EURADOS

IRSN
INSTITUT
DE RADIOPROTECTION
ET DE SÛRETÉ NUCLÉAIRE

Enhancing nuclear safety

Intercomparisons on eye-lens dosemeters
EURADOS exercices

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Introduction

For many years, EURADOS has been organising intercomparison exercises dedicated to individual monitoring services (IMS).
⇒ for whole-body,
⇒ extremity,
⇒ environmental dosemeters.

These exercises give IMS the opportunity to compare their results with other participants and develop plans for improving their dosimetry systems.

In the context of the new eye lens dose limit for occupational exposure of 20 mSv per year stated by the revision of the European Basic Safety Standards Directive 2013/59/EURATOM, **EURADOS organized two intercomparisons dedicated to eye lens dosemeters.**

First intercomparison in 2014	Second intercomparison in 2016
$IC2014_{eye}$	**$IC2016_{eye}$**
Photon radiation fields	**Photon and beta** radiation fields

Organisation Group

Each exercise was managed and coordinated by an **Organisation Group** composed of members of EURADOS.

$IC2014_{eye}$

Photon radiation fields

- Eleftheria **Carinou**, EEAE, Greece
- Isabelle **Clairand**, IRSN, France
- Josiane **Daures**, CEA, France
- Marc **Denozière**†, CEA, France
- Mercè **Ginjaume**, UPC, Spain
- Filip **Vanhavere**, SCK-CEN, Belgium

$IC2016_{eye}$

Photon and beta radiation fields

- Rolf **Behrens**, PTB, Germany
- Marcin **Brodecki**, NIOM, Poland
- Eleftheria **Carinou**, EEAE, Greece
- Isabelle **Clairand**, IRSN, France
- Joanna **Domienik**, NIOM, Poland
- Mercè **Ginjaume**, UPC, Spain
- Oliver **Hupe**, PTB, Germany

Project phases and time schedule for $IC2016_{eye}$

Phase	Date
Preparation	**Dec. 2015 - February 2016**
Selection of participants	**March 2016**
Execution	**April 2016 - February 2017**
Reception of dosemeters by coordinating laboratory	June 2016
Irradiations	July-August 2016
Irradiated dosemeters sent to the participants	September 2016
Results reported by the participants	November 2016
First draft individual result datasheets sent to participants	February 2017
Interpretation of results and reporting	**February 2017 - May 2017**
FINAL individual result datasheets + certificates of attendance	June 2017

Preparation phase ($IC2016_{eye}$)

- Decision about the irradiation plan
- Identification of the irradiation facilities
- Definition of general modalities (maximum number of participants, identification codes, etc.)
- Provisional budget
- Time schedule

Participant application (IC2016$_{eye}$)

- The announcement was made during the EURADOS AM 2016 in Milan (Feb. 2016) and a direct emailing was made to EURADOS members and additional IMS
- Candidate participants were invited to complete and return an application form
- 24 participants were selected, 2 cancelled before the beginning of IC.
- A letter of confirmation was sent to each participant with a set of instructions + a questionnaire (administrative and technical)
- A financial participation of 900 euros was asked to each participant to cover a part of the costs induced by the intercomparison
(800 euros for EURADOS sponsor Institutes)

Participant questionnaire (IC2016$_{eye}$)

EURADOS European Radiation Dosimetry Group

Questionnaire for participating individual monitoring services to the EURADOS intercomparison exercise of eye lens dosemeters (IC2016$_{eye}$).

GENERAL INFORMATION	
Name of the laboratory	
Name of the head of the laboratory	
Contact person for the intercomparison	
Mailing address	
Fax number	
Phone number	
E-mail address	

Participant questionnaire (IC2016$_{eye}$)

DOSEMETER INFORMATION	
Manufacturer	
Type of detector (*for example*, if TLD: please specify the TLD type)	
Filters (material and thickness)	
Calibration source	
Calibration quantity ($H_p(3)$, $H_p(0.07)$, Ka, $H_p(10)$, other)	
Type of calibration phantom	
Photon energy range	
Any special protocol for eye lens dosimetry? (correction factors, energy correction, lead glasses correction, etc.)	

Participant questionnaire (IC2016$_{eye}$)

EURADOS European Radiation Dosimetry Group

SERVICE INFORMATION	
Number of people monitored per year	
Number of eye lens dosemeters issued per year (photon fields)	
Number of eye lens dosemeters issued per year (beta fields or mixed photon-beta fields)	
Number of people monitored per year in the medical field	
Number of eye lens dosemeters issued per year in the medical field	
Do you have an accreditation (e.g. ISO 17025) for your eye lens dosimetry service? Please specify	
Is your passive system in agreement with IEC 62387 standard? If others, please specify	

Execution phase ($IC2016_{eye}$)

- Instructions given to participants:
  - Preparation of dosemeters according to their normal procedures
  - Identify the dosemeters with a specific codification provided by OG
  - Send the dosemeters to a contact person from the OG
- The contact person dispatched the dosemeters to irradiating laboratories
- The dosemeters were sent back to participants with instructions to report their results (Excel sheet). Participants were asked to report the doses in terms of $H_p(3)$ using their routine measurement protocol.
- The doses provided by each participant were compared with the reference delivered doses. All the results were analysed anonymously.
- First draft results were individually reported back to each participant for comments.

Excel sheet to report the results (1/2) - (IC2016$_{eye}$)

EURADOS WG12 intercomparison exercise of eye lens dosemeters for medical applications, IC2016eye

Worksheet dedicated to participants to report the results : **the response will be evaluated in terms of $H_p(3)$**

Date

PARTICIPANT ID		XXX			
		$H_p(3)$* (mSv) (*final result* - *after substraction of background + any other correction*)	Background** substracted (mSv)	Expanded combined uncertainty % (k=2)***	*COMMENT*
XXX_1	irradiated				
XXX_2	irradiated				
XXX_3	irradiated				
XXX_4	irradiated				
XXX_5	irradiated				
XXX_6	irradiated				
XXX_7	irradiated				
XXX_8	irradiated				
XXX_9	irradiated				
XXX_10	irradiated				
XXX_11	irradiated				
XXX_12	irradiated				
XXX_13	irradiated				
XXX_14	irradiated				
XXX_15	irradiated				
XXX_16	irradiated				
XXX_17	irradiated				
XXX_18	irradiated				
XXX_19	irradiated				
XXX_20	irradiated				

Excel sheet to report the results (2/2) - (IC2016$_{eye}$)

XXX_19	irradiated				
XXX_20	irradiated				
XXX_21	irradiated				
XXX_22	irradiated				
XXX_23	irradiated				
XXX_24	irradiated				
XXX_25	spare				
XXX_26	spare				
XXX_27	spare				
XXX_28	spare				
XXX_29	spare				
XXX_30	spare				
XXX_31	spare				
XXX_32	spare				
XXX T_1	*transit*				
XXX T_2	*transit*				
XXX T_3	*transit*				
XXX T_4	*transit*				

*if you report your results in another quantity, please specify

** please indicate the dose due to the background (**usually used in your routine protocol**) that was substracted to obtain the final result.

