Physikalisch-Technische Bundesanstalt
Braunschweig and Berlin
National Metrology Institute

Dosimetry of the lens of the eye

Dosimetric units and quantities for eye lens monitoring, standards, type testing, calibration procedures and phantoms

R. Behrens

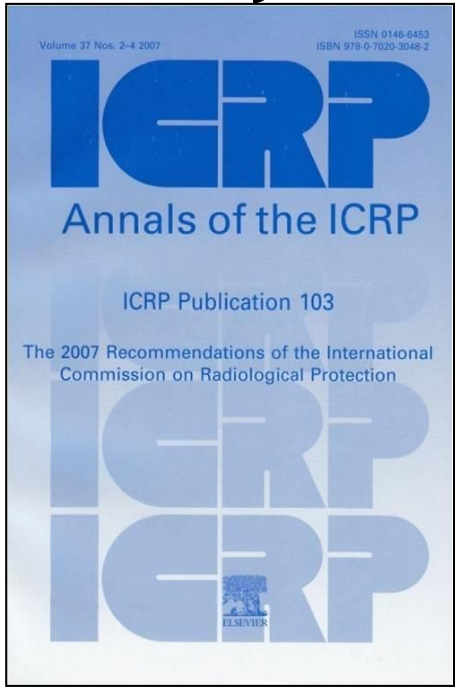
13th EURADOS Winter School
"Eye lens dosimetry"
30th January 2020

Contents

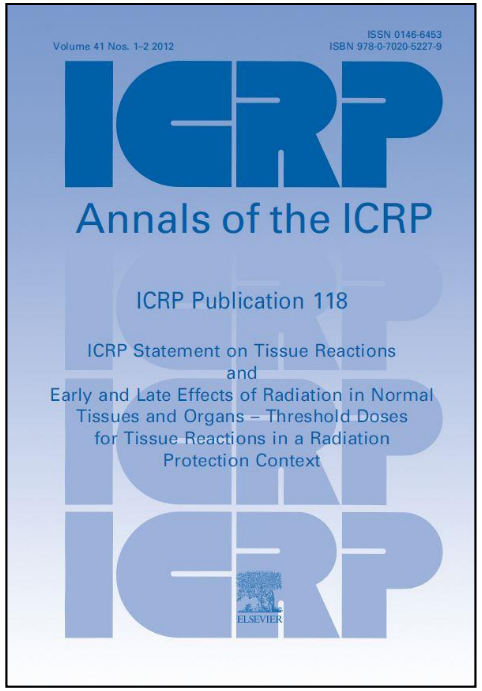
ICRP 103 (2007) vs. 118 (2012): Tissue reactions

Threshold dose for the induction of cataract at irradiations

- acute: 2 Gy → 0.5 Gy (.. 0 Gy?)
- protracted: 5 Gy



(2007)



(2012)

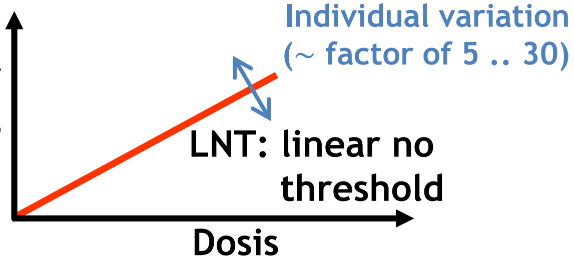
Definition of threshold dose: *effect for 1 % of exposed; not necessarily cataract!*
More shall be prevented ➔ 500 mSv / 25 years
➔ limit: 20 mSv/a
75 % "normal" cataract in public; can be operated

Death by cancer: 5 % per 1 Sv
death for 1 % of exposed ➔ 1 % per 200 mSv
If more should be prevented ➔ 200 mSv / 25 years
➔ limit: 8 mSv/a !?
20 % "normal" mortality in public by cancer

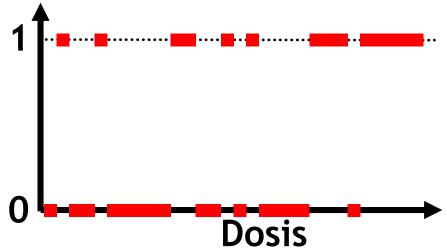
Contents

Terms: Sievert (*H*) vs. Gray (*D*)

- Low doses (≲ 0.5 Sv) ➔ DSB
- Effect: cancer, hereditary disease
- Depends on radiation type ➔ w_R ➔ Sv
- Probability of effect

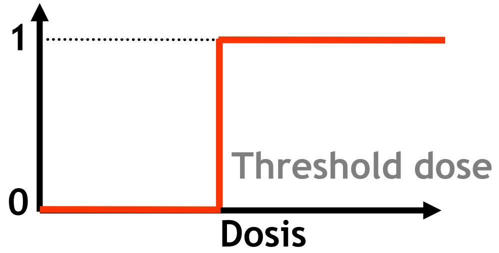


- Stochastic effects
- Long after irradiation (years to decades)
- Strength of effect

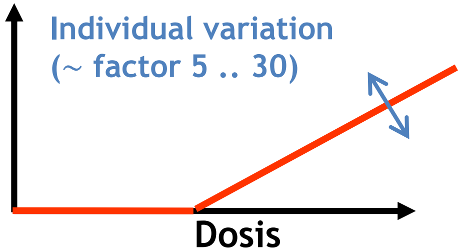


- Use e.g. for effective dose (risk of cancer) and in epidemiological studies; in therapy only for secondary cancer!

- High doses (≳ 0.5 Gy) ➔ cell dead
- Effect: e.g. erythema, organ-fail or -dead, dead (e.g. tumor therapy)
- Independent of radiation type ➔ Gy
- Probability of effect



- Deterministic effects
- Shortly after irradiation (days to weeks)
- Strength of effect

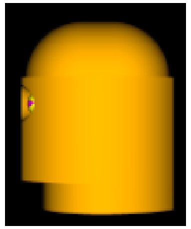
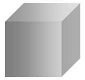


- Use e.g. at radiation accidents, tumor therapy (dose in target volume)

Effect not yet clear for the lens of the eye (ICRP 118)

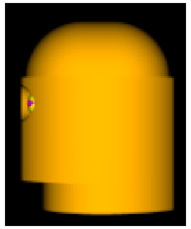
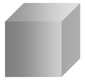
Protection quantities

Sievert

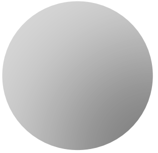
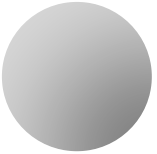
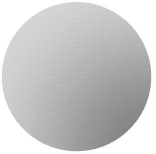
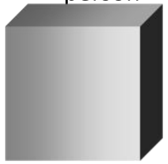
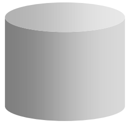
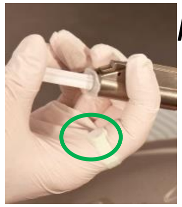
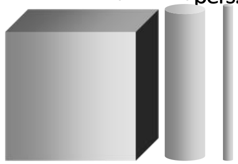
	Whole body	Lens of the eye	Local skin
Protection quantities (ICRP 116)	 ICRP reference voxel phantoms: $E_{eff} = \sum_T w_T \sum_R w_R D_{T,R}$	 Stylized eye model; whole lens (ICRP 116, Annex F): $H_{lens} = \sum_R w_R D_{lens,R}$	 Tissue-equivalent cube (10x10x10 cm3); 1 cm^2 area at 50 – 100 µm depth (ICRP 116, Annex G): $H_{local\ skin} = \sum_R w_R D_{local\ skin,R}$

Protection quantities vs. operational quantities

Sievert

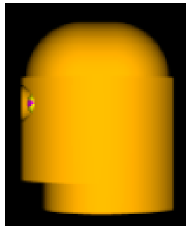
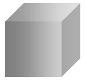
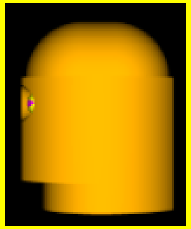
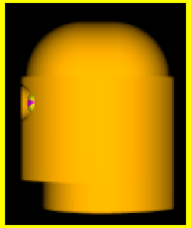
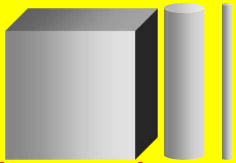
	Whole body	Lens of the eye	Local skin
Protection quantities (ICRP 116)	 ICRP reference voxel phantoms: $E_{eff} = \sum_T w_T \sum_R w_R D_{T,R}$	 Stylized eye model; whole lens (ICRP 116, Annex F): $H_{lens} = \sum_R w_R D_{lens,R}$	 Tissue-equivalent cube (10x10x10 cm3); 1 cm^2 area at 50 – 100 µm depth (ICRP 116, Annex G): $H_{local\ skin} = \sum_R w_R D_{local\ skin,R}$

Operational quantities: definition: $H = Q(L) \cdot D$

Operational quantities for monitoring (ICRU 51)	Whole body	Lens of the eye	Local skin
Area	 ICRU 4-element tissue sphere: Ø = 30 cm: $H^*(10) = Q \cdot D(10)_{sph}$	 ICRU 4-element tissue sphere: Ø = 30 cm: $H'(3;\Omega) = Q \cdot D(3;\Omega)_{sph}$	 ICRU 4-element tissue sphere: Ø = 30 cm: $H'(0.07;\Omega) = Q \cdot D(0.07;\Omega)_{sph}$
Individual	 $H_p(10) = Q \cdot D(10)_{person}$  For calibration: ICRU 4-element tissue slab: 30x30x15 cm^3: $H_p(10) = Q \cdot D(10)_{slab}$	 $H_p(3) = Q \cdot D(3)_{person}$  For calibration: ICRU 4-element cylinder: Ø = h = 20 cm: $H_p(3) = Q \cdot D(3)_{cylinder}$	 $H_p(0.07) = Q \cdot D(0.07)_{pers.}$  For calibration: ICRU 4-el. tissue slab, pillar, rod (Ø = 73, 19 mm): $H_p(0.07) = Q \cdot D(0.07)_{slab,\ pillar,\ rod}$

Quantities: proposal of ICRU RC26

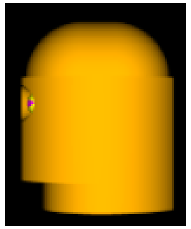
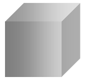
Sievert

