FROM RESEARCH TO INDUSTRY

cea tech

LNE
Laboratoire national de métrologie et d'essais (LNE)

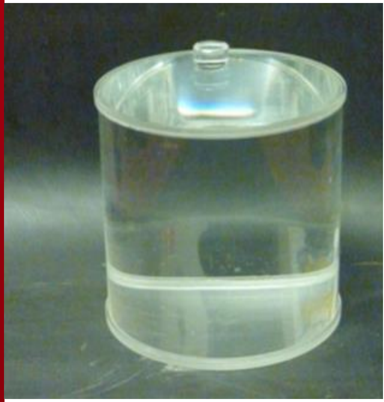
Laboratoire National
LNHB
Henri Becquerel

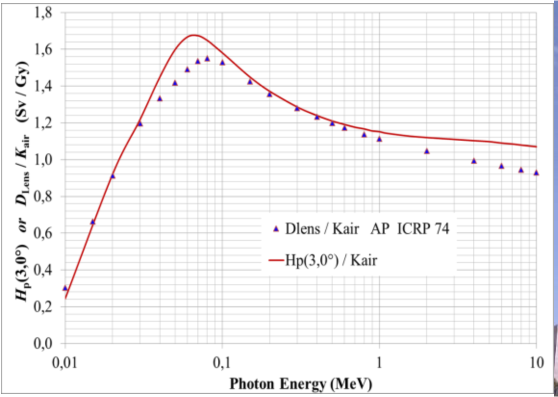
list

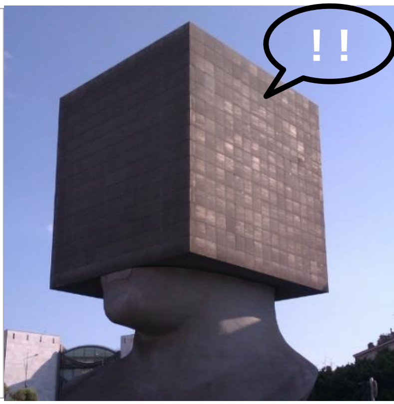
NEW DATA REGARDING THE LENS OF THE EYE

(FOR RADIATION PROTECTION PURPOSES)

EU Scientific Seminar, Emerging issues with regard to organ doses
Luxembourg, 17th May 2017, Bordy Jean-Marc







INTRODUCTION

LNE

French National Metrological Institute

LNE / CEA / LNHB

French National metrological laboratory for Ionizing radiations

It develops and transfers to the end users references in terms of air kerma, absorbed doses and dose equivalents for radiotherapy, radio diagnosis and radiation protection (public, patients, workers).

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INTRODUCTION

The lens of the eye is a special case:

- First, it is included in the ICRP’s list of organs to calculate the effective dose - E
- Second, one can do routine individual monitoring of eye lens equivalent dose - H_{lens} - thoughout the operational quantity (dose equivalent $H_{\text{p}}(3)$)

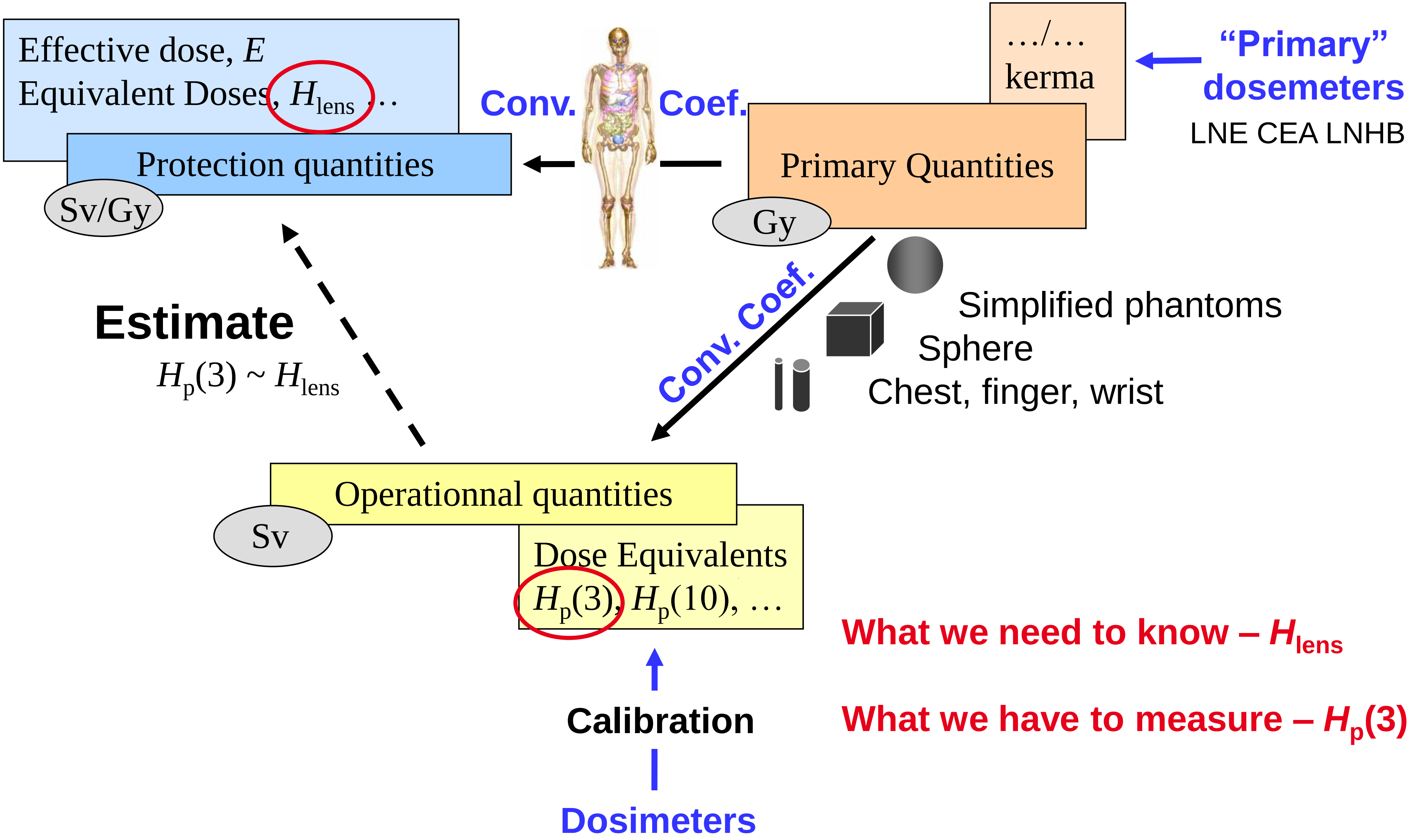
Today, we will speak about RADIATION PROTECTION for eye lens dosimetry

Part of this work was already presented or published in:

- Radioprotection 50(3), 177-185 (2015) | Monitoring of eye lens doses in radiation protection / Bordy JM DOI:10.1051/radiopro/2015009
- Technical information sheets of the Société Française de RadioProtection SFRP: Eye lens – Regulatory limits, Measurement, Dosimetry and Medical surveillance. http://www.sfrp.asso.fr/medias/sfrp/documents/Divers/Fiche_SFRP_-_Eye_Lens_-_GB___06-2016_V2.pdf
- Individual monitoring IM2015 / Bruges – Belgium and EPRI 2016 / Charlotte - North Carolina - USA | Proposal for a criterion to choose between a direct or indirect evaluation of eye lens doses / Bordy JM

Other references on the definition of the dose equivalent quantity are given on slide 8 of this presentation

GENERAL SCHEME FOR RAD. PROT. QUANTITIES



Effective dose, *E*

Equivalent Doses, H_{lens} …

Protection quantities

Sv/Gy

Conv. Coef.

…/…

kerma

Primary Quantities

Gy

"Primary" dosemeters

LNE CEA LNHB

Conv. Coef.