The transit dose will be taken into account by the organisers.

***UNCERTAINTY EVALUATION

Please indicate if some components (reading, calibration factor, energy and angle correction, ambient conditions or others) were taken into account in the calculation of the uncertainty

Uncertainty evaluation budget				
Reading (%, k=2)	Reference calibration factor (%, k=2)	Energy/angle (%, k=2)	Ambient conditions (%, k=2)	**Expanded combined uncertainty associated to the final result** (%, k=2)

Final results ($IC2016_{eye}$)

Final individual result datasheets are completed
+ certificates of participation

EURADOS European Radiation Dosimetry Group

Eye lens dosemeter intercomparison $IC2016_{eye}$

CERTIFICATE OF PARTICIPATION

EURADOS Intercomparison 2016 for eye lens dosemeters ($IC2016_{eye}$)

Certificate number	EURADOS- $IC2016_{eye}$-001-rev1
Number of pages	5
Date of issue	February 2018
Participating institute	AAA
Dosimetry system	Eye lens dosemeter
Intercomparison procedure	The EURADOS Intercomparison 2016 for eye lens dosemeters was managed and coordinated on behalf of EURADOS by the WG12 Intercomparison Organization Group (OG). This intercomparison was designed to be a blind test for all participants who reported their results without knowing the beam qualities and the reference dose values. The only information they had was that the irradiations were performed in photon radiation fields representative of medical workplaces and S-Cs, as well as beta radiation fields (^{85}Kr, ^{90}Sr+^{90}Y and ^{106}Ru+^{106}Rh). The OG established the irradiation plan and announced the intercomparison in February 2016. After completing the application procedures the participants sent their dosemeters, in accordance with the instructions, to the OG in June 2016. The laboratories irradiated the dosemeters according to the irradiation plan in July and August 2016. The dosemeters were sent back to the participants in September 2016. Each participant was instructed to follow normal routine procedures as far as possible. The participants sent the results of the dosemeter readings to the OG coordinator in October 2016. The final individual results were sent to each participant in May 2017. This certificate is a revision of the first one, EURADOS- $IC2016_{eye}$-001. In the first version the performance limits (i.e. trumpet curves) were calculated and represented in the participant's graphs using H_0 = 0.085 mSv, as stated in ISO 14146[1], whereas in the present version the value of H_0 = 0.3 mSv has been used as stated in the current draft revision of ISO 14146 valid for eye lens dosemeters[2]. This change does not imply any modification in the numerical results shown in the Tables and the Graphs. Only for few data mainly for the lower doses a result that did not comply with the preliminary criteria might now fulfil the ISO requirement. When applicable this is specifically indicated in the results' table. The global results in page 5/5 were correctly represented in the original certificate.
Number of participants/systems	22 (1 system per participant)
Irradiation conditions	See details in page 2.
Participant results	See tables and figures in pages 3 and 4.
Global results	See figures in page 5.

On behalf of the Intercomparison Organization Group

Isabelle Clairand
Coordinator

On behalf of EURADOS

Werner Rühm
Chairperson

European Radiation Dosimetry Group e.V., Postfach 1129, D-85758 Neuherberg
EURADOS - $IC2016_{eye}$-001-rev1 – Participant AAA – February 2018

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Scope and organization of $IC2014_{eye}$ and $IC2016_{eye}$

- Both **intercomparisons** were designed to be a **blind test for all participants** who reported their results without knowing the reference dose values.

Information given to participants

- **For photon radiation fields (both):** S-Cs + photon fields representative of medical workplaces (without knowing the exact beam qualities),
- **For beta radiation fields (IC2016eye):** ^{85}Kr, ^{90}Sr+^{90}Y and ^{106}Ru+^{106}Rh.
- The participants did not know which dosemeter would be irradiated to which type of radiation.

- All participants were requested **to prepare their dosemeters according to their usual procedures** and **to report the doses in terms of $H_p(3)$ using their routine protocol.**

- All the data were treated **confidentially** using an identification code assigned to each participant.

Participants (1/2)

IC2014$_{eye}$

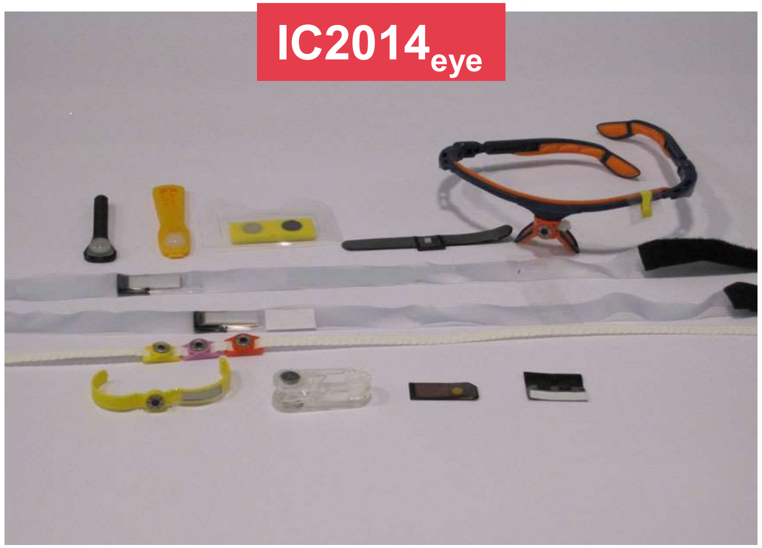


Photo credit IRSN

IC2016$_{eye}$

Photo credit PTB

Participants: 20 European IMS from 15 different countries participated *(Austria, Belgium, Czech Rep., France, Greece, Italy, Lithuania, Poland, Rumania, Serbia, Slovakia, Spain, Switzerland, UK and Ukraine).*

Participants: 22 IMS from 12 different countries *(Bulgaria, Czech Republic, France, Germany, Israel, Italy, Slovakia, Spain, Switzerland, Turkey, United Kingdom and USA).*

All the provided dosemeters were composed of **thermoluminescent** detectors.

