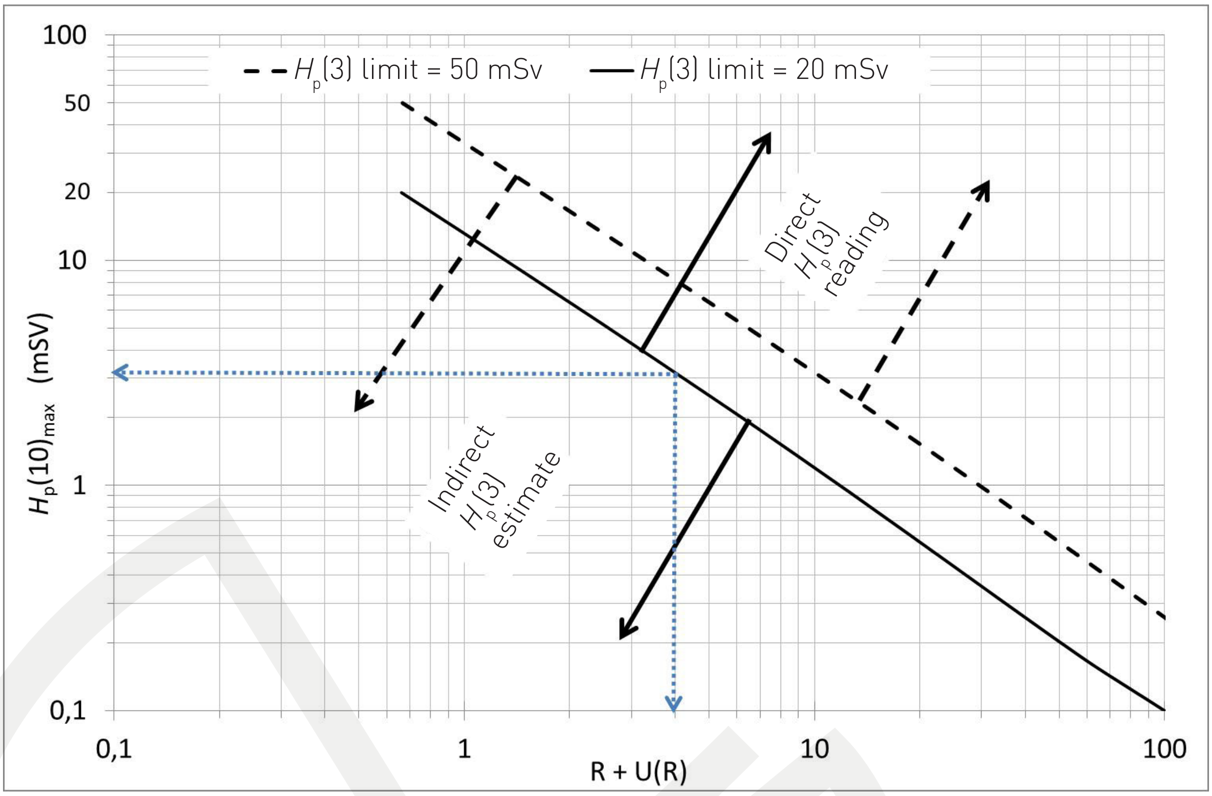

Figure: Graph of areas for direct $H_p(3)$ reading or indirect $H_p(3)$ estimation.

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The above graph illustrates the variations in $H_p(10)_{max20}$ (solid line) and $H_p(10)_{max50}$ (dotted line) depending on the ratio R plus its expanded uncertainty, i.e. R+U(R), based on photon dosimetry and monthly monitoring period of a whole body dosimeter in accordance with the EUR 14852 EN [32,33]. For the value R+U(R)=4 (blue dotted arrows), monitoring of the dose to the eye lens based on the "whole body dose" with a conversion factor applied could be considered only if the $H_p(10)$ reading is below 3.1 mSv, where the annual exposure limit for $H_p(3)$ is taken to be 20 mSv per year.

Theoretically, a ratio (R) based on a quantity other than $H_p(10)$ is possible. However, in the case of extremity dosemeters measuring $H_p(0.07)$, the uncertainty (U[R]) has to be high, as it is difficult to reproduce the positioning of the dosemeter on the hand. As a result, the $H_p(0.07)_{max}$ value is lower and therefore more restrictive than the $H_p(10)_{max}$ value that would have been found for the same work place.
If one of the ambient dosimetry values with the R denominator applied is used, sudden variations in the person's working conditions within an unchanged radiological environment can lead to variations in R that are sufficiently large to significantly change the value of R+U(R); whereas the value of R+U(R) based on the ratio $H_p(3)/H_p(10)$ varies to a lesser degree, as both values are read on the person and therefore take variations in working conditions into account in the same way, or at least partially.