Simplified phantoms

Sphere

Chest, finger, wrist

Estimate

$H_p(3) \sim H_{\mathrm{lens}}$

Operationnal quantities

Sv

Dose Equivalents

$H_p(3)$, $H_p(10)$, …

Calibration

Dosimeters

What we need to know – H_{lens}

What we have to measure – $H_p(3)$

TO BE ABLE TO MONITOR IR EXPOSURES

Operationnal Quantities (OQ) **$H_p(d)$ - $H'(d)$ or $H^*(10)$**

(tissu equivalent phantoms)

Dosimeter satisfying type test requirements

Calibration in terms of OQ (**on phantom** / **free in air**)

indiv. **Area**

Dosimeter used/worn as specified

In international recommandations

Measure/evaluation of operationnal quantities at workplaces

Estimate of H_{skin}, H_{lens}, E

Check the exposure limits

APPLICATION TO EYE LENS DOSIMETRY

~~Operationnal Quantities (OQ) $H_p(3)$~~ - **$H'(3)$**

(tissu equivalent phantoms)

~~Dosimeter~~ satisfying type test requirements

ISO 12794

~~Calibration in terms of OQ~~ (**on phantom** / **free in air**)

indiv. **Area**

Dosimeter used/worn as specified

In international recommandations

Measure/evaluation of ~~operationnal quantities~~ at workplace

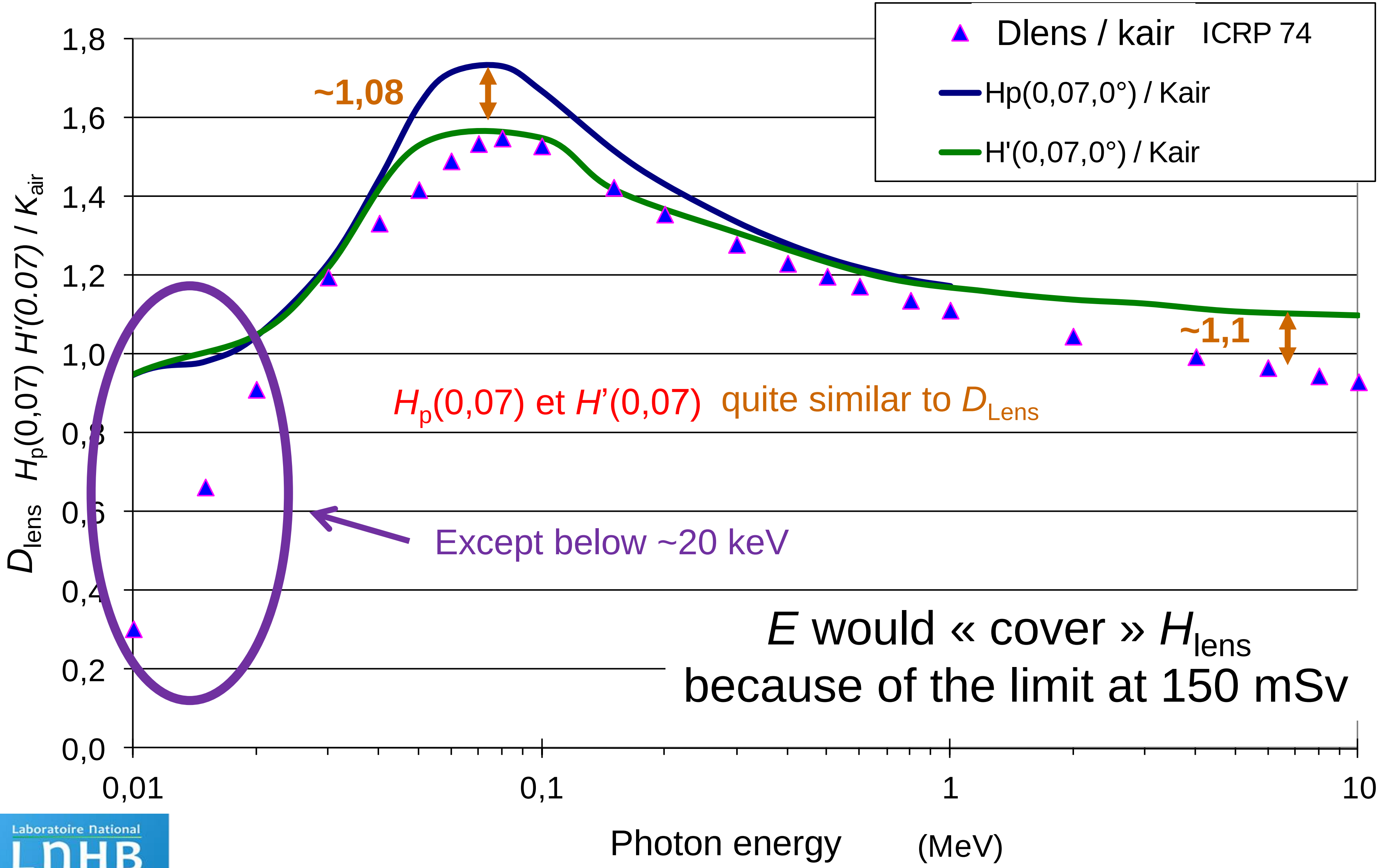
Estimate of H_{lens}

Check the exposure limits

150 mSv /year

COMPARAISON WITH D_{LENS}

NORMAL INCIDENCE



~1,08

~1,1

$H_p(0,07)$ et $H'(0,07)$ quite similar to D_{Lens}

Except below ~20 keV

E would « cover » H_{lens} because of the limit at 150 mSv

APPLICATION TO EYE LENS DOSIMETRY

~~Operationnal Quantities (OO~~ $H_p(3)$ - $H'(3)$

ssu equivalent phantoms)

~~Dosimeter~~ satisfyin uirements

ISO 12794

~~Calibration in t~~ **n / free in air)**

indiv. **Area**

Dosim orn as specified
In intern nal recommandations

Not Applicable

~~Measure/evaluation of operationnal quantities~~ at workplace

Estimate of H_{lens}

H_{skin} ; E Conservatives

Check the exposure limits

150 mSv /year

APPLICATION TO EYE LENS DOSIMETRY

~~Operationnal Quantities (OQ) $H_p(3)$ - $H'(3)$~~

(tissu equivale s)

~~Dosimeter~~ satisfying type test requir

/94

~~Calibration in terms of OQ (o~~ in air)

Area

Dosimete specified

In i mandations

Mea ~~operationnal quantities~~ at workplace

Estimate of H_{lens}

H_{skin} ; E atives

???

Check the exposure limits

1 20 mSv /year

Decision ICRP (4825-3093-1464) **2011**

150 mSv → 20 mSv

WE NEED $H_p(3)$

CEA LNE LNHB – ENEA works on the definition of $H_p(3)$ – ORAMED project

- Definition of the quantity $H_p(3)$ clarified through the use of cylinder (H=D=20cm) made of ICRU tissue as the phantom

- Use of a water cylindrical phantom with PMMA walls (H=D=20cm) for calibration purposes (ISO 29661 & future revised version of ISO DIS 4037)

Principle for the design of radiation protection dosemeters for operational and protection quantities, J.M. Bordy, G. Gualdrini, J. Daures and F. Mariotti, *Radiation protection dosimetry, (2011) 144(1-4): 257-261*

Monte carlo determination of the conversion coefficients $H_p(3)/K_a$ in a right cylinder phantom with penelope code. comparison with "mcnp" simulations“ J. Daures, J. Gouriou, J.M. Bordy,