IC2014$_{eye}$	Dosemeter type	IC2016$_{eye}$
9	Eye-D^{TM} system (ORAMED[1] European project)	6
3	dosemeters with a specific holder	3
8	dosemeters placed in a plastic bag	11
0	whole body dosemeters	2

[1]*Vanhavere, F. et al. ORAMED: optimization of radiation protection of medical staff. EURADOS report 2012-02, ISSN 2226-8057, ISBN 978-3-943701-01-2. Braunschweig (2012).*

Participants (2/2)

In addition, most of the participants indicated, via a **questionnaire,** some **technical information** such as:

- the type of the included detector,
- the filter used if any,
- the phantom and energy quality used for calibration.

$IC2014_{eye}$	Calibration conditions	$IC2016_{eye}$
9	participants use pure S-Cs or pure S-Co or both	13
8	participants use various X-ray spectra	8
3	participant use mixed S-Cs and X-ray	1

Radiation qualities and doses imparted - photons

Radiation quality and angle of incidence	Ref.	Mean E. (keV)	Dose range $H_p(3)$ (mSv)
S-Cs; 0°	*ISO 4037-1*	667	0.4 – 0.5
S-Cs; 0°	*ISO 4037-1*	667	2.0 – 2.2
S-Cs; 60°	*ISO 4037-1*	667	2.0 - 2.1
N-40; 0°	*ISO 4037-1*	33	3.0 - 3.1
N-60; 0°	*ISO 4037-1*	48	3.0 - 3.1
N-80; 0°	*ISO 4037-1*	65	3.0 - 3.1
RQR6; 0°	*IEC 61267*	44	2.6 - 2.7
RQR6; 45°	*IEC 61267*	44	2.5 – 2.6
RQR6; 75°	*IEC 61267*	44	2.1 – 2.2
Realistic field (scattered field in int rad.)	*CONRAD/ORAMED European projects (PCRD 7)*	45	0.9 – 1.0

Conversion coefficients to relate air kerma to $H_p(3)$ were taken from Behrens (2012) for ISO 4037 qualities and from Principi et. Al (2015) for IEC 61267 qualities. For the "realistic field" the conversion coefficient was calculated with PENELOPE Monte Carlo code as described in EURADOS 2012-02 report (2012).

- *Behrens, R. Air kerma to Hp(3) conversion coefficients for a new cylinder phantom for photon reference radiation qualities. Radiat. Prot. Dosim. 151(3), 450-455 (2012).*
- Principi S., et al. Air kerma to $H_p(3)$ conversion coefficients for IEC 61267 RQR X-ray radiation qualities. Application to dose monitoring of the lens of the eye in medical diagnostics. International Conference on Individual Monitoring of Ionizing Radiation, Bruges 2015.
- Vanhavere, F., et al. ORAMED: Optimization of Radiation Protection of Medical Staff. EURADOS Report 2012-02, ISSN 2226-8057, ISBN 978-3-943701-01-2. Braunschweig (2012)

Radiation qualities and doses imparted - photons

Radiation quality and angle of incidence	Ref.	Mean E. (keV)	Dose range $H_p(3)$ (mSv)
RQR6; 0°	*IEC 61267*	44	2.0 - 3.0
RQR6; 45°	*IEC 61267*	44	2.0 - 3.0
RQR6; 75°	*IEC 61267*	44	2.0 - 3.0
N-100; 0°	*ISO 4037-1*	85	2.0 - 3.0
S-Cs; 0°	*ISO 4037-1*	662	2.0 - 3.0
S-Cs; 60°	*ISO 4037-1*	662	2.0 - 3.0

Conversion coefficients to relate air kerma to $H_p(3)$ were taken from Behrens (2012) for ISO 4037 qualities and from Principi et al. (2016) for IEC 61267 qualities.

- *Behrens, R. Air kerma to Hp(3) conversion coefficients for a new cylinder phantom for photon reference radiation qualities. Radiat. Prot. Dosim. 151(3), 450-455 (2012).*
- *Principi S., Guardiola C., Duch MA., Ginjaume M. Air kerma to Hp(3) conversion coefficients for IEC 61267 RQR X-ray radiation qualities: application to dose monitoring of the lens of the eye in medical diagnostics. Radiat Prot Dosimetry. 170(1-4), 45-8 (2016).*

Radiation qualities and doses imparted - betas

Radiation quality and angle of incidence	Ref.	Mean energy (MeV)	Dose range $H_p(3)$ (mSv)
^{85}Kr; 0°	*ISO 6980-1*	0.24	0.03 – 0.04
$^{90}Sr+^{90}Y$; 0°	*ISO 6980-1*	0.8	2.0 - 3.0
$^{90}Sr+^{90}Y$; 60°	*ISO 6980-1*	0.8	2.0 - 3.0
$^{106}Ru+^{106}Rh$; 0°	*ISO 6980-1*	1.2	1.0 - 1.5

The low energy beta quality (^{85}Kr, 0.24 MeV) was chosen to test the design of the dosemeters, in particular to check if the filter in front of the detector is sufficient. Even if this quality is not used in practice, such energies are produced by partially shielded high energy beta sources and are therefore of relevance.

Conversion coefficients to relate absorbed to tissue at 0.07 mm depth, D_t, to $H_p(3)$ were taken from Behrens (2012, 2015) for beta radiation qualities

- *Behrens R. and Buchholz G. Extensions to the Beta Secondary Standard BSS 2. J. Instrum. 6, P11007 (2011) and Erratum: J. Instrum. 7, E04001 (2012) and Addendum: J. Instrum. 7, A05001 (2012).*
- *Behrens R. Correction factors for the ISO rod phantom, a cylinder phantom, and the ICRU sphere for reference beta radiation fields of the BSS 2. J. Instrum. 10, P03014 (2015).*

Irradiation conditions

- Irradiations were performed in terms of personal dose equivalent $\boldsymbol{H_p(3)}$
- The **head phantom** (20 cm * 20 cm) was used (ORAMED project[1] and ISO 4037-3)
- **Two dosemeters** of each participant were irradiated for each setup.