	Whole body	Lens of the eye	Local skin
Protection quantities (ICRP 116)	 ICRP reference voxel phantoms: $E_{eff} = \sum_T w_T \sum_R w_R D_{T,R}$	 Stylized eye model; whole lens (ICRP 116, Annex F): $H_{lens} = \sum_R w_R D_{lens,R}$	 Tissue-equivalent cube (10x10x10 cm3); 1 cm^2 area at 50 – 100 µm depth (ICRP 116, Annex G): $H_{local\ skin} = \sum_R w_R D_{local\ skin,R}$
Operational quantities: definition: $H = h \cdot \Phi$; $D = d \cdot \Phi$			
Operational quantities for monitoring (ICRU RC26) – Area	 ICRP reference voxel phantoms: $H^* = h_{E,max} \cdot \Phi$	 Stylized eye model; whole lens (ICRP 116, Annex F): $D'_{lens}(\Omega) = d_{lens}(\Omega) \cdot \Phi$	 ICRU 4-element tis. slab ($30x30x15\ cm^3$) with 2 mm skin cover over 1 cm^2 at 50-100 µm $D'_{local\ skin}(\Omega) = d_{local\ skin}(\Omega) \cdot \Phi$
Operational quantities for monitoring (ICRU RC26) – Individual	 ICRP reference voxel phantoms: $H_p = h_E \cdot \Phi$	 Stylized eye model; whole lens (ICRP 116, Annex F): $D_{p\ lens}(\Omega) = d_{lens}(\Omega) \cdot \Phi$	ICRU 4-elementslab, pillar, rod; 2 mm skin cover; 1 cm^2 area at 50 – 100 µm:  $D_{p\ local\ skin} = d_{local\ skin} \cdot \Phi$

Contents

Is an operational quantity conservative?

Sievert

	Whole body	Lens of the eye	Local skin
Protection quantities (ICRP 116)	 ICRP reference voxel phantoms: $E_{eff} = \sum_T w_T \sum_R w_R D_{T,R}$	 Stylized eye model; whole lens (ICRP 116, Annex F): $H_{lens} = \sum_R w_R D_{lens,R}$	 Tissue-equivalent cube (10x10x10 cm3); 1 cm² area at 50 – 100 µm depth (ICRP 116, Annex G): $H_{local\ skin} = \sum_R w_R D_{local\ skin,R}$

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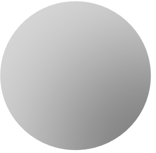
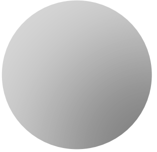
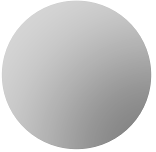
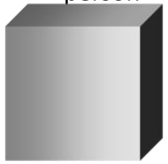
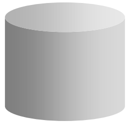
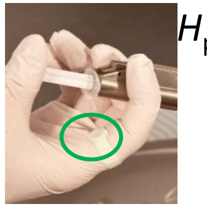
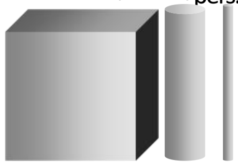
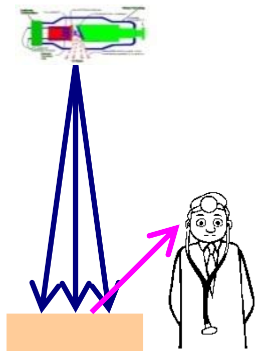
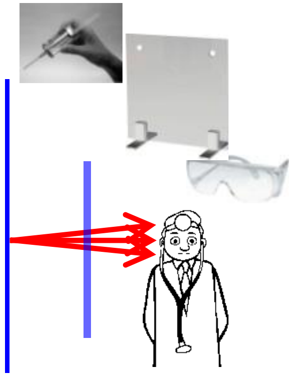
Area	 ICRU 4-element tissue sphere: Ø = 30 cm: $H^*(10) = Q \cdot D(10)_{sph}$	 ICRU 4-element tissue sphere: Ø = 30 cm: $H'(3;\Omega) = Q \cdot D(3;\Omega)_{sph}$	 ICRU 4-element tissue sphere: Ø = 30 cm: $H'(0.07;\Omega) = Q \cdot D(0.07;\Omega)_{sph}$
Individual	 $H_p(10) = Q \cdot D(10)_{person}$  For calibration: ICRU 4-element tissue slab: 30x30x15 cm³: $H_p(10) = Q \cdot D(10)_{slab}$	 $H_p(3) = Q \cdot D(3)_{person}$  For calibration: ICRU 4-element cylinder: Ø = h = 20 cm: $H_p(3) = Q \cdot D(3)_{cylinder}$	 $H_p(0.07) = Q \cdot D(0.07)_{pers.}$  For calibration: ICRU 4-el. tissue slab, pillar, rod (Ø = 73, 19 mm): $H_p(0.07) = Q \cdot D(0.07)_{slab,\ pillar,\ rod}$

? >

Which quantity for the lens of the eye?





Radiation field	$H_p(0.07)_{rod}$ / H_{lens}	$H_p(0.07)_{slab}$ / H_{lens}	$H_p(3)_{slab}$ / H_{lens}	$H_p(10)_{slab}$ / H_{lens}
X-ray mean $E < 30$ keV	0.9 – 5	1 – 5	≈ 1	0.01 – 0.9
X-ray mean $E > 30$ keV	0.8 – 0.9	≈ 1	≈ 1	0.9 – 1.2
Beta max. $E < 0.6$ MeV and X-rays	1 – 100	1 – 100	≈ 1	see above
Beta max. $E \approx 1$ MeV and X-rays	1 – 500	1 – 500	≈ 1	$2\text{x}10^{-4}$ – 1
Beta max. $E > 1.5$ MeV and X-rays	1 – 60	1 – 60	≈ 1	$2\text{x}10^{-4}$ – 1

$H_p(0.07)_{slab}$ is ONLY adequate for photon radiation.

$H_p(3)$ is NECESSARY for beta radiation.

$H_p(10)$ is NOT adequate for E_{ph}<40keV & ß

R. Behrens and G. Dietze:
Phys. Med. Biol. 55 (2010) 4047-4062
and Phys. Med. Biol. 56 (2011) 511

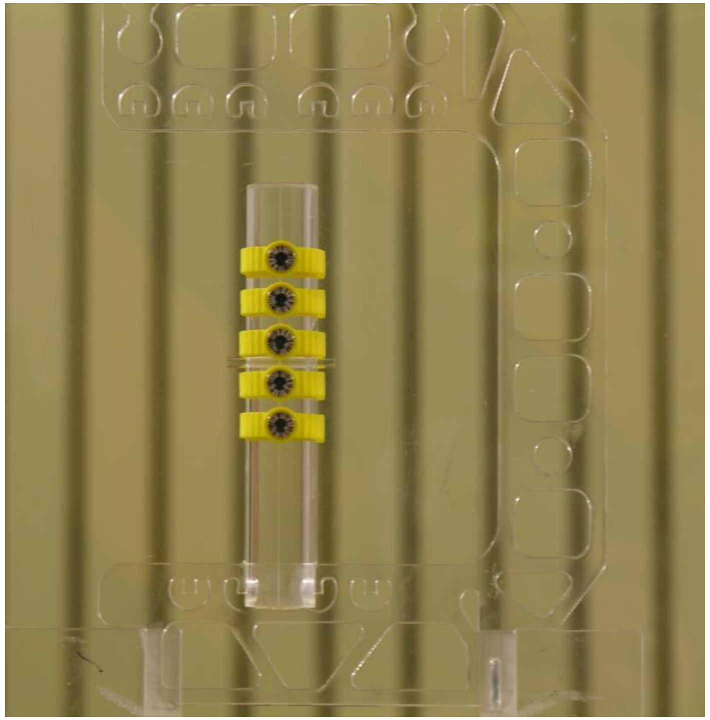
Contents

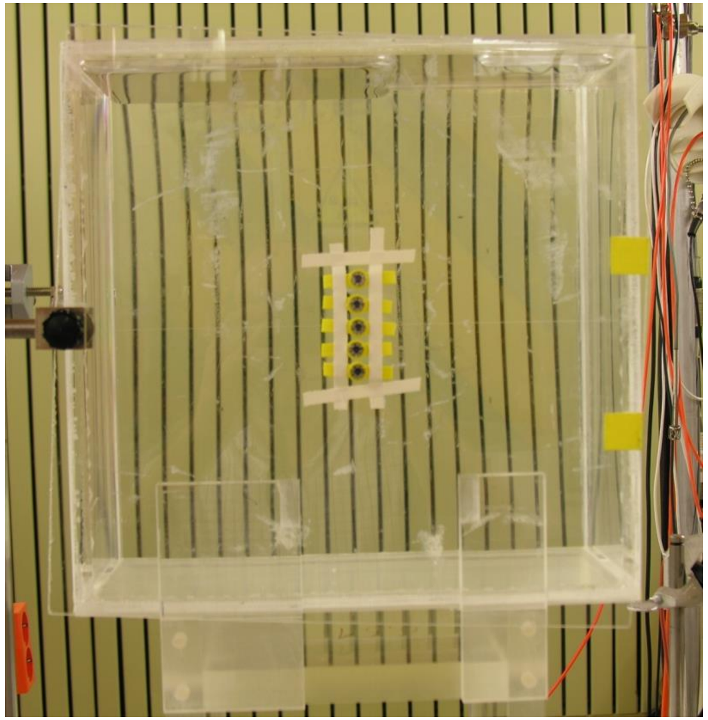
Extremity dosem. for the lens? Calibration phantom?