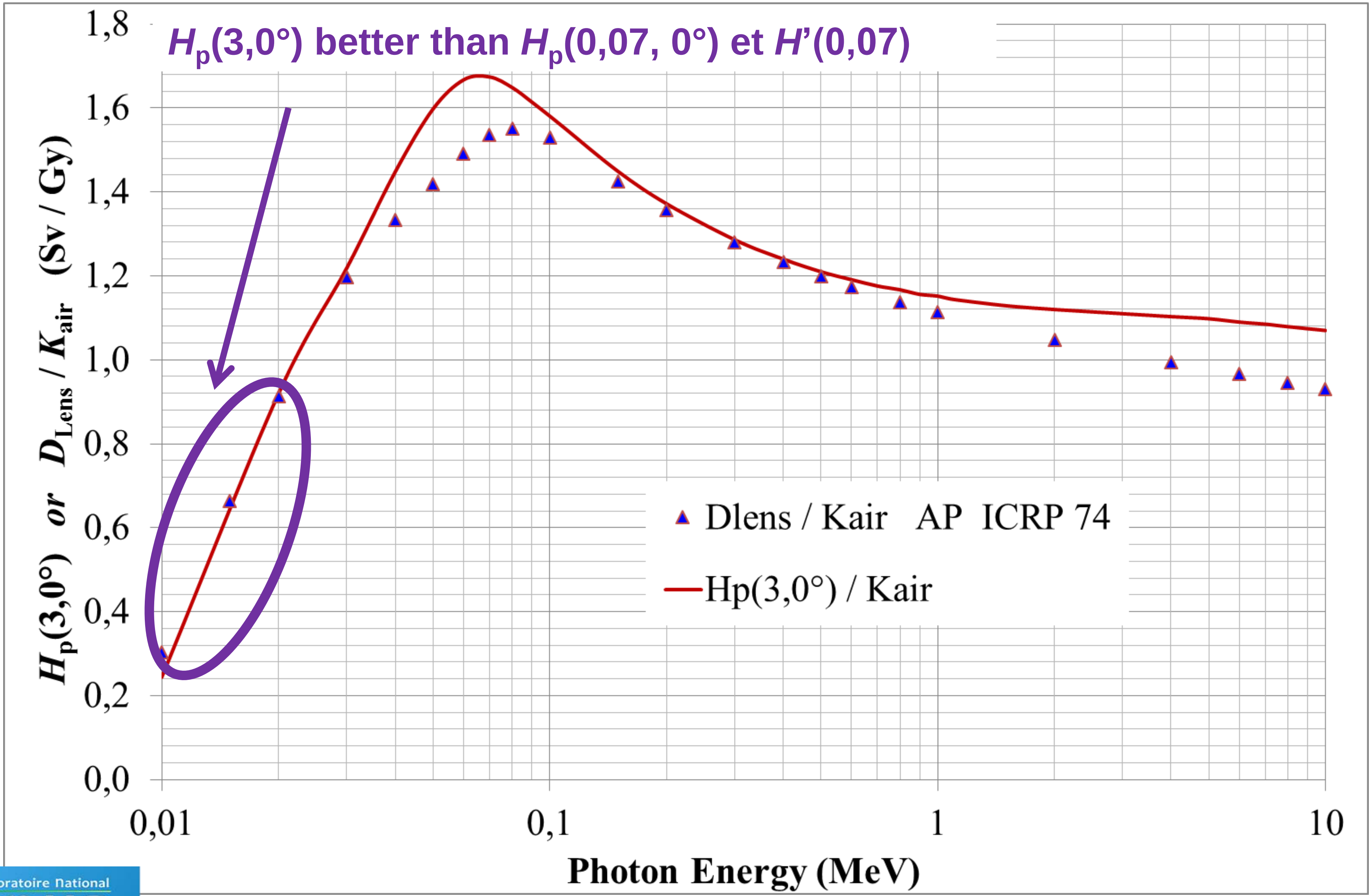
Radiation Protection Dosimetry (2011) 144(1-4): 37-42 ; more details in Conversion coefficients from air kerma to personal dose equivalent, Hp(3) for eye-lens dosimetry, Daures, J., Gouriou, J. and Bordy, J.-M., ISSN/0429-3460, CEA-R-6235. CEA (2009)

Eye lens dosimetry: task 2 within the ORAMED project G. Gualdrini, F. Mariotti, S. Wach, P. Bilski, M. Denoziere, J. Daures, J.M. Bordy, P. Ferrari, F. Monteventi, and E. Fantuzzi; *Radiation Protection Dosimetry (2011) 144(1-4): 473-477*

ORAMED project. Eyelens dosimetry. A new Monte Carlo approach to define the operational quantity Hp(3)., Marriotti, F. and Gualdrini, G., ISSN/0393-3016, RT/2009/1/BAS. ENEA (2009)

Dose conversion coefficients for photon exposure of the human eye lens, Behrens, R. and Dietze, G., 2011 *Phys. Med. Biol.* 56 415–437. …/…

COMPARAISON WITH D_{LENS}
NORMAL INCIDENCE



WE NEED DOSIMETERS FOR A DIRECT MEASUREMENT OF $H_P(3)$

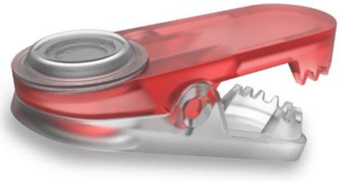
A few individual dosemeters are commercially available (list not exhaustive)

the principle is to allow a morphological adaptation as ergonomic as possible

UK rotundascitech company*

http: // www.rotundascitech.com/EyeDosimetry.html

* Health Protection Agency (HPA) proposed a similar design



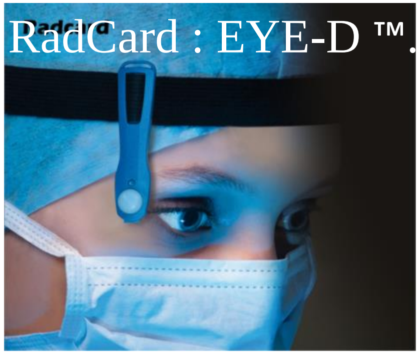
dosilab – dosiEYE

http://www.dosilab.fr/

DOSIRIS

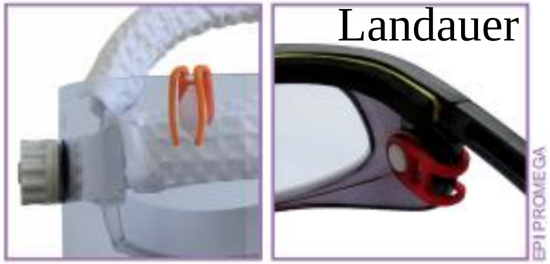
IRSN

http://dosimetre.irsn.fr/fr-fr/Documents/Fiches%20produits/IRSN_Fiche_dosimetre_Cristallin.pdf



RadCard : EYE-D ™.

www.radpro-int.com / assets / eye-d.pdf



Landauer

http://www.landauer-fr.com/lentreprise/actualites.html

PRESENT SITUATION OF EYE LENS DOSIMETRY

Operationnal Quantities (OQ) **H_p(3) cylinder 20cm « head »**

(tissu equivalent pl

Dosimeter satisfying type test requirements **(I 7)**

Calibration in terms of OQ (**c phantom**)

indiv.

Dosimeter u n as specified
In internatio mandations **(ISO 15382)**

Measu ation of operationnal quantities in laboratories

Estimate of H_{lens}

Verification of the exposure limits

20 mSv /year

50 mSv/year

One can monitor H_p(3) in routine

PRESENT SITUATION OF EYE LENS DOSIMETRY

Even if it is agreed that lens “doses” must be measured/monitored, the modalities of its implementation is the cause for debate.