[1]*Gualdrini, G., Mariotti, F., Wach, S., Bilski, P., Denoziere, M., Daures, J., Bordy, J.-M., Ferrari, P., Monteventi, F., Fantuzzi, E., Vanhavere, F. A new cylindrical phantom for eye lens dosimetry development. Rad. Meas.* ***46****, 1231-1234 (2011)"*

Results evaluation

The numerical results in the intercomparisons are reported as the dosemeter response R, where R is defined as:

R = $H_p(3)_{participant}$ corrected for transit dose / $H_p(3)_{reference}$

The performance limits according to the ISO 14146 standard, commonly known as "trumpet curves", were adopted to analyze the results :

$$\frac{1}{F}\left(1-\frac{2H_0}{H_0+H_c}\right) \leq R \leq F\left(1+\frac{H_0}{2H_0+H_c}\right)$$

- **R** is the response, the ratio between the participant measured value and the conventional true value
- **F** = 1.5 (ICRP 75)
- H_C is the conventional true value, in this case, $H_p(3)_{reference}$
- H_0: was chosen equal to:

ISO14146-2000

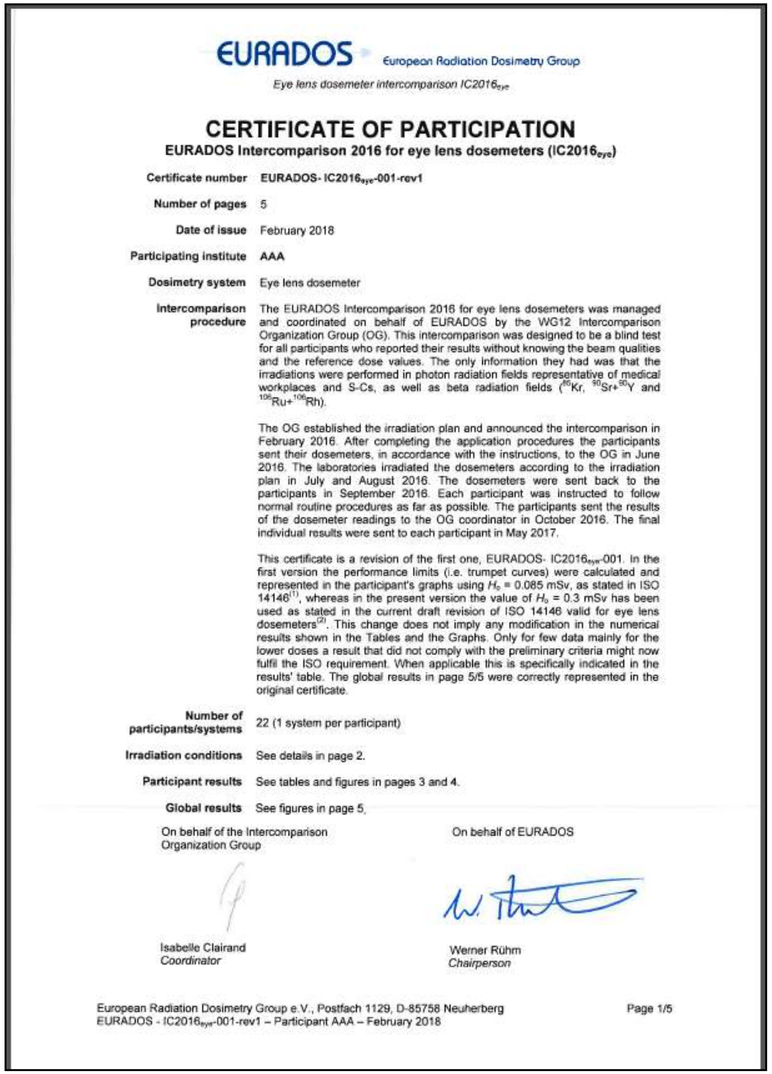
- **2014:** was chosen equal to **0.085 mSv** for all participants, assuming a "lower limit of the dose range for which the system has been approved" of 1 mSv in a year, and an issuing frequency of 12 per year, consistent with the EURADOS report "*EURADOS Intercomparison 2008 for Whole Body Dosemeters in Photon Fields*" EURADOS Report 2012-01.

« Draft version » ISO14146 -2018

- **2016: 0.3 mSv**

EURADOS

Individual result datasheet (1/3) $IC2016_{eye}$



EURADOS European Radiation Dosimetry Group

Eye lens dosemeter intercomparison $IC2016_{eye}$

CERTIFICATE OF PARTICIPATION

EURADOS Intercomparison 2016 for eye lens dosemeters ($IC2016_{eye}$)

Certificate number	**EURADOS- $IC2016_{eye}$-001-rev1**
Number of pages	5
Date of issue	February 2018
Participating institute	**AAA**
Dosimetry system	Eye lens dosemeter

Intercomparison procedure

The EURADOS Intercomparison 2016 for eye lens dosemeters was managed and coordinated on behalf of EURADOS by the WG12 Intercomparison Organization Group (OG). This intercomparison was designed to be a blind test for all participants who reported their results without knowing the beam qualities and the reference dose values. The only information they had was that the irradiations were performed in photon radiation fields representative of medical workplaces and S-Cs, as well as beta radiation fields (^{85}Kr, $^{90}Sr+^{90}Y$ and $^{106}Ru+^{106}Rh$).

The OG established the irradiation plan and announced the intercomparison in February 2016. After completing the application procedures the participants sent their dosemeters, in accordance with the instructions, to the OG in June 2016. The laboratories irradiated the dosemeters according to the irradiation plan in July and August 2016. The dosemeters were sent back to the participants in September 2016. Each participant was instructed to follow normal routine procedures as far as possible. The participants sent the results of the dosemeter readings to the OG coordinator in October 2016. The final individual results were sent to each participant in May 2017.

This certificate is a revision of the first one, EURADOS- $IC2016_{eye}$-001. In the first version the performance limits (i.e. trumpet curves) were calculated and represented in the participant's graphs using H_0 = 0.085 mSv, as stated in ISO 14146[1], whereas in the present version the value of H_0 = 0.3 mSv has been used as stated in the current draft revision of ISO 14146 valid for eye lens dosemeters[2]. This change does not imply any modification in the numerical results shown in the Tables and the Graphs. Only for few data mainly for the lower doses a result that did not comply with the preliminary criteria might now fulfil the ISO requirement. When applicable this is specifically indicated in the results' table. The global results in page 5/5 were correctly represented in the original certificate.

Number of participants/systems	22 (1 system per participant)
Irradiation conditions	See details in page 2.
Participant results	See tables and figures in pages 3 and 4.
Global results	See figures in page 5.