7 - OCCUPATIONAL MEDICAL MONITORING, CLASSIFICATION AND SURVEILLANCE.

NATURE OF THE HEALTH RISK:

The lens is an avascular part of the eye and fulfils the function of accommodation. Lens tissue is radiosensitive and can be affected by ionising radiations: it develops opacities which can go on to become cataracts. Cataracts are areas of opacification on the lens which lead to reduced visual acuity. Here, the opacification occurs primarily on the back of the capsule that surrounds the inner core of the lens; hence they are referred to as radiation-induced posterior cortical or posterior sub-capsular cataracts.

The disorder is deterministic, but also stochastic, involving alteration of the target cell genome and disruption of cell division and daughter cell differentiation. Treatment consists in removing the lens and replacing it with an intraocular implant.

MEDICAL MONITORING:

An eye examination must be carried out at appropriate intervals by a person of known competence who has been told the specific requirements of the investigation; i.e. to look for any lens opacities and state their size, and if they are smaller than 5 mm to state whether or not they are spread out and where they are located.

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Eye lens:

REGULATORYLIMITS,MEASUREMENT,DOSIMETRYANDMEDICALSURVEILLANCE

CLASSIFICATION AND DOSIMETRY MONITORING[34]:

By conducting a work place study, it should be possible to estimate the probable dose that will be received by the lens. Workers will be classified as Category A if their work situation exposes them to ionising radiation likely to involve doses to the eye lens higher than 15 mSv/year. (Article R.4451-53).

Technically speaking, the worker's category should determine how often dosimetric monitoring should take place (using either a direct or an indirect method). Since 2010, it has been possible to input lens dosimetry results into the (French) information system for ionising radiation exposure monitoring (SISERI). In practice, following the availability of the monitoring devices for the eye lens, since the 2015 report on occupational exposure to ionizing radiations produced by the Radiological Protection and Nuclear Safety Institute (IRSN) the exposure data for the lens of the eye are recorded. If prevention and protection actions are to be effective, it is important to get all the relevant stakeholders involved

Exposure traceability includes recording dosimetry monitoring results, post-exposure follow-up, a certificate of exposure when workers leave their job and monitoring in retirement if necessary. Occupational Illness Table 64 mentions radiation-induced cataracts. It is reproduced below:

DESCRIPTION OF ILLNESS (RESTRICTIVE LIST)	Time limit compensation claim (delay between the diagnosis and the end of the exposure)	Indicative list of the main occupational areas likely to cause these disorders
BLEPHARITIS OR CONJUNCTIVITIS	7 days	All work involving exposure to the action of X-Rays, natural or artificial radioactive substances, or to any other source of particle emission.
KERATOCONJUNCTIVITIS	1 year	
CATARACT	10 years	

4-Table of recognition of radiation induced occupational illness according to the French law

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SOME REFERENCES

1 - Worgul B.V. et al. (2007) Cataracts among Chernobyl Clean-up Workers: Implications Regarding Permissible Eye Exposure., Radiation Research 167, 233-243.

2 - Chodick G.et al. (2008) Risk of cataract after exposure to low doses of ionizing radiation: a 20-year prospective cohort study among US radiologic technologists, Am. J. Epidemiol. 168, 620–31.

3 - Nakashima E.et al. (2006) A reanalysis of atomic-bomb cataract data, 2000–2002: a threshold analysis. Health Phys. 90, 154–60.

4 - ICRP (2011) International Commission on Radiological Protection Statement on tissue reactions, ICRP ref 4825-3093-1464.

5 - JORF n°0127 du 5 juin 2018, texte n° 65, Décret n° 2018-437 du 4 juin 2018 relatif à la protection des travailleurs contre les risques dus aux rayonnements ionisants.

6 - ICRP publication 116 (2010) Conversion coefficients for radiological protection quantities for external radiation exposures, ICRP.

7 - ICRU report 43 (1988) Determination of dose equivalents from external radiation sources- Part 2, Bethesda.

8 - ICRU report 47 (1992) Measurement of dose equivalent from external photons and electron radiations, International commission on radiation units and measurements, Bethesda.

9 - ICRU report 57 (1995) Conversion coefficients for use in radiological protection against external radiation, ICRU, Bethesda.

10 - Daures J.et al. (2009) Conversion coefficients from air kerma to personal dose equivalent $H_p(3)$ for eye-lens dosimetry, ISSN-0429-3460, CEA-R-6235 Saclay, France.

11 - Daures J. et al. (2011) Monte Carlo determination of the conversion coefficients $H_p(3)$/Ka in a right cylinder phantom with penelope code. Comparison with "mcnp" simulations", Radiation Protection Dosimetry 144 (1-4), 37-42.

12 - Gualdrini G. et al. (2011) A new cylindrical phantom for eye lens dosimetry development, Radiation Measurements 46, 1231-1234.