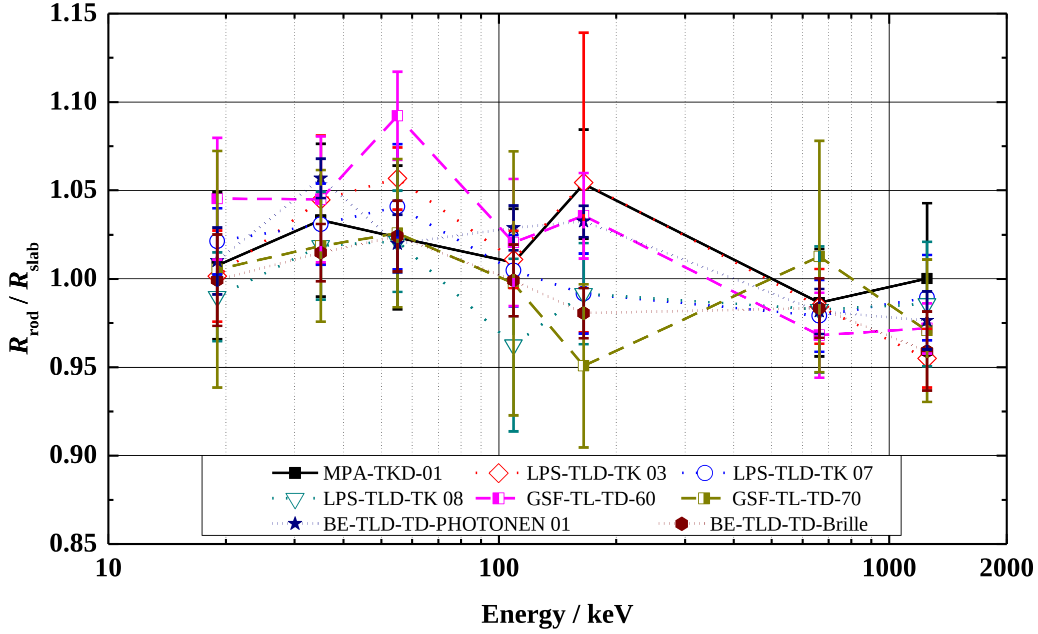
Are extremity dosemeters (for photons for $H_p(0.07)$) appropriate?

Calibration on

rod phantom *slab phantom* … *yield the same results!*



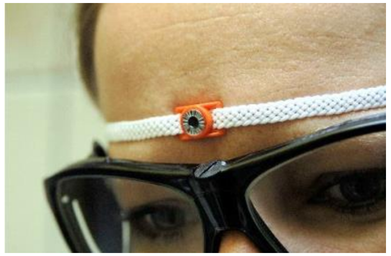




R. Behrens et al.:
Rad. Prot. Dosim. 148 (2012) 139-142

Routine measurements

- D: $H_p(3)$- and $H'(3)$-dosemeters
- D: alternatively until end of 2021 (§ 197 (1) and § 90 (2) StrlSchV): $H_p(0.07)$- and $H'(0.07)$-dosemeters in photon fields

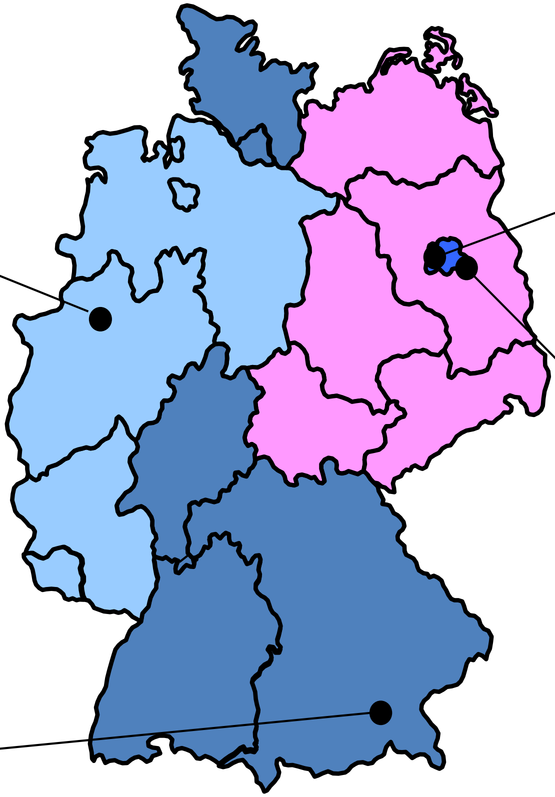


MPA-TKD-01

MPANRW
Ihr Partner für Sicherheit und Qualität

GSF-TL-TD-60 also with headband

HelmholtzZentrum münchen
Deutsches Forschungszentrum für Gesundheit und Umwelt



BE-TLD-TD-Brille

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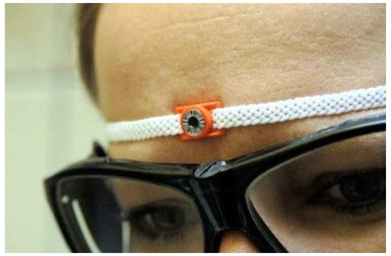
LPS

LPS TLD-TK 07

Monitoring of the lens of the eye: practice in Germany

Routine measurements

- D: $H_p(3)$- and $H'(3)$-dosemeters
- D: alternatively until end of 2021 (§ 197 (1) and § 90 (2) StrlSchV): $H_p(0.07)$- and $H'(0.07)$-dosemeters in photon fields

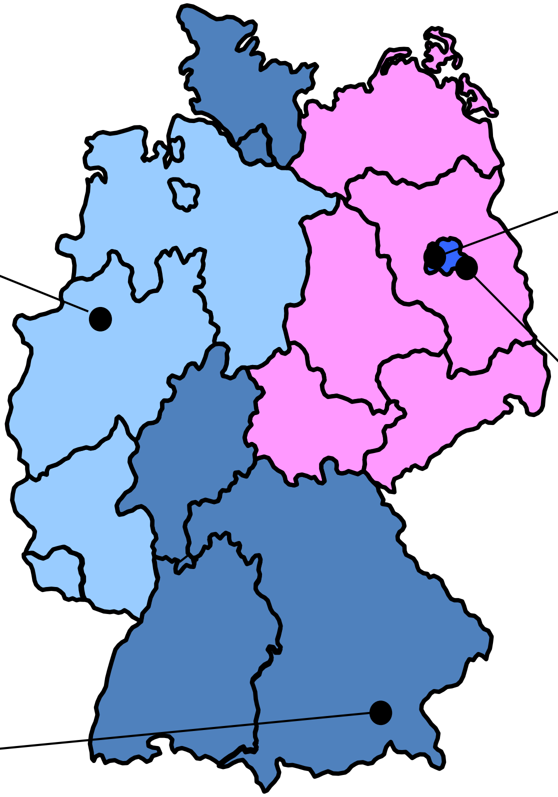


MPA-TKD-01

MPA NRW
Ihr Partner für Sicherheit und Qualität

Future: goggles with integrated $H_p(3)$-dosemeter

HelmholtzZentrum münchen
Deutsches Forschungszentrum für Gesundheit und Umwelt



BE-TLD-TD-Brille

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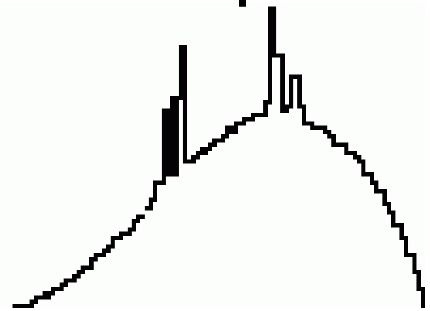
LPS TLD-TK 07

Irradiations and type tests in $H_p(3)$ and $H'(3)$ possible

Photon spectra:



- Conversion coefficients for K_a ➔ $H_p(3)_{cyl}$:
  Radiat. Prot. Dosim. 151 (2012) 450
- Conversion coefficients for K_a ➔ $H'(3)$:
  J. Radiol. Prot. 37 (2017) 354

Beta radiation:

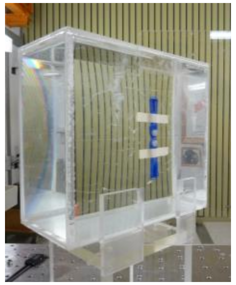
- Extensions to the Beta Secondary Standard BSS 2 incl. conversion factors from $H_p(0.07)$ ➔ $H_p(3)$ and $H'(3)$:
  J. Instrum. 6 (2011) P11007 and Erratum and Addendum
- Available for old instruments via SW update

Use cylinder or slab phantom for $H_p(3)$?

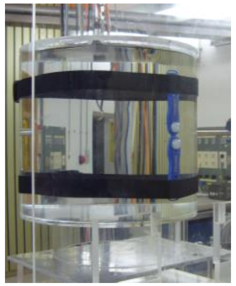
Response on slab above 45° significantly different!