On behalf of the Intercomparison Organization Group

Isabelle Clairand
Coordinator

On behalf of EURADOS

Werner Rühm
Chairperson

European Radiation Dosimetry Group e.V., Postfach 1129, D-85758 Neuherberg
EURADOS - $IC2016_{eye}$-001-rev1 – Participant AAA – February 2018

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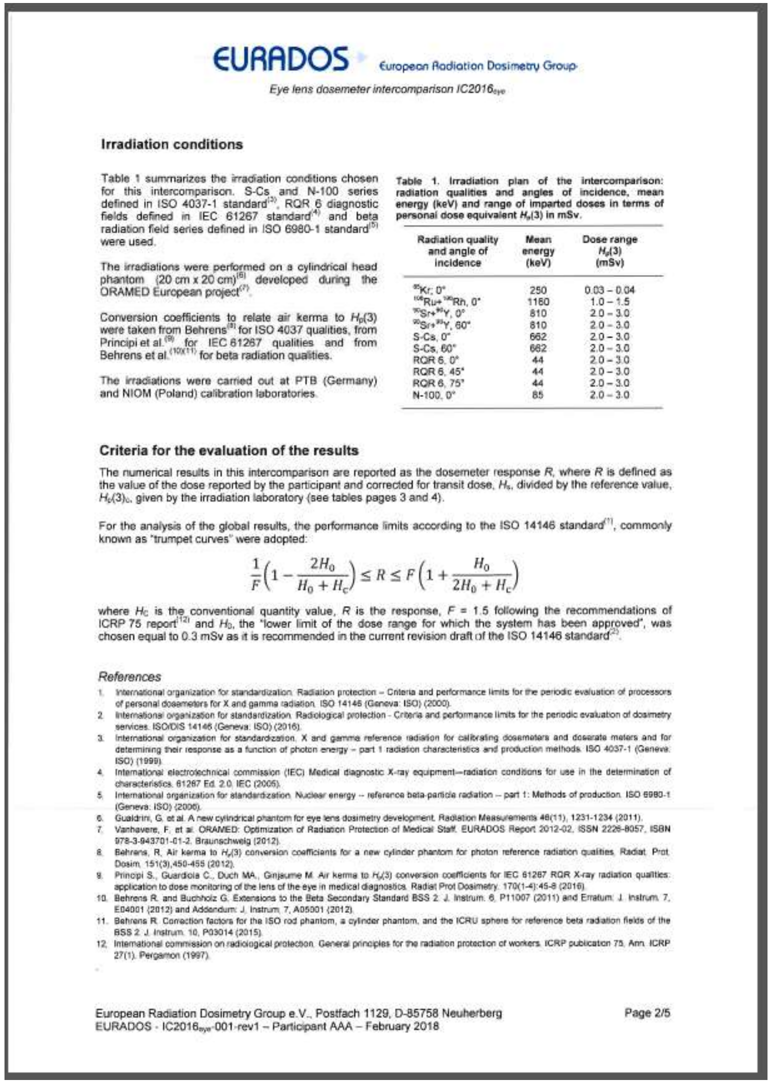

EURADOS European Radiation Dosimetry Group

Eye lens dosemeter intercomparison $IC2016_{eye}$

Irradiation conditions

Table 1 summarizes the irradiation conditions chosen for this intercomparison. S-Cs and N-100 series defined in ISO 4037-1 standard[3], RQR 6 diagnostic fields defined in IEC 61267 standard[4] and beta radiation field series defined in ISO 6980-1 standard[5] were used.

The irradiations were performed on a cylindrical head phantom (20 cm x 20 cm)[6] developed during the ORAMED European project[7].

Conversion coefficients to relate air kerma to $H_p(3)$ were taken from Behrens[8] for ISO 4037 qualities, from Principi et al.[9] for IEC 61267 qualities and from Behrens et al.[10][11] for beta radiation qualities.

The irradiations were carried out at PTB (Germany) and NIOM (Poland) calibration laboratories.

Table 1. Irradiation plan of the intercomparison: radiation qualities and angles of incidence, mean energy (keV) and range of imparted doses in terms of personal dose equivalent $H_p(3)$ in mSv.

Radiation quality and angle of incidence	Mean energy (keV)	Dose range $H_p(3)$ (mSv)
^{85}Kr, 0°	250	0.03 – 0.04
$^{106}Ru+^{106}Rh$, 0°	1160	1.0 – 1.5
$^{90}Sr+^{90}Y$, 0°	810	2.0 – 3.0
$^{90}Sr+^{90}Y$, 60°	810	2.0 – 3.0
S-Cs, 0°	662	2.0 – 3.0
S-Cs, 60°	662	2.0 – 3.0
RQR 6, 0°	44	2.0 – 3.0
RQR 6, 45°	44	2.0 – 3.0
RQR 6, 75°	44	2.0 – 3.0
N-100, 0°	85	2.0 – 3.0

Criteria for the evaluation of the results

The numerical results in this intercomparison are reported as the dosemeter response R, where R is defined as the value of the dose reported by the participant and corrected for transit dose, H_s, divided by the reference value, $H_p(3)_c$, given by the irradiation laboratory (see tables pages 3 and 4).

For the analysis of the global results, the performance limits according to the ISO 14146 standard[1], commonly known as "trumpet curves" were adopted:

$$\frac{1}{F}\left(1-\frac{2H_0}{H_0+H_c}\right) \le R \le F\left(1+\frac{H_0}{2H_0+H_c}\right)$$

where H_C is the conventional quantity value, R is the response, F = 1.5 following the recommendations of ICRP 75 report[12] and H_0, the "lower limit of the dose range for which the system has been approved", was chosen equal to 0.3 mSv as it is recommended in the current revision draft of the ISO 14146 standard[2].

References

1. 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 (Geneva: ISO) (2000).
2. International organization for standardization. Radiological protection - Criteria and performance limits for the periodic evaluation of dosimetry services. ISO/DIS 14146 (Geneva: ISO) (2016).
3. International organization for standardization. X and gamma reference radiation for calibrating dosemeters and doserate meters and for determining their response as a function of photon energy – part 1 radiation characteristics and production methods. ISO 4037-1 (Geneva: ISO) (1999).
4. International electrotechnical commission (IEC) Medical diagnostic X-ray equipment—radiation conditions for use in the determination of characteristics. 61267 Ed. 2.0. IEC (2005).
5. International organization for standardization. Nuclear energy -- reference beta-particle radiation – part 1: Methods of production. ISO 6980-1 (Geneva: ISO) (2006).
6. Gualdrini, G. et al. A new cylindrical phantom for eye lens dosimetry development. Radiation Measurements 46(11), 1231-1234 (2011).
7. Vanhavere, F. et al. ORAMED: Optimization of Radiation Protection of Medical Staff. EURADOS Report 2012-02, ISSN 2226-8057, ISBN 978-3-943701-01-2. Braunschweig (2012).
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Individual result datasheet (2/3) IC2016$_{eye}$

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Eye lens dosemeter intercomparison IC2016$_{eye}$