Of course, estimate H_{lens} means a direct measurement of $H_p(3)$ with a dosimeter specifically designed to measure $H_p(3)$, worn at the level of the eye, behind individual protections if any (glasses, faceguards)

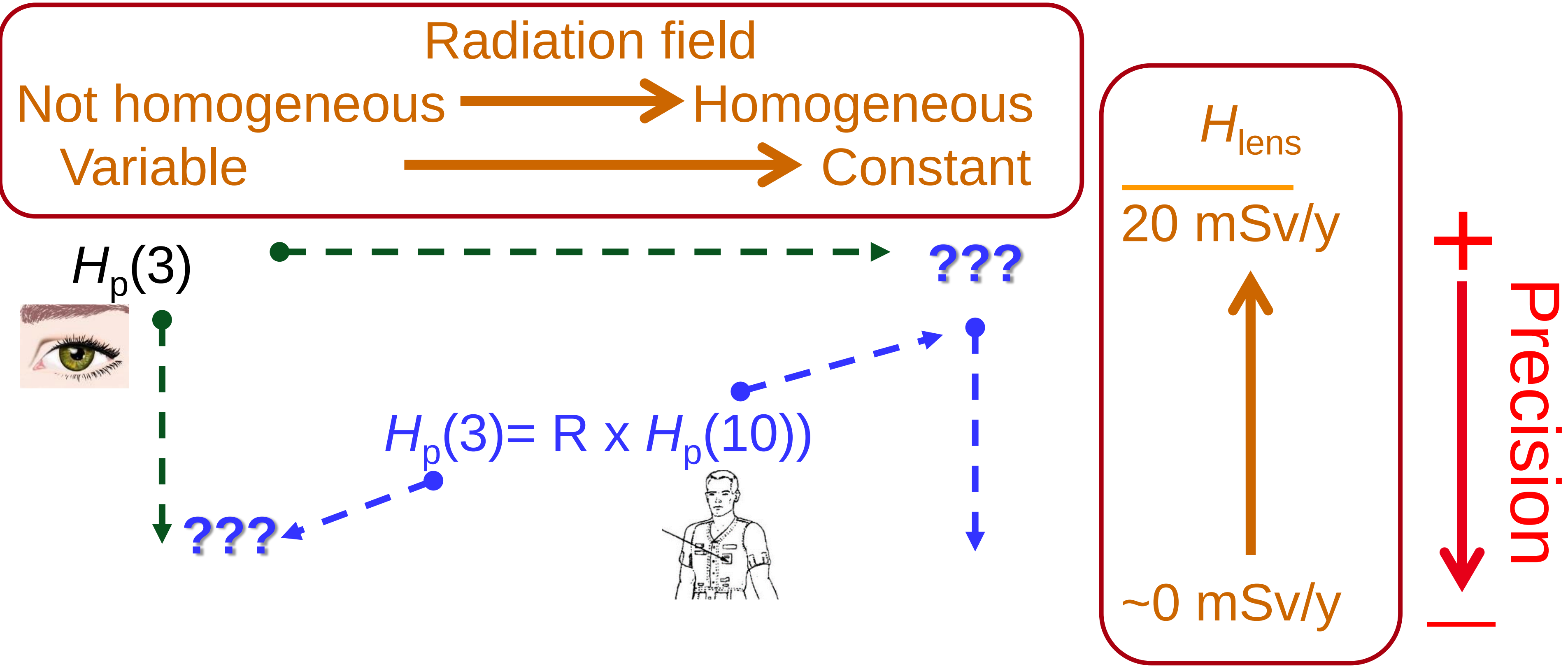
A compromise solution between the constraint **to wear an additional dosimeter close to the eye**, and the need to monitor accurately the lens exposure, could lead an indirect measurement. That is to say:

- To estimate $H_p(3)$ through $H_P(10)$ – whole body dosimetry (chest)

$$R = H_p(3) / H_p(10)$$

In such a case, an objective index is needed to justify
if it might be possible to evaluate $H_p(3)$ from another quantity.

DIRECT OR INDIRECT THAT IS THE QUESTION



Radiation field

Not homogeneous → Homogeneous

Variable → Constant

$H_p(3)$

???

$H_p(3) = R \times H_p(10))$

???

$\frac{H_{lens}}{20 \text{ mSv/y}}$

~0 mSv/y

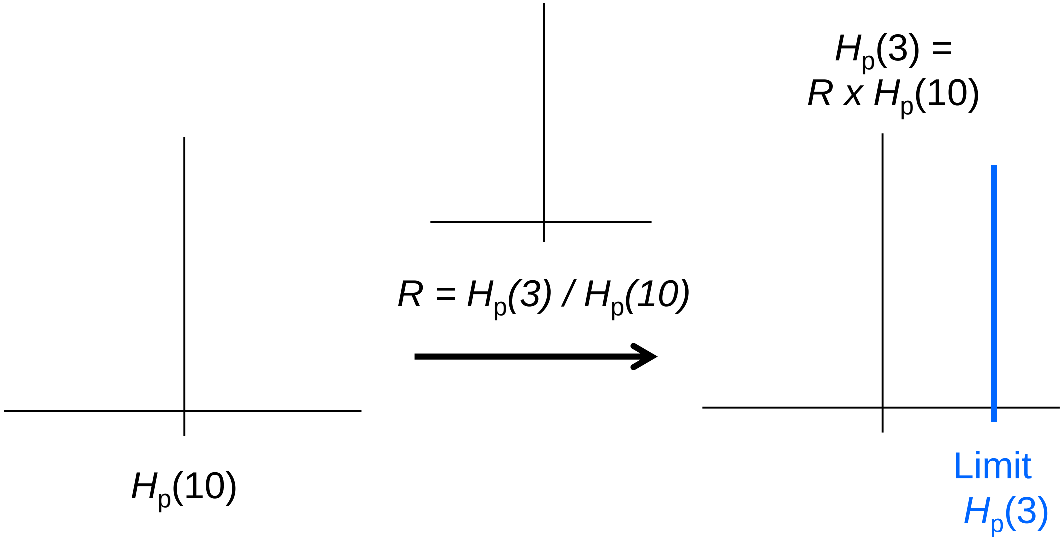
+ Precision −

One has to keep in mind that the calculation infers a loss in terms of accuracy
So that one has to know to which extend the indirect method can be used.

When $H_p(3) = R \times H_p(10)$ can be used « without » a risk to exceed $H_p(3)$ limits?

INDIRECT EVALUATION OF H_p(3)

Simple direct proportionality

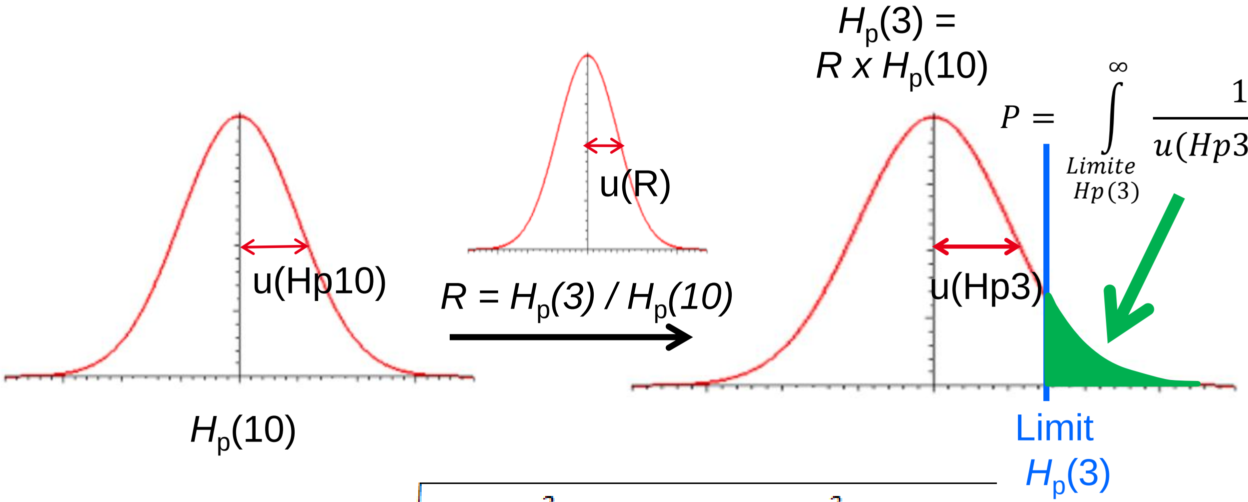


Perfect World

☺

One has to keep in mind that the calculation infers a loss in terms of accuracy

With uncertainty



$$P = \int_{\substack{Limite\\ Hp(3)}}^{\infty} \frac{1}{u(Hp3)\sqrt{2\pi}} e^{-\frac{1}{2}\left(\frac{H_p(3)-H_p(3)_m}{u(Hp3)}\right)^2}$$