R. Behrens and O. Hupe
Radiat. Prot. Dosim.
168 (2016) 441

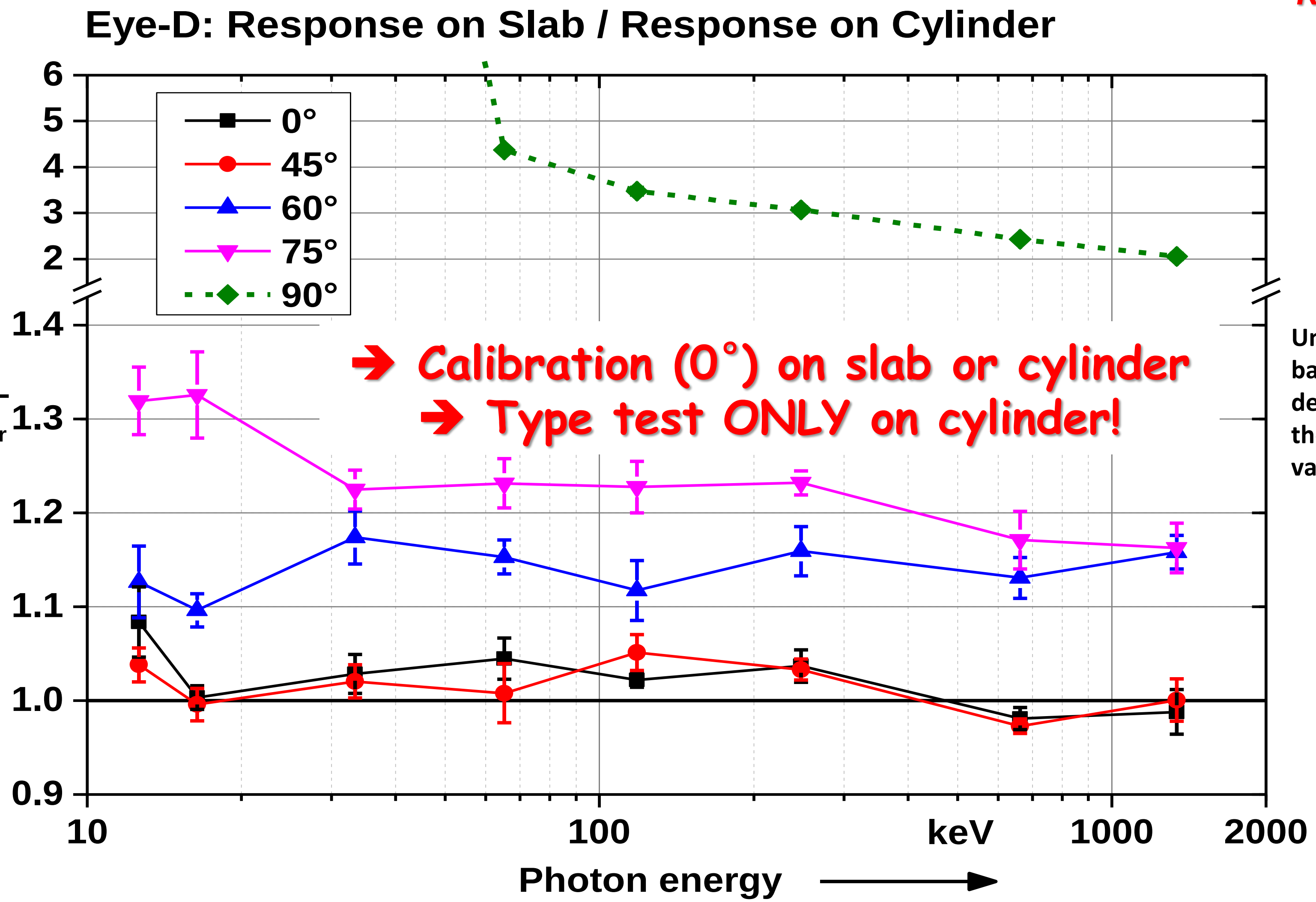
30 x 30 x 15 cm³



vs. $\frac{R_{Slab}}{R_{Cylinder}}$



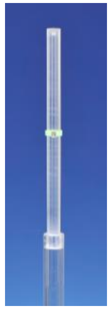
Ø = 20 cm *h* = 20 cm



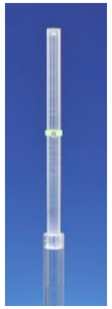
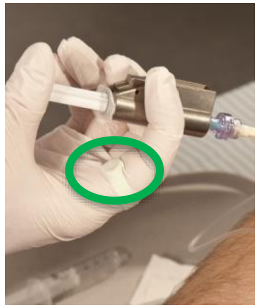
Uncertainty bars: standard deviation of the mean values

$H_p(3)$ eye lens dosemeters: Calibration and characteriz.

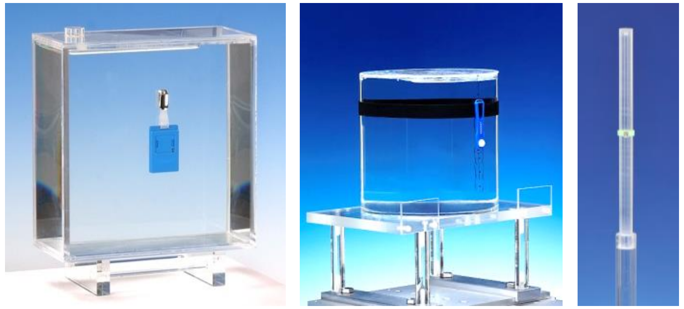
R. Behrens and O. Hupe
Radiat. Prot. Dosim.
168 (2016) 441

Calibration (0°)		Characterization (0° .. α)	
Area monitoring	Individual monitoring	Area monitoring	Individual monitoring
	  		
free in air	*Eye lens dosemeters on water cylinder, water slab or PMMA rod phantom*	*free in air*	*Eye lens dosemeters on water-cylinder phantom*

Calibration, characterization and measurement

Calibration (0°) and characterization (0° .. α)		Measurement	
Area monitoring	**Individual monitoring**	**Area monitoring**	**Individual monitoring**
	  		  
free in air	*Whole body-, eye lens-, ring-dosem. on Water slab-, water-cyl.-, PMMA-rod-phantom (water-pillar not in Germany)*	*free in air*	*Whole body-, eye lens-, ring-dosem. at the person at representative part of the body behind / below protection*

Calibr., charact. and meas.: proposal of ICRU RC26

Calibration (0°) and characterization (0° .. α)		Measurement	
Area monitoring	**Individual monitoring**	**Area monitoring**	**Individual monitoring**
			
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Procedures unchanged – ***"only"*** new conversion coefficients

➔ Calibration coefficient and energy dependence change!

Monitoring of the lens of the eye: nuclear medicine

Dose rate constants for the quantity $H_p(3)$ for frequently used radionuclides in nuclear medicine

Z. Med. Phys. 26 (2016) 304

Bastian Szermerski [1,*], Iris Bruchmann [1], Rolf Behrens [2], Lilli Geworski [1]

[1] Department for Radiation Protection and Medical Physics, Medical School Hannover
[2] Physikalisch-Technische Bundesanstalt (PTB), Bundesallee 100, 38116 Braunschweig

Table 1
Source characteristics and dose rate constants for the investigated nuclides and geometries (average of values measured at both eyes and at all distances).

Dose rate per activity at 1 m

Nuclide	Dominant emissions			Geometry	$k_{nuclide}$	$\Gamma(H_p(3))$ in $(mSv \cdot m^2)/(GBq \cdot h)$		
	Radiation	E_γ; $E_{\beta,max}$ keV	P			This work	From photon emission c)	Otto [19] c)
Tc-99m	γ	141	0.89	5 ml solution in 10 ml syringe	0.71 ± 0.04	0.021 ± 0.006	0.025 d)	0.026 u&s
I-131	β⁻ γ	606 365	0.90 0.82	Capsule in applicator	0.66 ± 0.03	0.071 ± 0.021	0.069 d)	0.068 u&s
F-18	β⁺ photons	634 511 a)	0.97 1.94 b)	5 ml solution in 10 ml syringe	0.60 ± 0.03	0.169 ± 0.049	0.169	0.005 u f) 0.169 s
Ga-68	β⁺ photons	1899 511 a)	0.89 1.78 b)	5 ml solution in 10 ml syringe	1.00 ± 0.05	0.499 ± 0.146	0.155	1.20 u 0.161 s
Y-90	β⁻	2280	0.99	Microspheres in 5 ml syringe	1.00 ± 0.05	2.566 ± 0.762	—	2.35 u 0.0 s

Monitoring of the lens of the eye: nuclear medicine

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[a]) Annihilation photons.
[b]) Two photons per annihilation.
[c]) See equation (3) for details.
[d]) For Tc-99m and I-131 all photon emissions above 10 keV are taken into account.
[e]) "u" denotes "unshielded", i.e. photons (without annihilation photons), β^-, and β^+ are taken into account;
"s" denotes "shielded", i.e. photons including annihilation photons are taken into account.
No uncertainties are given by Otto.
[f]) The value for the unshielded source is rather small as the contribution from the annihilation photons is missing.

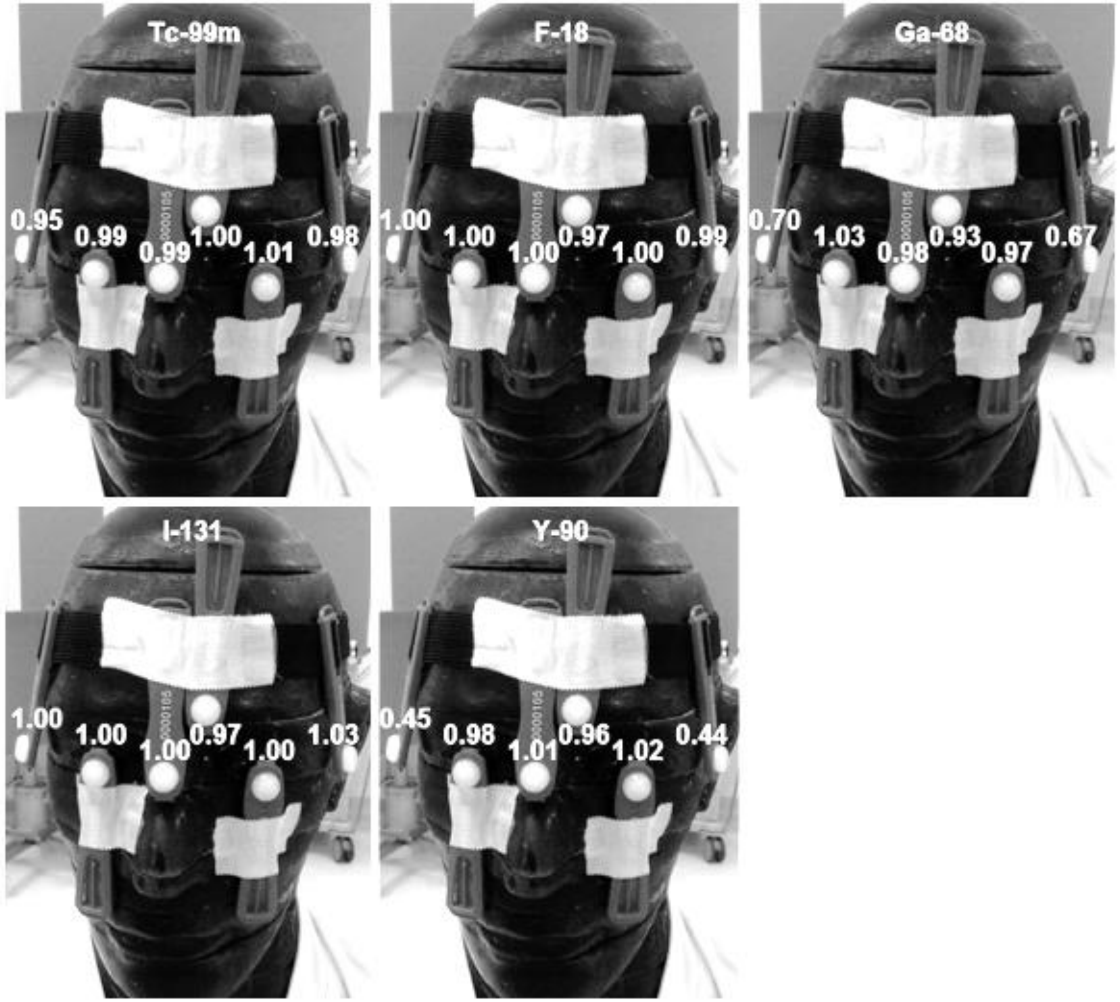


Figure 2. Dose rate constants divided by the average value of the dosemeters on the phantom's eyes.