PARTICIPANT RESULTS – beta qualities

PARTICIPANT - Reference quantity $H_p(3)$ - Beta qualities									
Radiation Quality	Dosimeter id	Conventional quantity value ± uncertainty (k=2) $H_p(3)_c$ (mSv)	Reported by participant H_r * (mSv)	Reported by participant H_s ** (mSv)	Response $R = \frac{H_s}{H_p(3)_c}$	Response ISO 14146 Criteria	Mean results per set-up $\overline{H_s}$ (mSv)	Mean results per set-up $\overline{R}$	Mean results per set-up CV (R) (%)
^{85}Kr, 0° ***		0.031 ± 0.022	21.41	21.16	683	NO	20.55	663	4.3
		0.031 ± 0.022	20.17	19.93	643	NO			
^{106}Ru+^{106}Rh, 0°		1.100 ± 0.042	1.585	1.338	1.22	YES	1.367	1.25	2.8
		1.100 ± 0.042	1.642	1.395	1.27	YES			
^{90}Sr+^{90}Y, 0°		2.301 ± 0.088	5.170	4.923	2.14	NO	4.897	2.13	0.7
		2.301 ± 0.088	5.117	4.870	2.12	NO			
^{90}Sr+^{90}Y, 60°		2.200 ± 0.170	14.04	13.79	6.27	NO	13.40	6.09	4.2
		2.200 ± 0.170	13.25	13.00	5.91	NO			

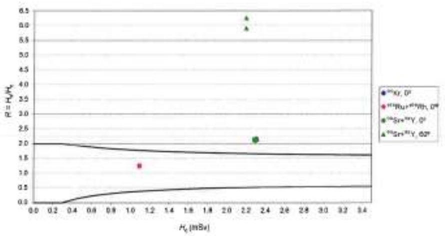
* H_r: *Participant reported value (corrected for background according to the routine protocol of the participant)*

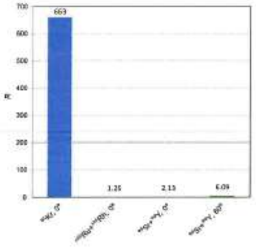
** H_s: *Participant reported value corrected for transit.* $H_s = H_r - \overline{H_t}$

Correction for transit for beta qualities: $\overline{H_t}$ *= 0.247 mSv*

*** ^{85}*Kr has a beta maximum energy of about 0.69 MeV, which does not contribute to the delivered* $H_p(3)$ *dose, with the exception of the respective small photon contribution. The significant overresponse to* ^{85}*Kr radiation of some dosemeters is due to an insufficient filter in front of the detector.*

The conventional quantity value for ^{85}*Kr (0.031 mSv) is below the usual reporting level and below the lower detection limit (LDL) of most personal dosimetry services.*





Note: ^{85}Kr is not represented in the figure. The results are out of scale.

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EURADOS European Radiation Dosimetry Group

Eye lens dosemeter intercomparison IC2016$_{eye}$

PARTICIPANT RESULTS – photon qualities

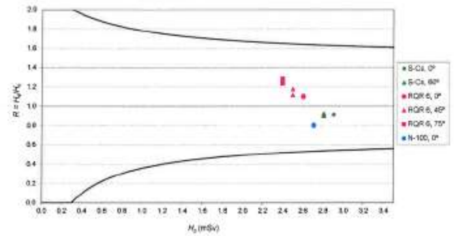
PARTICIPANT - Reference quantity $H_p(3)$ - Photon qualities									
Radiation Quality	Dosimeter id	Conventional quantity value ± uncertainty (k=2) $H_p(3)_c$ (mSv)	Reported by participant H_r * (mSv)	Reported by participant H_s ** (mSv)	Response $R = \frac{H_s}{H_p(3)_c}$	Response ISO 14146 Criteria	Mean results per set-up $\overline{H_s}$ (mSv)	Mean results per set-up $\overline{R}$	Mean results per set-up CV (R) (%)
S-Cs, 0°		2.900 ± 0.088	2.897	2.650	0.91	YES	2.639	0.91	0.0
		2.900 ± 0.088	2.875	2.628	0.91	YES			
S-Cs, 60°		2.800 ± 0.084	2.756	2.509	0.90	YES	2.540	0.91	1.6
		2.800 ± 0.084	2.817	2.570	0.92	YES			
RQR 6, 0°		2.600 ± 0.130	3.167	2.890	1.11	YES	2.876	1.11	0.6
		2.600 ± 0.130	3.139	2.862	1.10	YES			
RQR 6, 45°		2.500 ± 0.126	3.235	2.958	1.18	YES	2.880	1.15	3.7
		2.500 ± 0.126	3.078	2.801	1.12	YES			
RQR 6, 75°		2.400 ± 0.120	3.249	2.972	1.24	YES	3.021	1.26	2.2
		2.400 ± 0.120	3.346	3.069	1.28	YES			
N-100, 0°		2.700 ± 0.136	2.451	2.174	0.81	YES	2.167	0.81	0.9
		2.700 ± 0.136	2.437	2.160	0.80	YES			

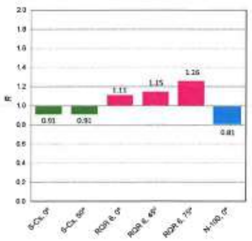
* H_r: *Participant reported value (corrected for background according to the routine protocol of the participant)*

** H_s: *Participant reported value corrected for transit.* $H_s = H_r - \overline{H_t}$

Correction for transit for S-Cs: $\overline{H_t}$ *= 0.247 mSv*

Correction for transit for other photon qualities: $\overline{H_t}$ *= 0.277 mSv*





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Individual result datasheet (3/3) IC2016$_{eye}$

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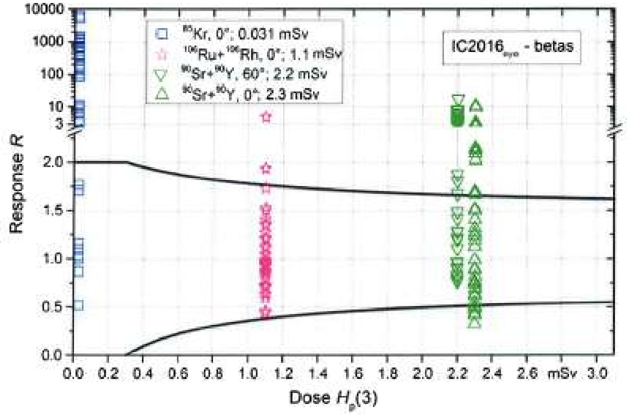
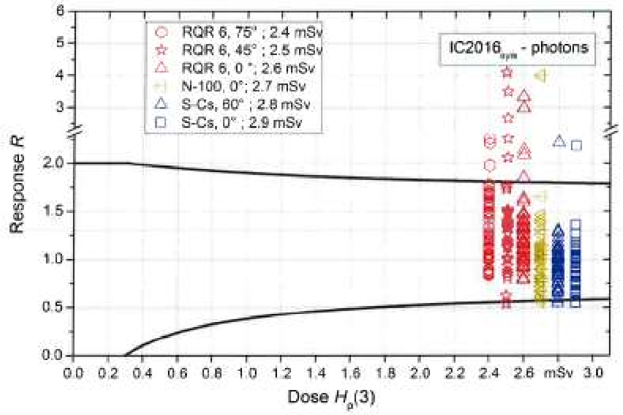
Eye lens dosemeter intercomparison IC2016$_{eye}$