Real life

😐

$$u(Hp3) = \sqrt{\left(\frac{\partial \mathrm{Hp3}}{\partial \mathrm{R}}\right)^2 \mathrm{u}^2(\mathrm{R}) + \left(\frac{\partial \mathrm{Hp3}}{\partial \mathrm{Hp10}}\right)^2 \mathrm{u}^2(\mathrm{Hp10})}$$

CRITERION TO APPLY AN INDIRECT METHOD

Perfect World !

$$R = H_p(3) / H_p(10) \longrightarrow H_p(10) = H_p(3) / R$$

Taking into account the limit of exposure for $H_p(3)$ (20 mSv on average over 5 years or 50 mSv over one year), one can substitute $H_p(3)$ for these exposure limits to define a maximum value of $H_p(10)$ such as:

$$H_p(10)_{max20} = 20 \ / R \quad \text{or} \quad H_p(10)_{max50} = 50 \ / R$$

For example, if the R = 5, it means that at this workplace, the limit of exposure in terms of $H_p(3)$ corresponds to a maximum value of $H_p(10)$

$H_p(10)_{max20} = 4$ mSv if $H_p(3)$ limit of 20 mSv
$H_p(10)_{max50} = 10$ mSv if $H_p(3)$ limit of 50 mSv

Over these values of $H_p(10)_{max}$, the limit in terms of $H_p(3)$ is exceeded.

CRITERION TO APPLY AN INDIRECT METHOD

Real Life !

$H_p(10)_{max20} = 20 / R$ or $H_p(10)_{max50} = 50 / R$ (eq. 1)

When including the uncertainty on $H_p(10)$ measurement

Considering the extended uncertainty U(H_p10) (k=2 or 3 or ..) on the measurement of $H_p(10)$, equations 1 become:

$$H_p(10)_{max20} + U(H_p10) = 20 / R \longrightarrow H_p(10)_{max20} = (20 / R) - U(H_p10)$$

$$H_p(10)_{max50} + U(H_p10) = 50 / R \longrightarrow H_p(10)_{max50} = (50 / R) - U(H_p10)$$

Applying these equations and depending on the confidence level, one can infer that the exposure limit in terms of $H_p(3)$ might not be exceeded.

If U(H_p10) = 2 mSv and R = 5, $H_p(10)_{max}$ is:

$H_p(10)_{max20}$ = 2 mSv (4 mSv) if $H_p(3)$ limit 20 mSv

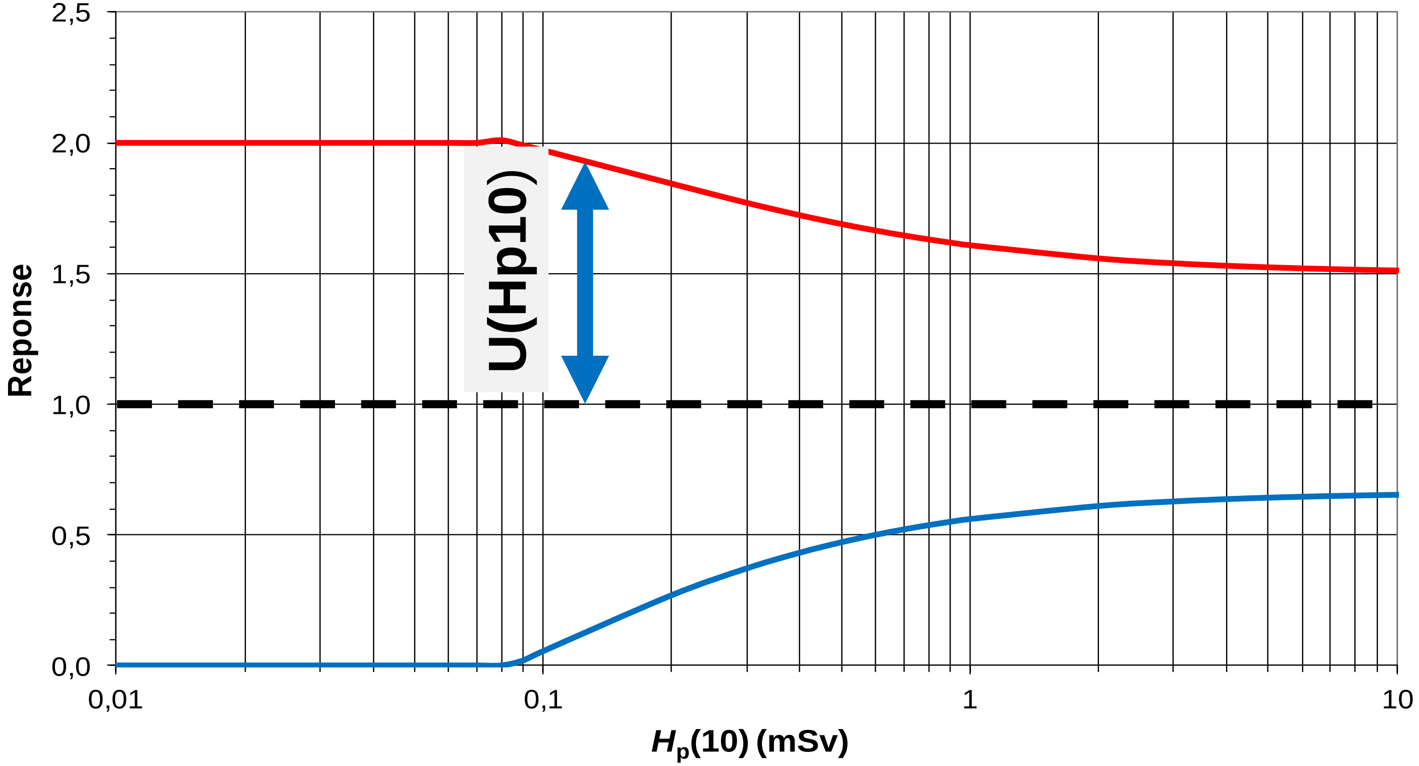
$H_p(10)_{max50}$ = 8 mSv (10 mSv) if $H_p(3)$ limit 50 mSv

CRITERION TO APPLY AN INDIRECT METHOD

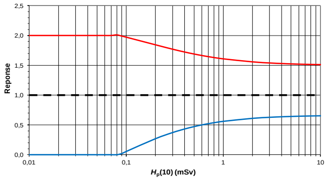
Equations 2

$$\begin{cases} H_p(10)_{max20} = (20 / R) - U(H_p10) \\ H_p(10)_{max50} = (50 / R) - U(H_p10) \end{cases}$$

U(H_p10) can be taken from the so called "trumpet curves" (ISO 14146, 2000, EUR 14852 EN)



CRITERION TO APPLY AN INDIRECT METHOD



Upper limit is given by

$H_p(10)_{ul} = 1.5\, H_p(10)_t\, (1 + H_0 / (2\, H_0 + H_p(10)_t))$ if $H_p(10)_t \geq H_0$

$H_p(10)_{ul} = 2\, H_p(10)_t$ if $H_p(10)_t < H_0$

Lower limit is given by

$H_p(10)_{ll} = H_p(10)_t\ / 1.5\, (1 - 2\, H_0 / (2\, H_0 + H_p(10)_t))$ if $H_p(10)_t \geq H_0$

$H_p(10)_{ll} = 0$ if $H_p(10)_t < H_0$

Where - $H_p(10)_t$ is the true value of the dose equivalent.

- H_0 is the lowest dose equivalent required to be measured, here 0.17 mSv for $H_p(10)$ for photons for a monthly wearing period and a limit equal to 20 mSv (EUR 14852 EN), a value of 0.41 mSv could be used for a limit equal to 50 mSv.
- $H_p(10)_{ul}$ and $H_p(10)_{ll}$ are the upper and lower limits respectively.