Monitoring of the lens of the eye: nuclear medicine

Impact of radiation protection means on the dose to the lens of the eye while handling radionuclides in nuclear medicine

Z. Med. Phys. 26 (2016) 298

Iris Bruchmann[a,*], Bastian Szermerski[a], Rolf Behrens[b], Lilli Geworski[a]

[a] Department for Radiation Protection and Medical Physics, Medical School Hannover, Carl-Neuberg-Str. 1, 30625 Hannover
[b] Physikalisch-Technische Bundesanstalt (PTB), Bundesallee 100, 38116 Braunschweig

Figure 1. Set-up with four alderson head phantoms (above) and protection glasses (below); laboratory glasses (left) and X-ray goggles (right).

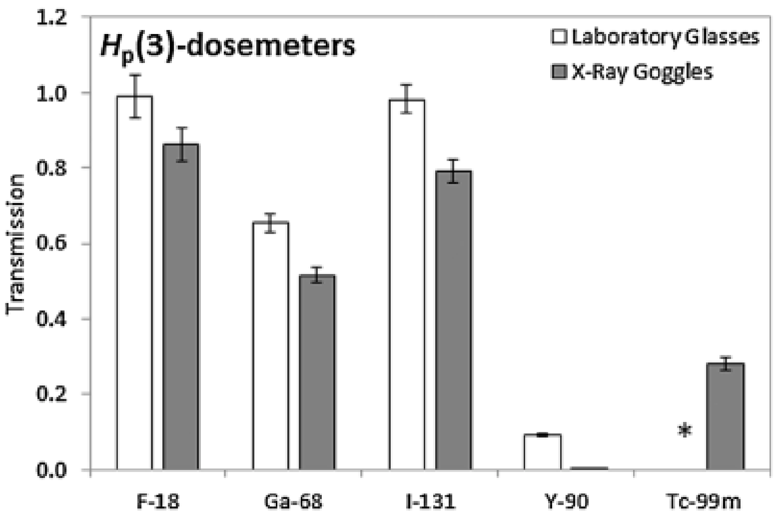


Figure 2. Nuclide-depending mean reciprocal attenuation factors determined for laboratory glasses and X-ray goggles with $H_p(3)$-dosemeters.
*not investigated

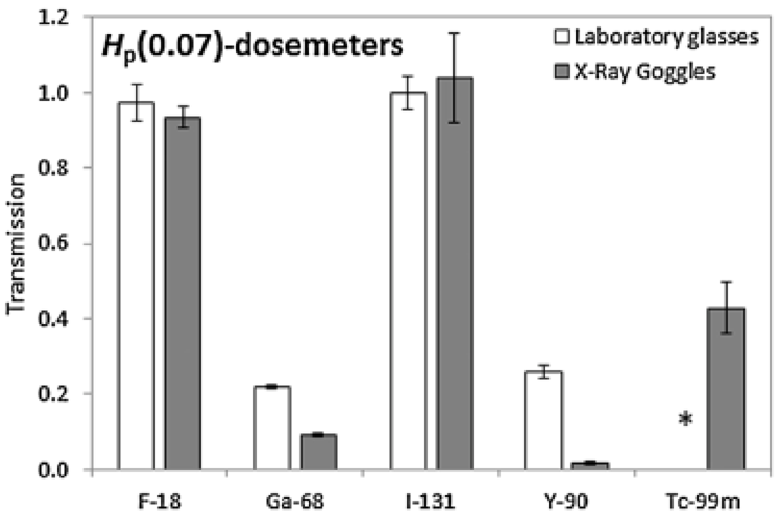


Figure 3. Nuclide-depending mean reciprocal attenuation factors determined for laboratory glasses and X-ray goggles with $H_p(0.07)$-dosemeters.
*not investigated

Contents

International documents with $H_p(3)$ and / or $H'(3)$

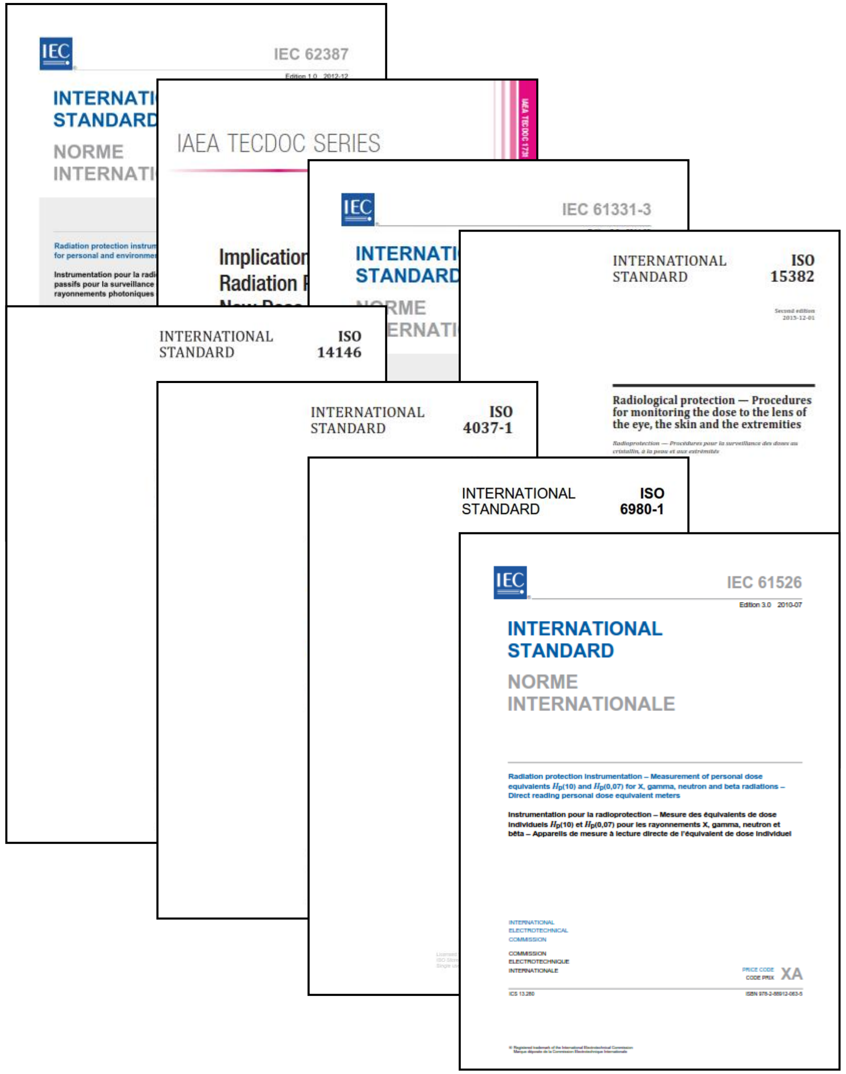
IEC 61331-3: Requirement to medical protective equipment (2014)

ISO 4037: Photon reference radiation fields (2019)
ISO 6980: Beta reference radiation fields (2004 – in revision)

IAEA TecDoc 1731: Dosimetry in practice (2013)
ISO 15382: Dosimetry in practice (2015)

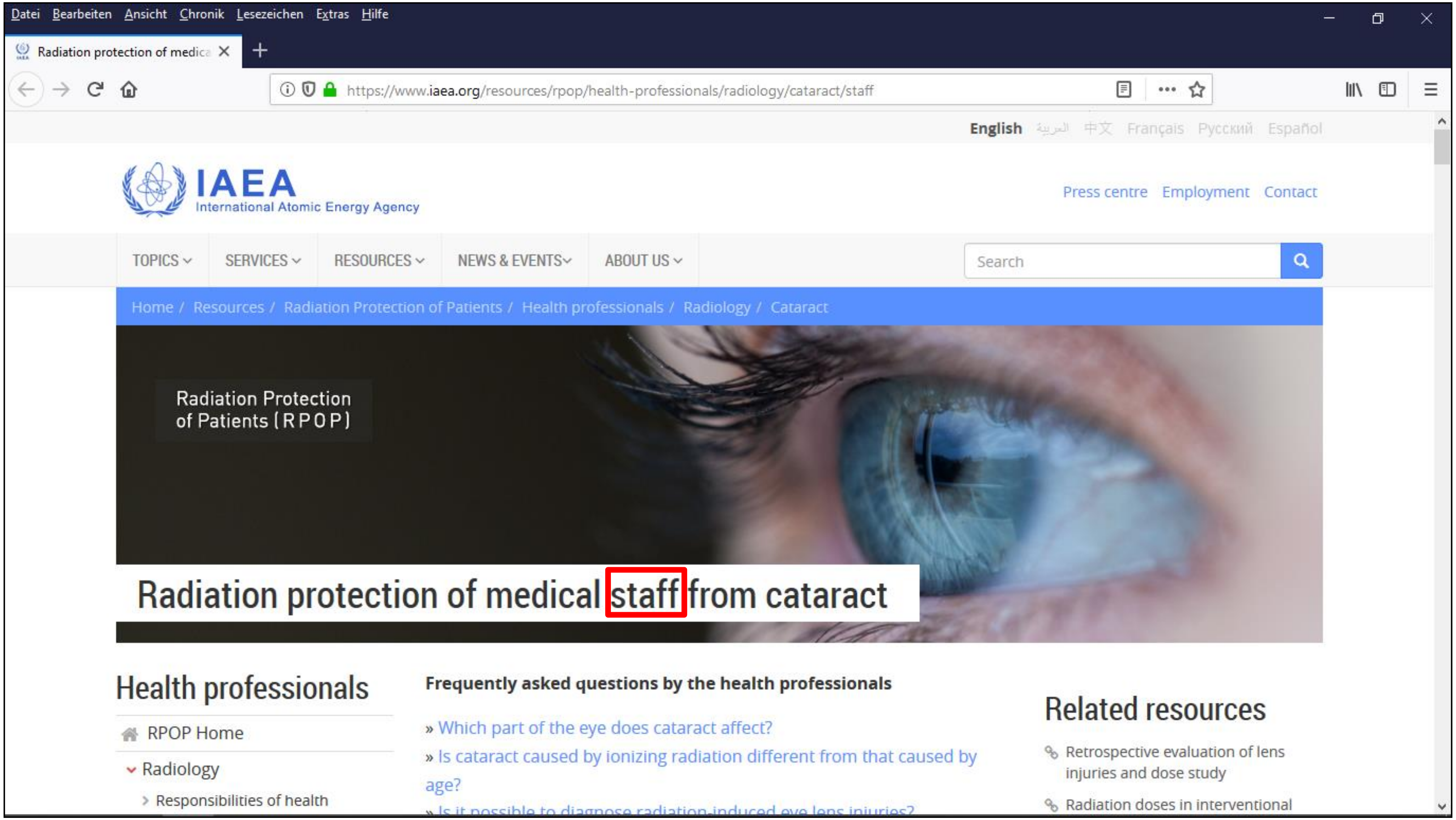
IEC 62387: Requirements to dosemeters (passive) (2020)
IEC 61526: Requirements to dosemeters (active) (2010 – in rev.)