GLOBAL RESULTS

Summary of all reported response values as a function of reference dose for all the participants – beta qualities



Summary of all reported response values as a function of reference dose for all the participants – photon qualities



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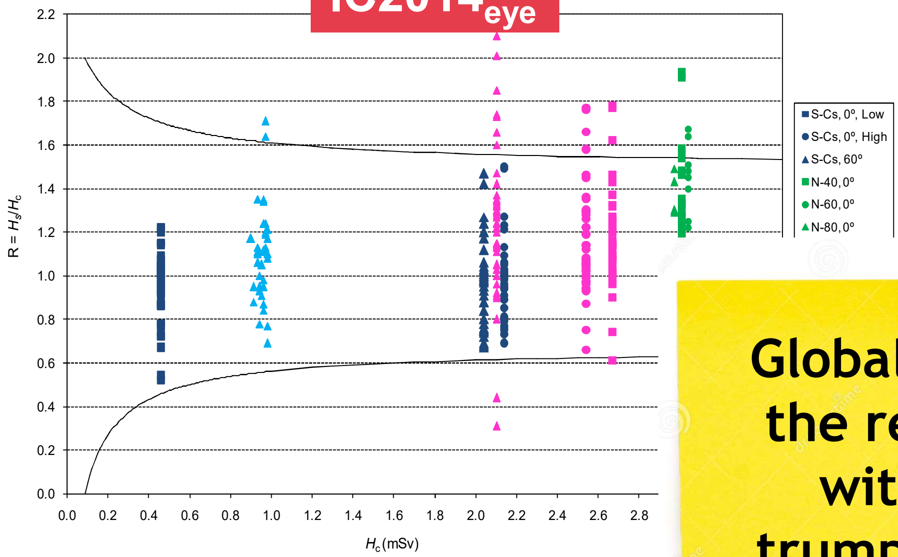
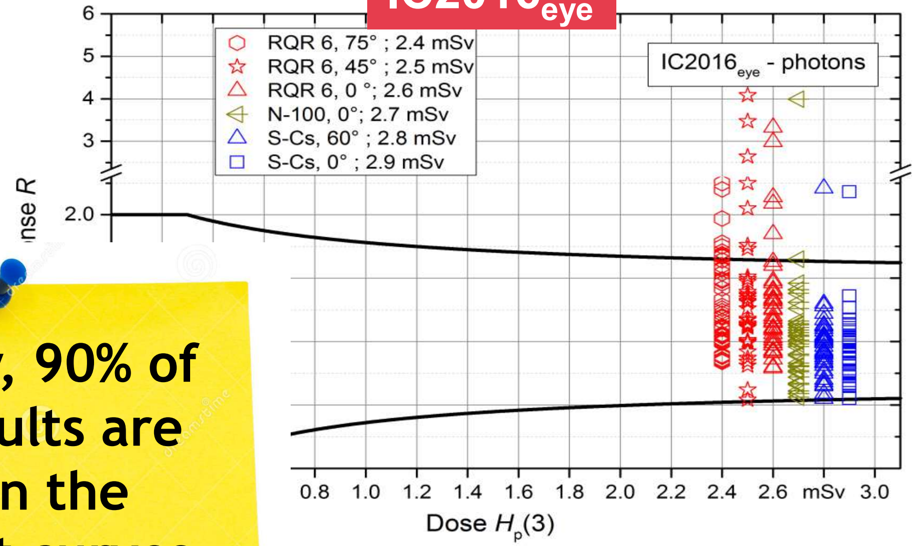
Results - photons (1/3)

IC2014eye



IC2016eye



Globally, 90% of the results are within the trumpet curves

Summary of all reported response values ... *l the participants for* ***photon qualities***.

- S-Cs: 100%
- N-80: 100%

- S-Cs: 98%
- N-100: 95%

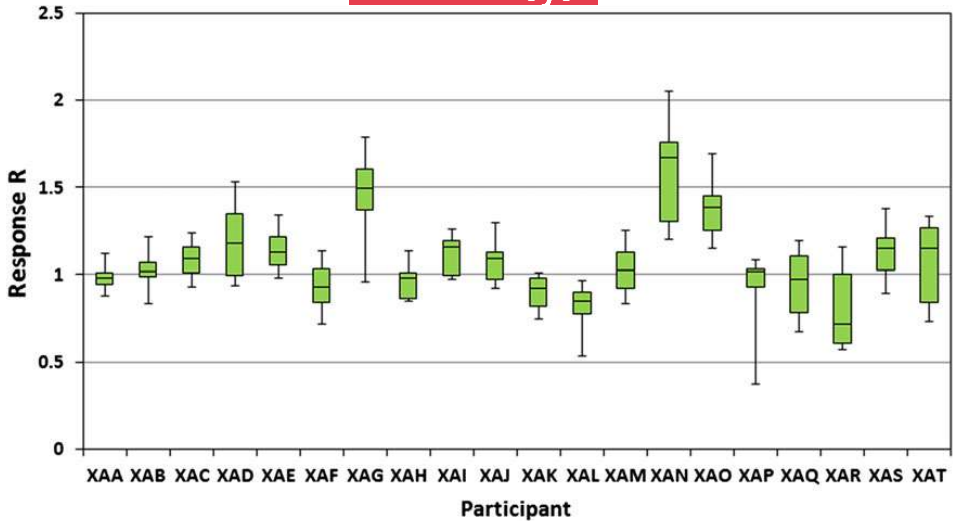
Consistent with the fact that these qualities are very often used for calibration purposes by the participants.