It turns that the upper limit is the most penalizing for this use

CRITERION TO APPLY AN INDIRECT METHOD

$$\left\{ \begin{array}{ll} H_p(10)_{max20} = (20 / R) - U(H_p10) \quad \text{and} \quad H_p(10)_{max50} = (50 / R) - U(H_p10) & \\ H_p(10)_{ul} = 1.5\, H_p(10)\, (1 + H_0 / (2\, H_0 + H_p(10))) & \text{if } H_p(10) \geq H_0 \\ H_p(10)_{ul} = 2\, H_p(10) & \text{if } H_p(10) < H_0 \end{array} \right.$$

$H_p(10)_{ul}$ is taken into account to substitute $U(H_p10)$ for the maximum error, one has :

$$H_p(10)_{max20} = (20 / R) - 1.5\, H_p(10)\, (1 + H_0 / (2\, H_0 + H_p(10))) \qquad \text{if } H_p(10) \geq H_0$$

$$H_p(10)_{max20} = (20 / R) - 2\, H_p(10) \qquad \text{if } H_p(10) < H_0$$

$$H_p(10)_{max50} = (50 / R) - 1.5\, H_p(10)\, (1 + H_0 / (2\, H_0 + H_p(10))) \qquad \text{if } H_p(10) \geq H_0$$

$$H_p(10)_{max50} = (50 / R) - 2\, H_p(10) \qquad \text{if } H_p(10) < H_0$$

The last thing to take into account is
the uncertainty, U(R), taken from the evaluation of R
through the workplace study

CRITERION TO APPLY AN INDIRECT METHOD

Introducing the uncertainties, U(R) and U(Hp10) equations 2 become:

$H_p(10)_{max20} = (20 / (R+U(R))) - H_p(10) \times 1.5\ (1 + H_0 / (2\ H_0 + H_p(10)))$

if $H_p(10) \geq H_0$

$H_p(10)_{max20} = (20 / (R+U(R))) - H_p(10) \times 2$ if $H_p(10) < H_0$

And

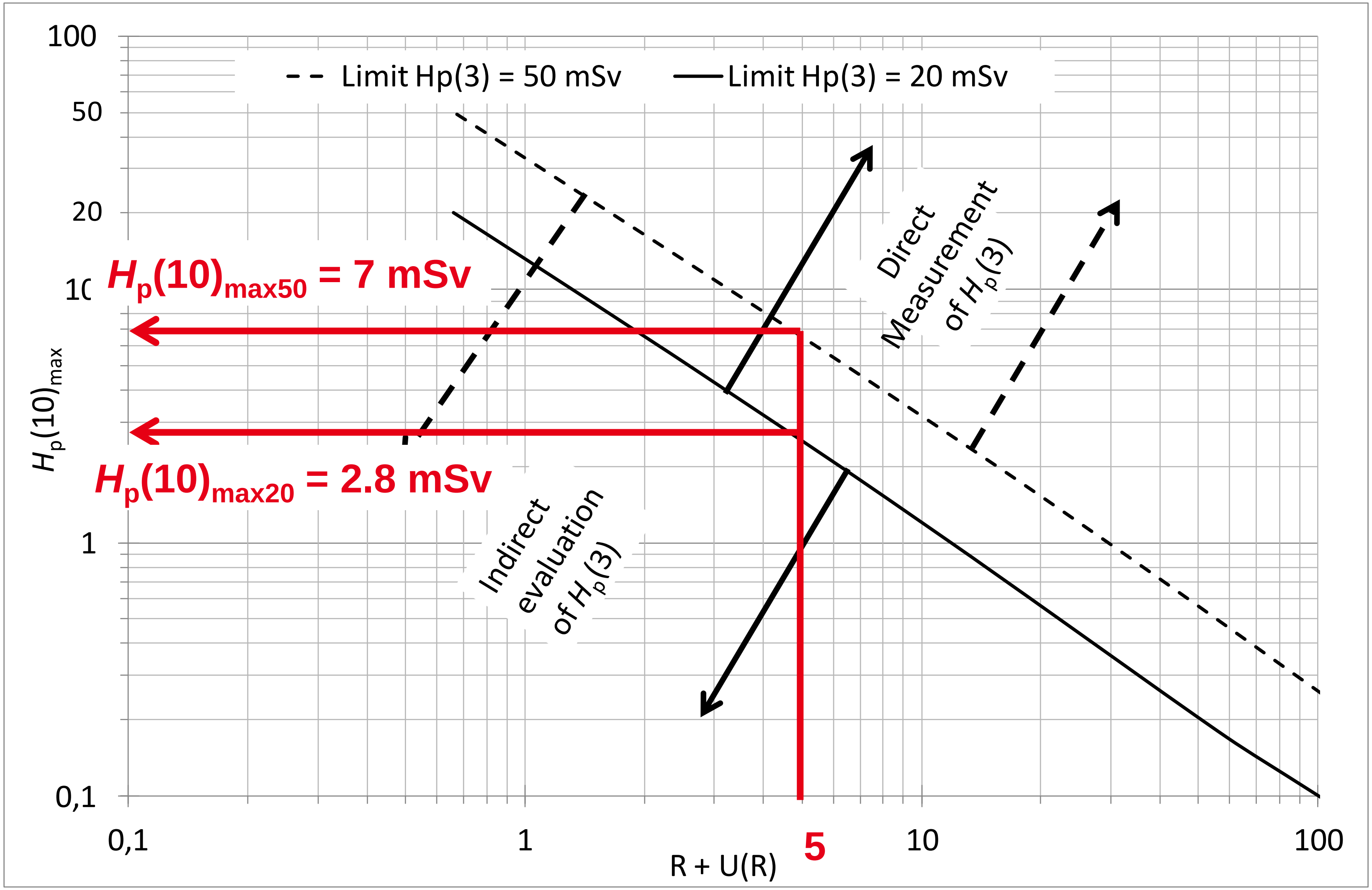
$H_p(10)_{max50} = (50 / (R+(U(R))) - H_p(10) \times 1.5\ (1 + H_0 / (2\ H_0 + H_p(10)))$

if $H_p(10) \geq H_0$

$H_p(10)_{max50} = (50 / (R+U(R))) - H_p(10) \times 2$ if $H_p(10) < H_0$

Now we can make a few calculations based on these equations…

CRITERION TO APPLY AN INDIRECT METHOD



CRITERION TO APPLY AN INDIRECT METHOD

Other trumpet curves equations for $H_p(10)$ (ICRP, IEC) could be introduced in the model instead of the ISO/EUR ones.