13 - Gualdrini G. et al. (2013) Air kerma to $H_p(3)$ conversion coefficients for photons from 10 keV to 10 MeV, calculated in a cylindrical phantom. Radiation Protection Dosimetry 154 (4), 517-521.

14 - P. Devin et al. (2013) 9ème Congrès National de Radioprotection, Bordeaux, La dosimètre du cristallin.

15 - Marcié S. et al. (2014) Exposition du cristallin du praticien lors des traitements avec des rayons X de basse énergie, Radioprotection 49(4), 289-292.

16 - K. Chamoulaud et al. (2012) 8ème rencontre des PCR, Issy-les-Moulineaux ; Etude dosimétrique en radiologie interventionnelle oncologique : dose efficace, dose équivalente à la main et au cristallin (communication privée).

17 - Dabli D. et al. (2015) 10ème Congrès National de Radioprotection, Reims, Évaluation de l'exposition du cristallin de l'oeil des cardiologues en coronarographie, http://www.sfrp.asso.fr/medias/sfrp/documents/201506-S7-Dabli-D.pdf

18 - Fiche inrs ED 4248 radioprotection médicale, curiethérapie bas débit non pulsé.

19 - Huet C. et al. (2013) 9ème Congrès National de Radioprotection, Bordeaux, Evaluation de la dose équivalente au cristallin suite à des incidents de contamination oculaire en médecine nucléaire, http://www.sfrp.asso.fr/medias/sfrp/documents/Bordeaux-S7d.pdf

20 - European Commission PR 160 (2009) Technical Recommendations for Monitoring Individuals Exposed to External Radiation, Radiation Protection No 160.

21 - Livre blanc sur la surveillance radiologique des travailleurs. http://www.asn.fr/Informer/Actualites/Livre-blanc-sur-la-surveillance-radiologique-des-travailleurs

22 - Bordy J.M. et al. (2013) 9ème Congrès National de Radioprotection, Bordeaux, la dosimétrie du cristallin : aspects théoriques, http://www.sfrp.asso.fr/medias/sfrp/documents/Bordeaux-S7b.pdf

23 - Rapport IRSN PRP-HOM/2013-00010 (2013) Recommandations sur les bonnes pratiques en matières de radioprotection des travailleurs dans la perspective de l'abaissement de la limite réglementaire de dose équivalente pour le cristallin.

24 - AIEA TECDOC 1731, (2013) Implications for Occupational Radiation Protection of the New Dose Limit for the Lens of the Eye.

25 - IEC 62387 Radiation protection instrumentation – Passive integrating dosimetry systems for environmental and personal monitoring.

26 - ISO 12794 :2000 Énergie nucléaire - Radioprotection - Dosimètres individuels thermolumines-cents pour yeux et extrémités.

27 - Bordy J.M. et al. (2013) 9ème Congrès National de Radioprotection, Bordeaux, la dosimétrie du cristallin : aspects pratiques, http://www.sfrp.asso.fr/medias/sfrp/documents/Bordeaux-S8a.pdf

28 - Bilski P. et al. (2011) The new eye-d™ dosemeter for measurements of $H_p(3)$ for medical staff, Radiation Measurements 46, (11), 1239-1242.

29 - Rannou A. et al. (2013) 9ème Congrès National de Radioprotection, Bordeaux, Abaissement de la limite de dose au cristallin pour les travailleurs : implications pratiques, http://www.sfrp.asso.fr/medias/sfrp/documents/Bordeaux-S7e.pdf

30 - Ouabdelkader S. et al. (2012) 8ème rencontre des PCR, Issy-les-Moulineaux, EFFICACITE DES PROTECTIONS OCULAIRES EN RADIOLOGIE, https://prezi.com/9pya292mef0i/efficacite-des-protections-oculaires-en-radiologie/?auth_key=af39db4b98edc961d9d0f0e4af0bd1e2bac71a23

31 - Bordy J.M. (2015), Monitoring of eye lens doses in radiation protection, Radioprotection 50(3), 177-185, http://dx.doi.org/10.1051/radiopro/2015009

31b - ISO 15382 :2024 Radiological protection — Procedures for monitoring the dose to the lens of the eye, the skin and the extremities

32 - ISO 14146 (2000) International Organization for Standardization Radiation protection – Criteria and performance limits for the periodic evaluation of processors of personal dosemeters for X and gamma radiation. ISO 14146 (ISO: Geneva).

33 - European Commission PR 73 (1994) Technical Recommendations for Monitoring Individuals Exposed to External Radiation, report EUR 14852 EN.

34 - Code du travail 4éme partie, livre IV, titre V, chapitre 1

This information sheet was produced by the members of the Technical Protection Section of the French Radiological Protection Society (work coordinated by JM. Bordy).

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