ISO 14146: Routine test for dosemeters (2018)



IAEA activities

https://rpop.iaea.org/RPOP/RPoP/Content/InformationFor/HealthProfessionals/6_OtherClinicalSpecialities/radiation-cataract/Radiation-and_cataract.htm



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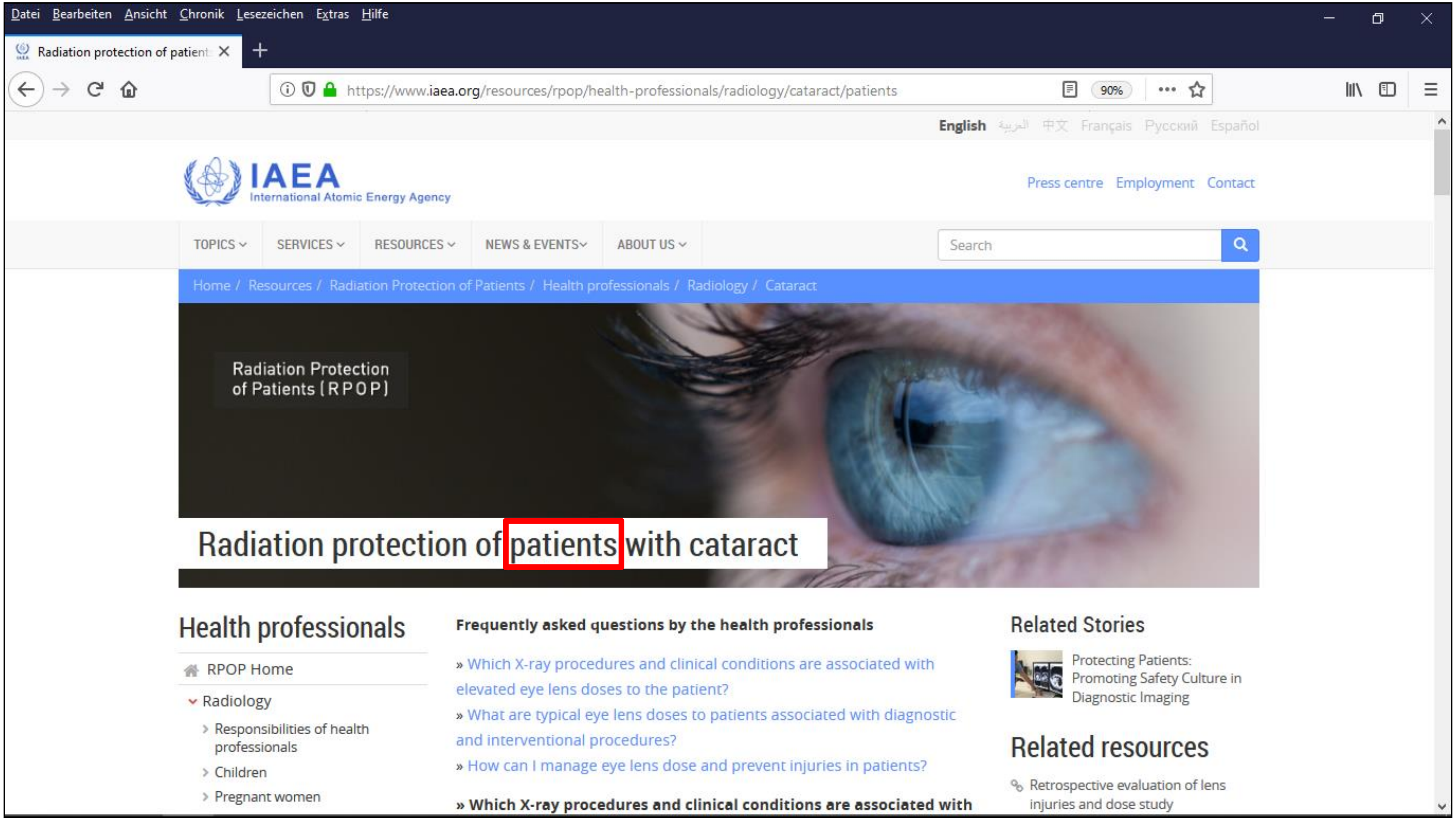

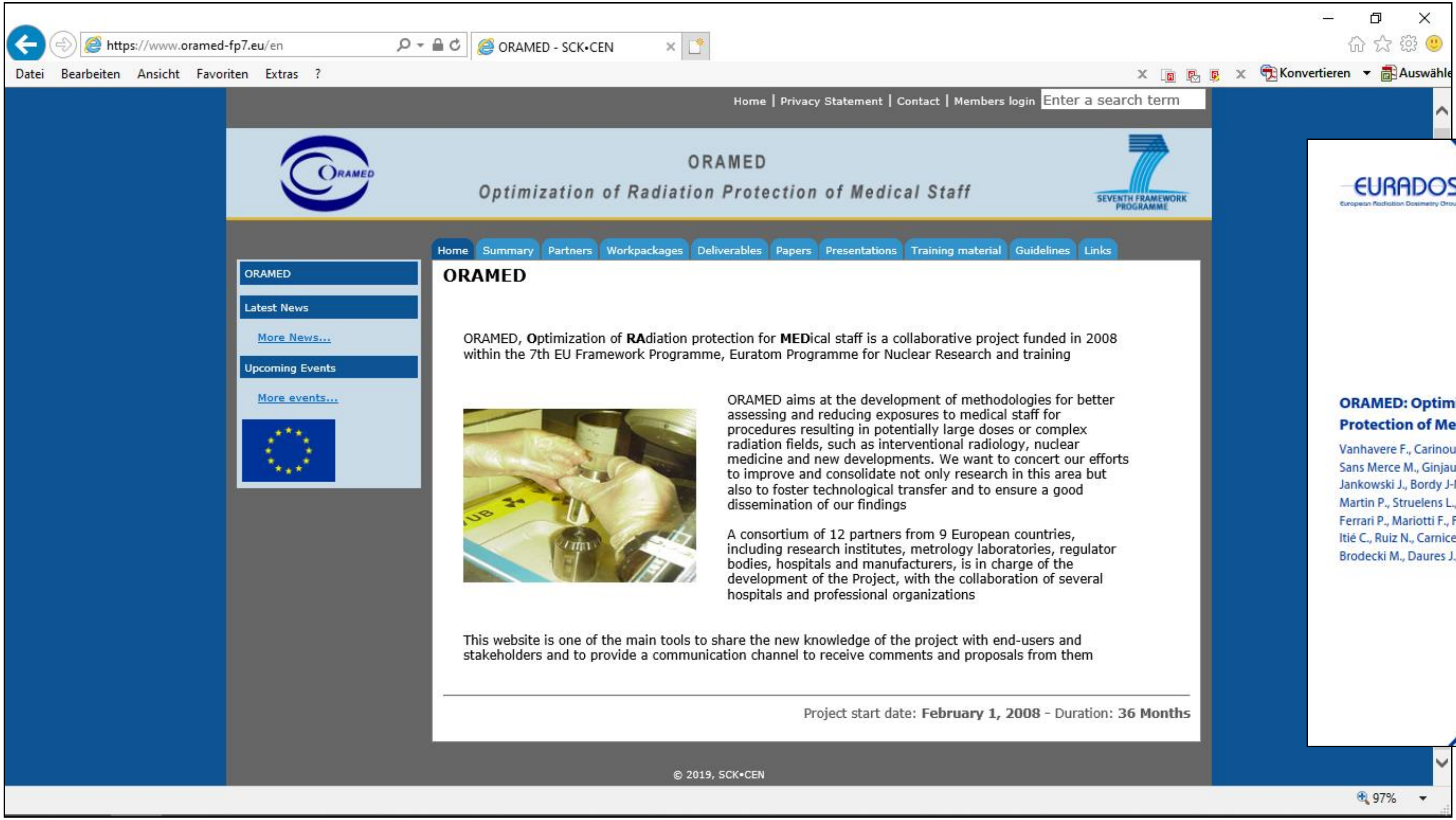
https://www.oramed-fp7.eu/en
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Optimization of Radiation Protection of Medical Staff
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Partners
Workpackages
Deliverables
Papers
Presentations
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Guidelines
Links
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Latest News
More News...
Upcoming Events
More events...
ORAMED
ORAMED, Optimization of RAdiation protection for MEDical staff is a collaborative project funded in 2008 within the 7th EU Framework Programme, Euratom Programme for Nuclear Research and training
ORAMED aims at the development of methodologies for better assessing and reducing exposures to medical staff for procedures resulting in potentially large doses or complex radiation fields, such as interventional radiology, nuclear medicine and new developments. We want to concert our efforts to improve and consolidate not only research in this area but also to foster technological transfer and to ensure a good dissemination of our findings
A consortium of 12 partners from 9 European countries, including research institutes, metrology laboratories, regulator bodies, hospitals and manufacturers, is in charge of the development of the Project, with the collaboration of several hospitals and professional organizations
This website is one of the main tools to share the new knowledge of the project with end-users and stakeholders and to provide a communication channel to receive comments and proposals from them
Project start date: February 1, 2008 - Duration: 36 Months
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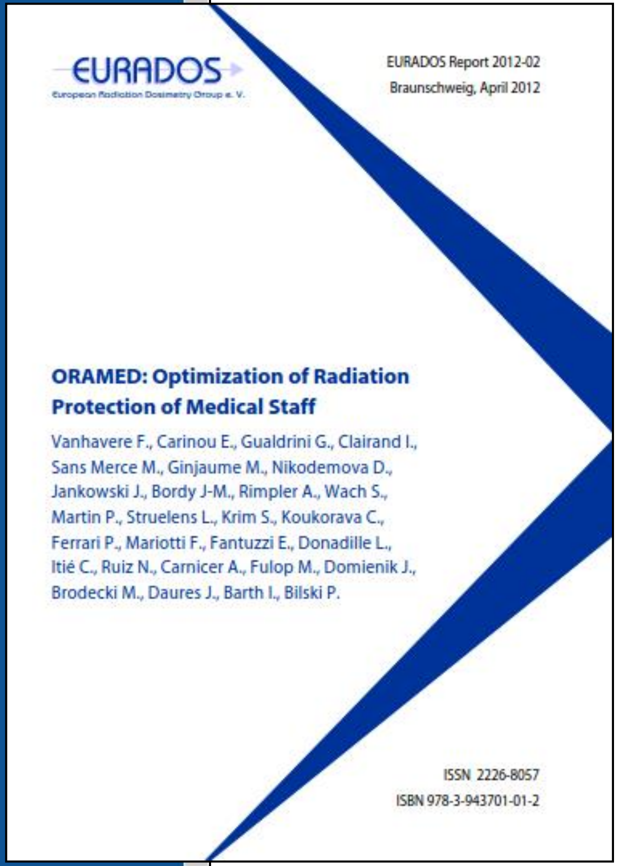
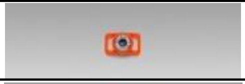
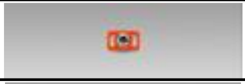
97%