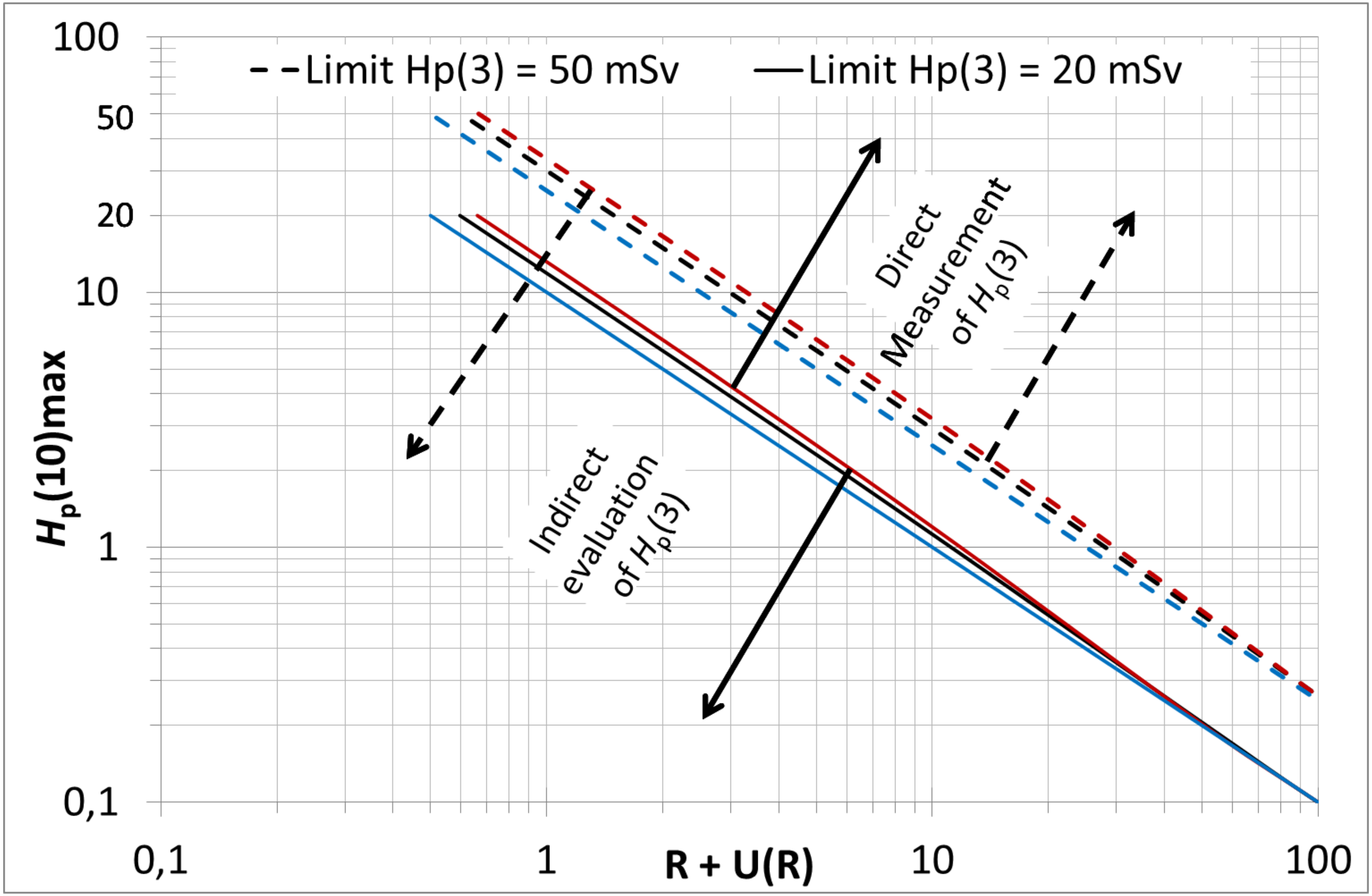
$\overline{E} > 65$ keV $H_0 = 0.1$ mSv

$$0.71\left(1-\frac{2H_0/1.33}{H_0/1.33+H}\right)x \le \text{response} \le 1.67\left(1+\frac{H_0}{4H_0+H}\right)$$

$\overline{E} \le 65$ keV $H_0 = 0.1$ mSv

$$0.5\left(1-\frac{2H_0/1.5}{H_0/1.5+H}\right)x \le \text{response} \le 2$$

CRITERION TO APPLY AN INDIRECT METHOD



CRITERION TO APPLY AN INDIRECT METHOD

R+U(R)	$H_p(10)_{max20}$; Limite $H_p(3)$ = 20 mSv			$H_p(10)_{max50}$; Limite $H_p(3)$ = 50 mSv		
	ISO 14142-2000	E > 65 keV	E < 65 keV	ISO14142-2000	E > 65 keV	E < 65 keV
10	1,20	1,12	1,00	3,18	2,91	2,50
7,5	1,64	1,52	1,33	4,29	3,90	3,33
5,0	2,52	2,31	2,00	6,50	5,89	5,00
4,0	3,18	2,91	2,50	8,15	7,39	8,34
3,0	4,28	3,90	3,35	11,0	9,88	12,0
2,0	6,50	5,90	5,00	16,5	14,9	12,5
1,0	**13,2**	**12,0**	**10,0**	33,2	29,8	25,0
0,8	16,5	14,9	12,5	41,5	37,3	31,3

Quite low but visible impact of the other trumpet curves

EVALUATION OF R AND U(R)

Example of ratios, R

http://www.amtsn.asso.fr/IMG/pdf/PrA_c_sentation_EDF_CRISTALLIN.pdf

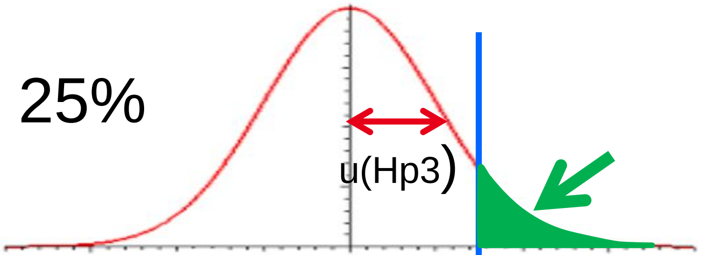
	***R* = *H*$_p$(3) / *H*$_p$(10)**
Glove box (reprocessing plants)	2.78 and 3.34 (photon)
	1 (neutron)
Nuclear power plants (PWR)	0,9 to 1,5
Glove box (nuclear medecine)	12.5 (photon)
orthopaedic	10 (X rays)
Interventional radiology	4 (X rays)

Huge variation of R depending on the workplace
So the uncertainty U(R) would be very large
if R covers a large range of workplace situations

+/- 50%
k=2 ~95%
confidence level

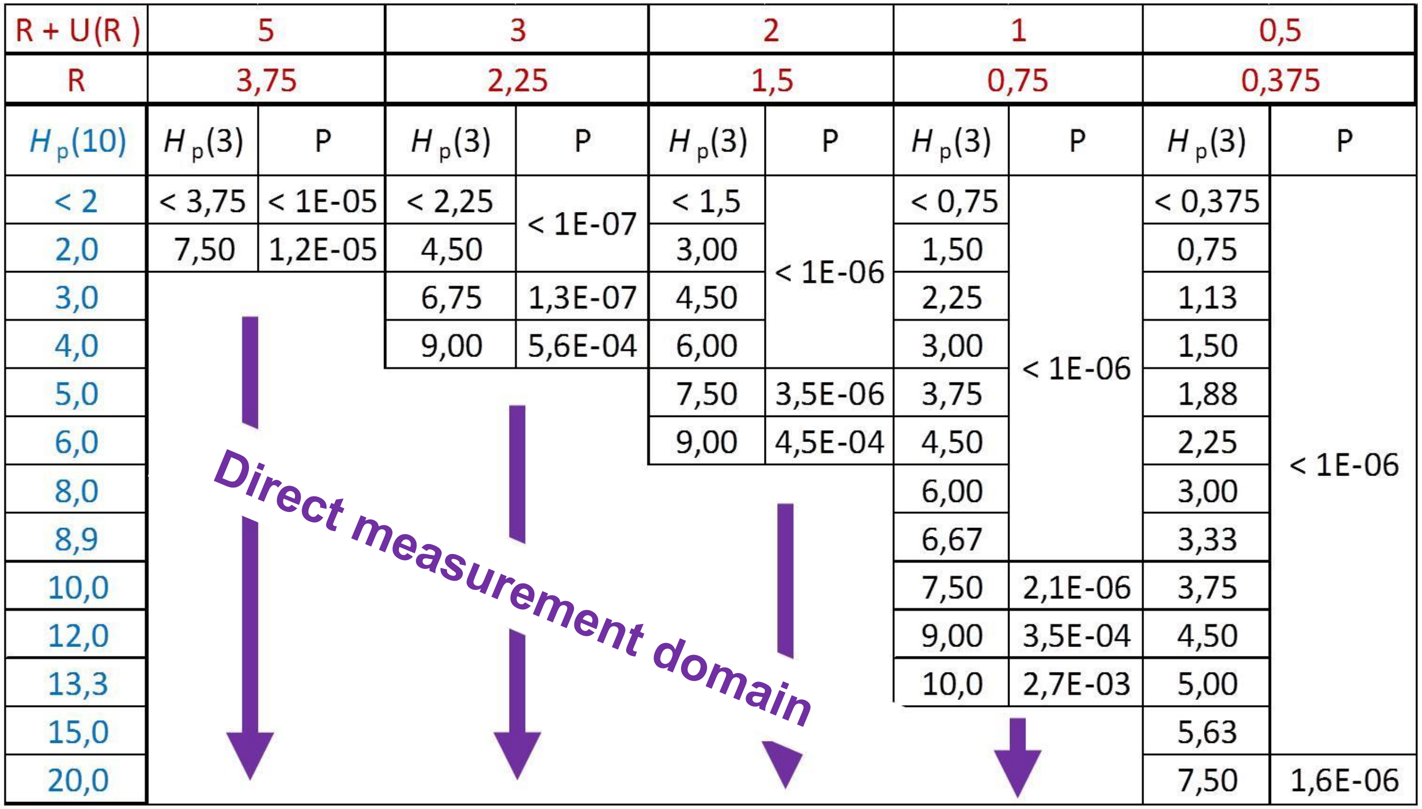
IS THE LIMIT EXCEEDED

Example for limit $H_p(3)$ = 20 mSv, u(R) = 25%



Estimated Value $H_p(3)$

Limit $H_p(3)$



R + U(R)	5		3		2		1		0,5	
R	3,75		2,25		1,5		0,75		0,375	
$H_p(10)$	$H_p(3)$	P	$H_p(3)$	P	$H_p(3)$	P	$H_p(3)$	P	$H_p(3)$	P
< 2	< 3,75	< 1E-05	< 2,25	< 1E-07	< 1,5	< 1E-06	< 0,75	< 1E-06	< 0,375	< 1E-06
2,0	7,50	1,2E-05	4,50		3,00		1,50		0,75	
3,0			6,75	1,3E-07	4,50		2,25		1,13	
4,0			9,00	5,6E-04	6,00		3,00		1,50	
5,0					7,50	3,5E-06	3,75		1,88	
6,0					9,00	4,5E-04	4,50		2,25	
8,0							6,00		3,00	
8,9							6,67		3,33	
10,0							7,50	2,1E-06	3,75	
12,0							9,00	3,5E-04	4,50	
13,3							10,0	2,7E-03	5,00	
15,0									5,63	
20,0									7,50	1,6E-06

Probability lower than $2.7\ 10^{-3}$

CONCLUSIONS

One can monitor H_{lens} with direct measurement or indirect evaluation

Conditions to apply the proposed indirect method are:

The $H_p(10)$ dosimeter must fulfill the type test requirements of IEC and ISO standards (at least within the domain it is used).

The dosimeter is calibrated as recommended in ISO standards.

One must have the results of the workplace study to evaluate R, U(R) and the expected value of $H_p(10)$ and to check if it is lower than $H_p(10)_{max}$ to allow using the indirect method.

Taking into account the uncertainty on $H_p(10)$ and R,
we can define the maximum values of $H_p(10)$ below which
the indirect evaluation of $H_p(3)$ is justified
minimizing the risk to « give » an $H_p(3)$ value lower than the limits
while the « real » value of $H_p(3)$ exceed the limit.

Operationnal Quantities (OQ) **$H_p(3)$ cylinder 20cm « head »**
(tissu equivalent phantom)

Dosimeter satisfying type test requirements **(IEC 62387)**

Calibration in terms of OQ (**on head phantom** / free in air)
indiv. zone

Dosimeter used/worn as specified
In international recommandations **(ISO 15382)**

Measure/evaluation of operationnal quantities in laboratories

Estimate of H_{lens}

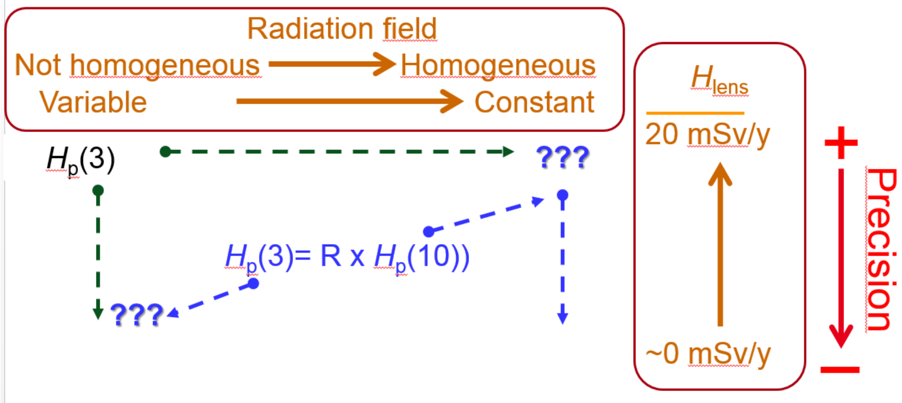
Verification of the exposure limits

Monitoring of eye lens doses in radiation protection

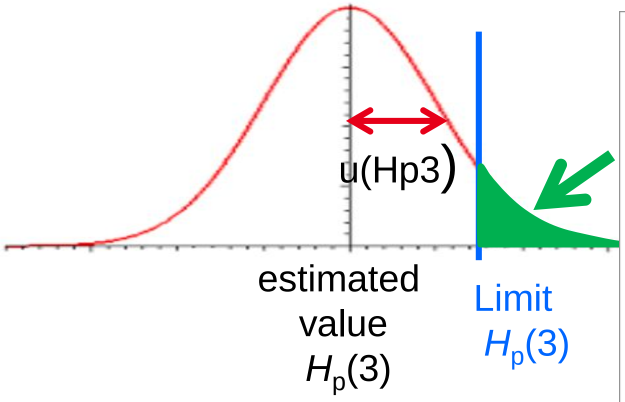
Radioprotection 50(3), 177-185 (2015),
http://dx.doi.org/10.1051/radiopro/2015009

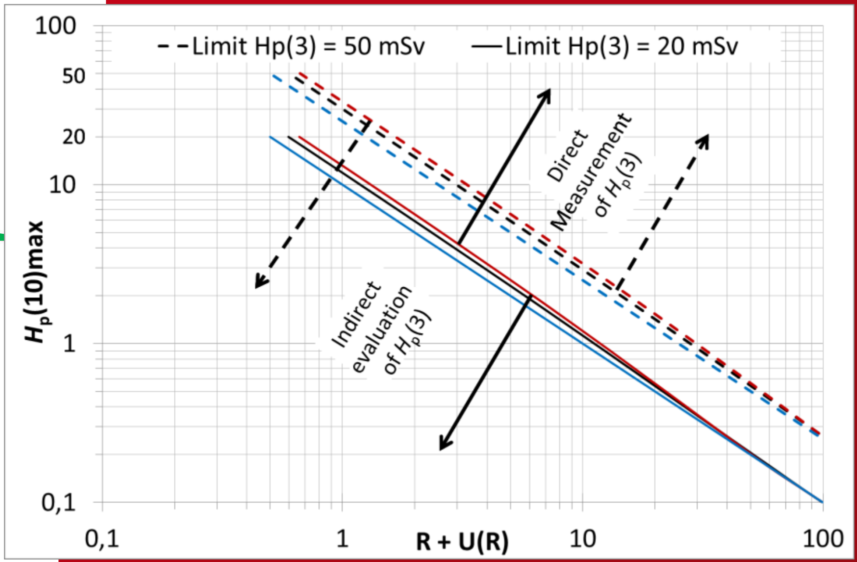
Technical Information Sheets of SFPR: Eye lens: REGULATORY LIMITS, MEASUREMENT, DOSIMETRY AND MEDICAL SURVEILLANCE

http://www.sfrp.asso.fr/medias/sfrp/documents/Divers/Fiche_SFRP_-_Cristallin_VA___01-2016.pdf



Thank you for your attention





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EU Scientific Seminar, Emerging issues with regard to organ doses
2017 - Luxembourg