EURADOS
European Radiation Dosimetry Group e. V.
EURADOS Report 2012-02
Braunschweig, April 2012
ORAMED: Optimization of Radiation Protection of Medical Staff
Vanhavere F., Carinou E., Gualdrini G., Clairand I., Sans Merce M., Ginjaume M., Nikodemova D., Jankowski J., Bordy J-M., Rimpler A., Wach S., Martin P., Struelens L., Krim S., Koukorava C., Ferrari P., Mariotti F., Fantuzzi E., Donadille L., Itié C., Ruiz N., Carnicer A., Fulop M., Domienik J., Brodecki M., Daures J., Barth I., Bilski P.
ISSN 2226-8057
ISBN 978-3-943701-01-2

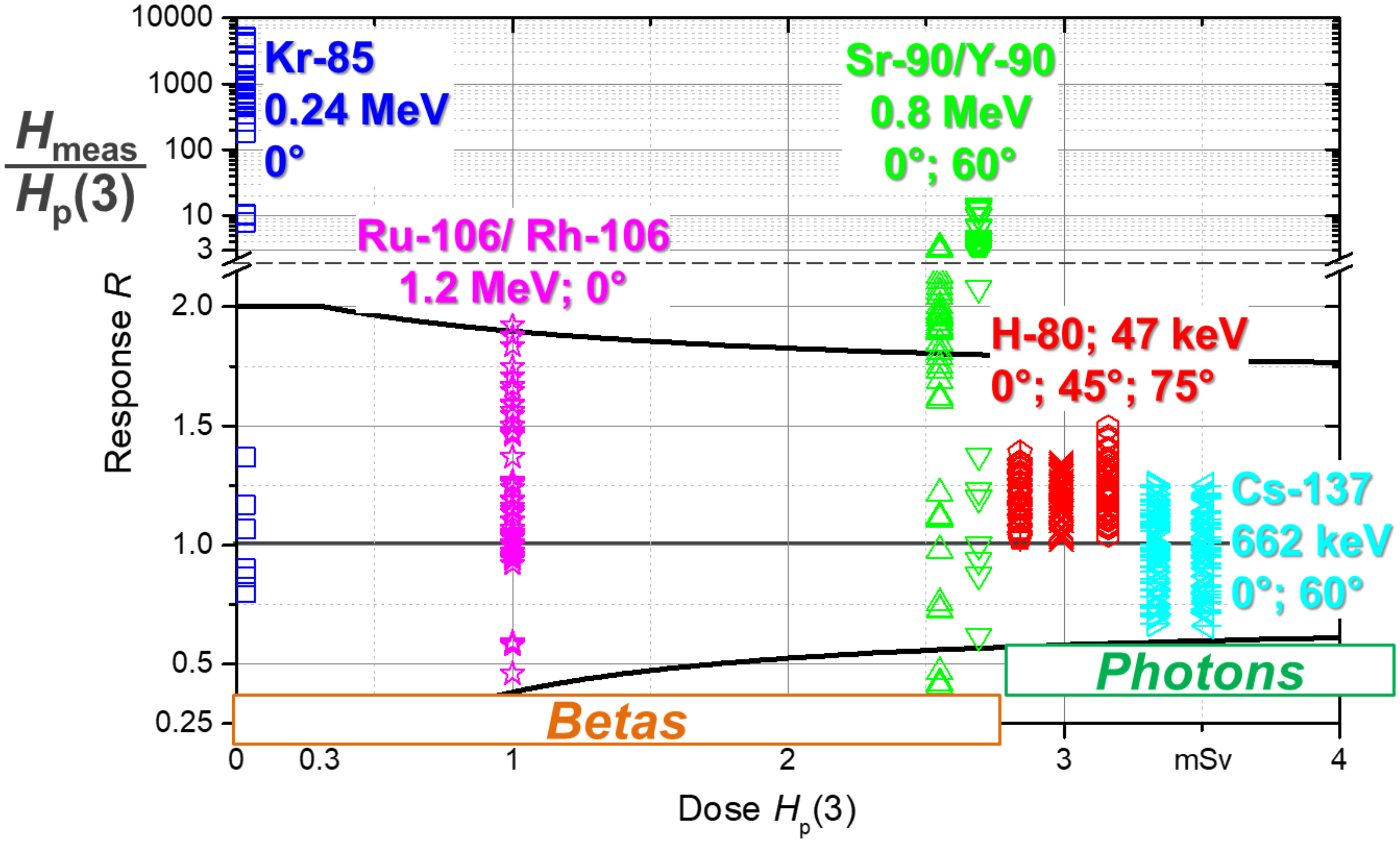
Dosemeter tests: Germany

Design quantity [a]	Institution	Type	Detector type and material	Photograph
$H_p(3)$	HMGU	Eye-D™	TLD-100: $^{nat.}$LiF:Mg,Ti	
	HMGU	Eye-D™ [c]	MCP-N: ^{7}LiF:Mg,Cu,P (ORAMED detector)	
	KIT	Augenlinsen-dosimeter	TLD-700 ^{7}LiF: Mg,Ti	
$H_p(0.07)$	HMGU	AWST-TL-TD 60 (Typ W)	TLD-100: $^{nat.}$LiF:Mg,Ti	
	HMGU	AWST-TL-TD 70 (Typ X)	MCP-Ns: $^{nat.}$LiF:Mg,Cu,P	
	HMGU	dosiEYE [b]	TLD-100: $^{nat.}$LiF:Mg,Ti	

Design quantity [a]	Institution	Type	Detector type and material	Photograph
$H_p(0.07)$	LPS	LPS-TLD-TD 03	TLD-700: ^{7}LiF:Mg,Ti	
	LPS	LPS-TLD-TD 07 [d]	TLD-100: $^{nat.}$LiF:Mg,Ti	
	MPA	MPA-TKD-01 [d]	TLD-100: $^{nat.}$LiF:Mg, Ti	
	PDMB	BE-TLD-TD-Brille [d]	TLD-100: $^{nat.}$LiF:Mg,Ti	
	PDMB	BE-TLD-TD-Brille	MCP-7s: ^{7}LiF:Mg,Cu,P	
	PDMB	BE-TLD-TD-Photonen 01	MCP-7s: ^{7}LiF:Mg,Cu,P	
	PDMB	BE-TLD-TD-Beta-Photonen [d]	MCP-7s: ^{7}LiF:Mg,Cu,P	

R. Behrens et al.: *Intercomparison of eye lens dosemeters.*
Radiat. Prot. Dosim., Vol. 174, 6 (2017)
https://doi.org/10.1093/rpd/ncw051

Dosemeter tests: Germany



Betas often overestimate
(up to a factor of 5000!)

Photons well detected

R. Behrens et al.: *Intercomparison of eye lens dosemeters.*
Radiat. Prot. Dosim., Vol. 174, 6 (2017)
https://doi.org/10.1093/rpd/ncw051

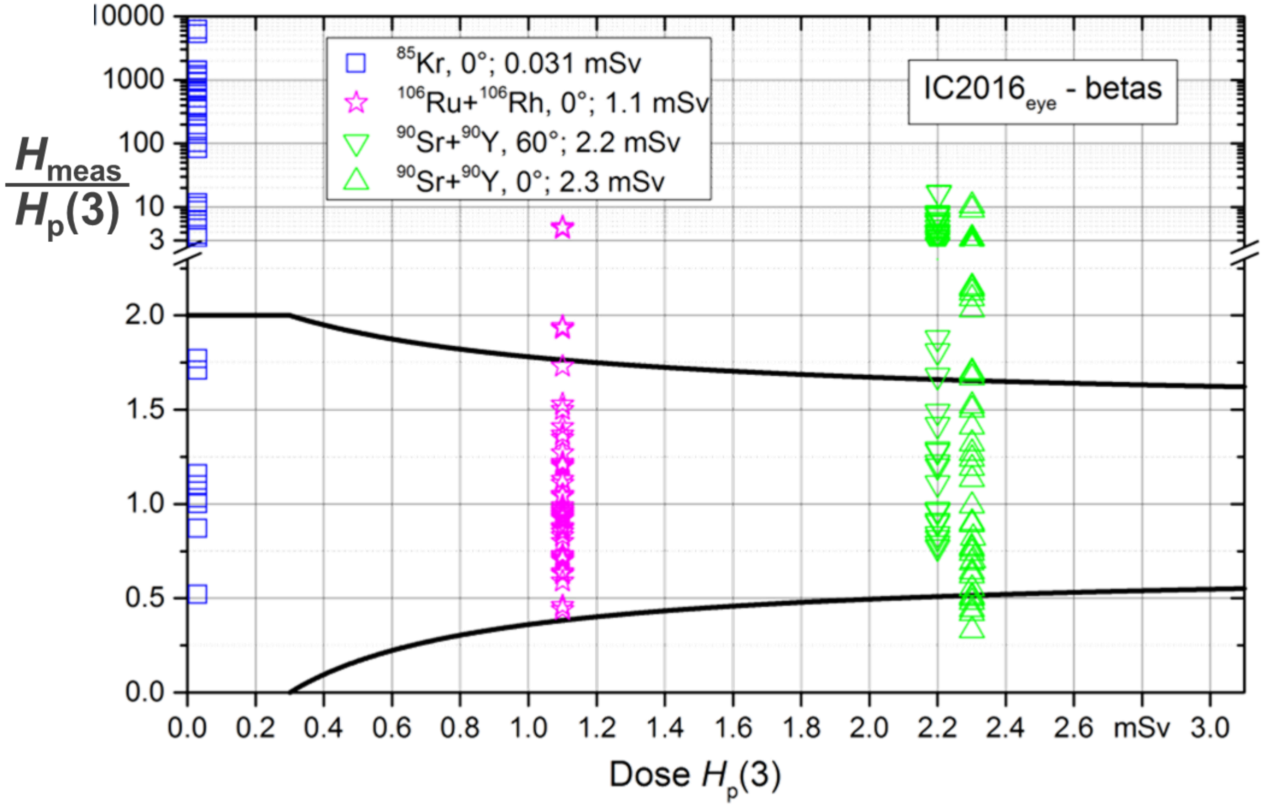
Dosemeter tests: international (EURADOS)

Participant from **12 nations** from
22 IMS (individual monitoring services).
Bulgaria, Czech Republic, France,
Germany, Israel, Italy, Slovakia, Spain,
Switzerland, Turkey, United Kingdom, USA

6 Eye-D^{TM} systems (ORAMED European project)
3 Dosemeters **with special badge** to wear near the eye
11 Dosemeters **in** a **plastic bag**
2 Whole body dosemeters

I. Clairand et al.: *EURADOS 2016 intercomparison exercise of eye lens dosemeters.* Radiat. Prot. Dosim., Vol. 182, 317 (2018) *https://doi.org/10.1093/rpd/ncy067*

Dosemeter tests: international (EURADOS)



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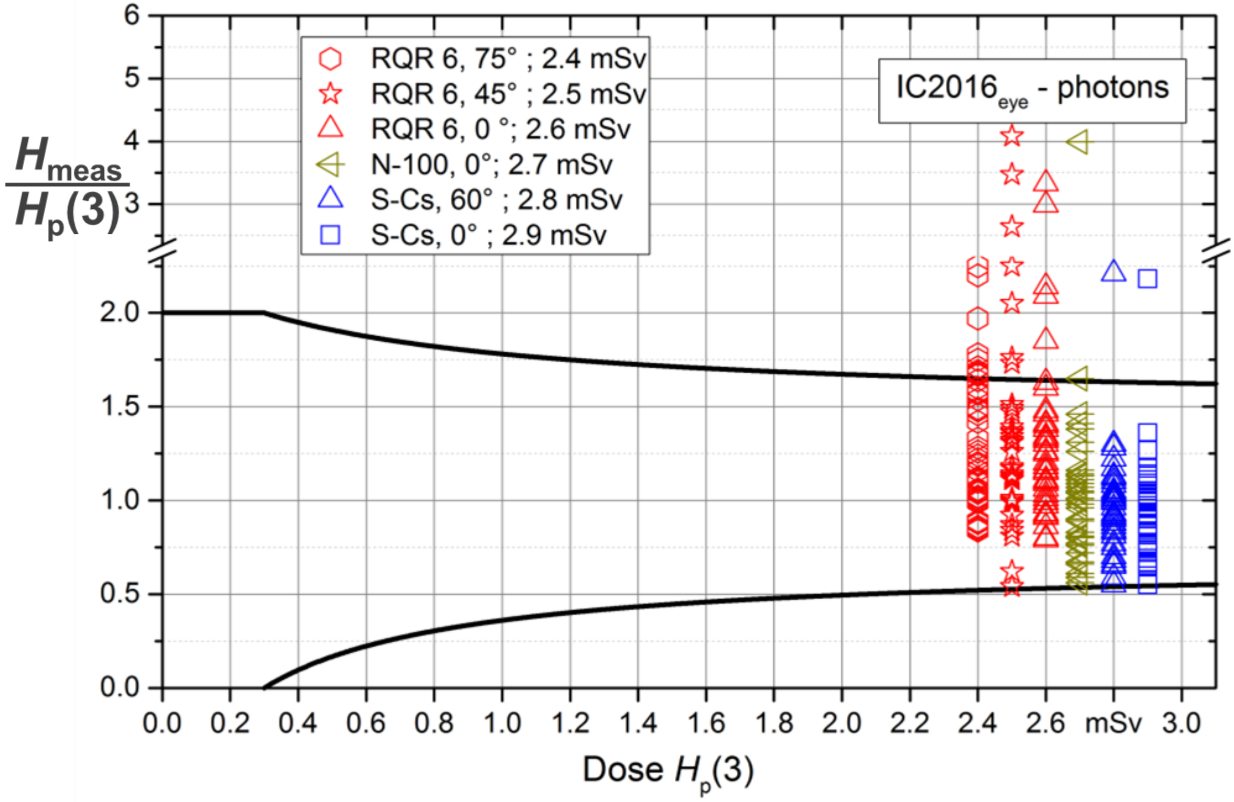

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I. Clairand et al.: *EURADOS 2016 intercomparison exercise of eye lens dosemeters.* Radiat. Prot. Dosim., Vol. 182, 317 (2018) *https://doi.org/10.1093/rpd/ncy067*

Contents

Conclusions / Challenges

Protection and operational quantities

- Equivalent dose to the lens of the eye, H_{lens}
- Personal dose equivalent to the lens of the eye, $H_p(3)$
- Directional dose equivalent to the lens of the eye at 3 mm depth, $H'(3)$

Calibration, characterization and measurement

Personal monitoring :

- Calibration: on cylinder or slab phantom, only at $\alpha = 0°$
- Characterization at $\alpha \neq 0°$: only on cylinder phantom
- Measurements: close to the eye

Area monitoring:

- Calibration, characterization and measurement „free in air“
- $H'(3)$ dosemeters not yet available

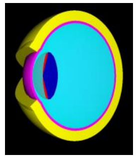
Dosemeter comparison in $H_p(3)$

- Betas often overestimated (up to a factor of 5000!), especially with $H_p(0.07)$ dosemeters
- Photons well detected, also with $H_p(0.07)$ dosemeters

Monitoring

- Obligation to measure on the person if H_{lens} > 15 mSv/year possible
- Use of $H_p(3)$ and $H'(3)$ as of 2022 (in Germany – different in other countries)
  until then in photon fielders also $H_p(0.07)$ and $H'(0.07)$ possible

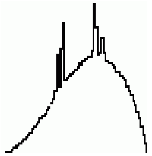
Literature (with links to each work)



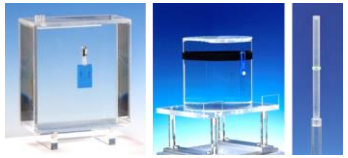
- Conversion coefficients for mono-energetic electrons: $\Phi \rightarrow H_{lens}$:
  Phys. Med. Biol. 54 (2009) 4069 & Phys. Med. Biol. 55 (2010) 3937 & Rad. Prot. Dosim. 155 (2013) 224
- Conversion coefficients for mono-energetic photons: $\Phi \rightarrow H_{lens}$: Phys. Med. Biol. 56 (2011) 415
- Compilation of conversion coefficients $\Phi \rightarrow H_{lens}$: Rad. Prot. Dosim. 174 (2017) 348

? $H_p(0.07)$, $H_p(3)$, $H_p(10)$?
$H'(0.07)$, $H'(3)$, $H^*(10)$

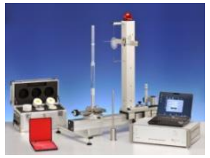
- Monitoring the eye lens: Which dose quantity is adequate?
  Phys. Med. Biol. 55 (2010) 4047 & Phys. Med. Biol. 56 (2011) 511
  J. Radiol. Prot. 32 (2012) 455 & IRPA13 contribution TS7e.3



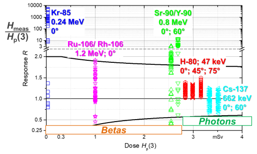
- Conversion coefficients for photon spectra: $K_a \rightarrow H_p(3)_{slab}$: Rad. Prot. Dosim. 147 (2011) 373
- Conversion coefficients for photon spectra: $K_a \rightarrow H_p(3)_{cyl}$: Rad. Prot. Dosim. 151 (2012) 450
- Conversion coefficients for photon spectra: $K_a \rightarrow H'(3)$: J. Radiol. Prot. 37 (2017) 354



- $H_p(0.07)$ photon dosemeters: Calibration on both rod and slab phantom: Rad. Prot. Dosim. 148 (2012) 139
- Type tests only on cylinder phantom: Rad. Prot. Dosim. 168 (2016) 441



- Beta irradiations in $H_p(3)$ and $H'(3)$: Extensions to the Beta Secondary Standard BSS 2:
  J. Instrum. 6 (2011) P11007 & Erratum & Addendum



- Dosemeter tests: Photon fields: $H_p(0.07)$ and $H_p(3)$ dosemeters perform well
  Beta fields: $H_p(0.07)$ dosemeters overestimate H_{lens} up to a factor of 5000!
  Rad. Prot. Dosim. 174 (2017) 6
  Rad. Prot. Dosim. 182 (2018) 317

- Nuclear medicine:
  Dose rate constants of beta-photon nuclides: Z. Med. Phys. 26 (2016) 304
  Absorption of googles for beta-photon nuclides: Z. Med. Phys. 26 (2016) 298

Dosimetry of the lens of the eye

Dosimetric units and quantities for eye lens monitoring, standards, type testing, calibration procedures and phantoms

R. Behrens

13th EURADOS Winter School "Eye lens dosimetry" 30th January 2020

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As of 01/2020