- Realistic field: 95%
- N-40, N-60, RQR6; 0° and 45°: 86%
- RQR6; 75°: 77% (low energy and large angle irradiation setup)

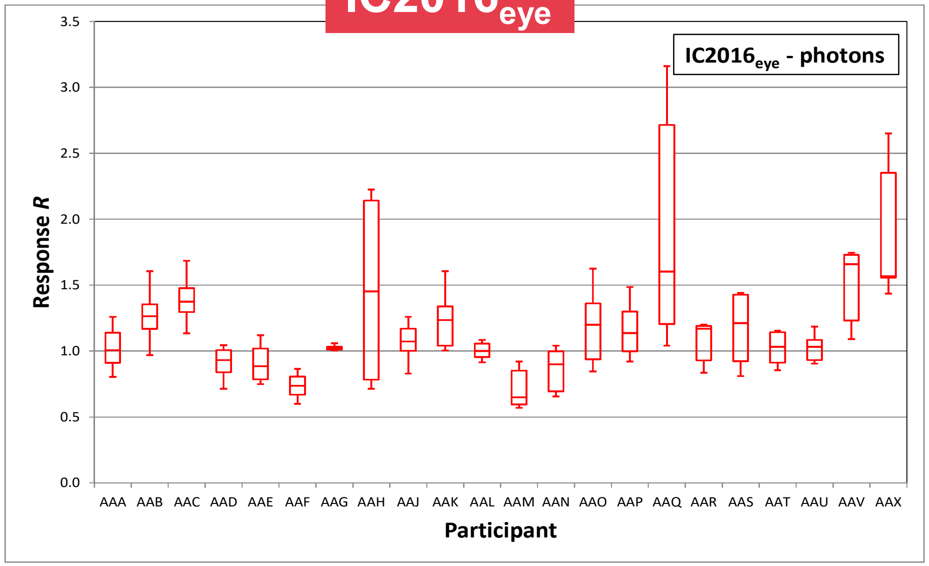
- RQR6; 0°: 89%
- RQR6; 45°: 84%
- RQR6; 75°: 77% (low energy and large angle irradiation setup)

Results - photons (2/3)

IC2014$_{eye}$



IC2016$_{eye}$



***Box plots** showing the minimum, 1st quartile, median, 3rd quartile and maximum responses **for each participant for photon qualities**.*

A relatively large variability is observed among participants, the median of responses ranges from:

- 0.7 to 1.7 in 2014,
- 0.7 to 1.6 in 2016.

Results – photons (3/3)

- The difficulties noticed for **large angle irradiation setups are more frequently observed for dosemeters placed in plastic bags**, but this is not systematic and the difficulties also occur for other types of dosemeters.

- These results **do not show any obvious link with the beam quality** used by participants **for the calibration.**

➡ *A deeper analysis cannot be carried out due the relatively low number of participants and dosemeter types considering the organizers' commitment to maintain the anonymity of results.*

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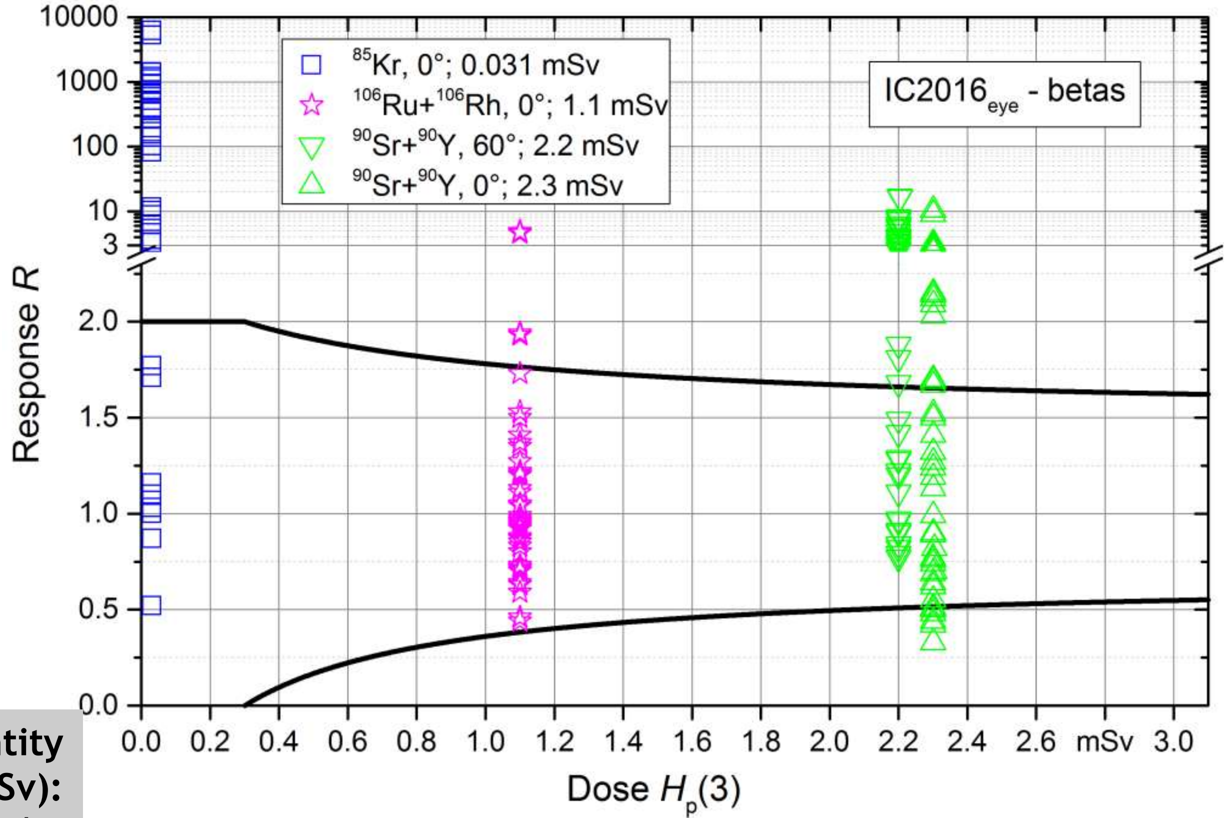
Results - betas (1/5)

In total, 56% of the results are within the trumpet curves.

- $^{106}Ru+^{106}Rh$: 91%
- $^{90}Sr+^{90}Y$: 47%
- ^{85}Kr : 41%



Summary of all reported response values R as a function of reference dose for all the participants for ***beta qualities.***

Remark: the **conventional quantity value for ^{85}Kr was low (0.03 mSv):** below the usual reporting level and the lower detection limit (LLD) of most IMS. For the **^{85}Kr irradiations, the response is considered correct for the participants who provided a measurement equal or below their LLD** (5 participants).

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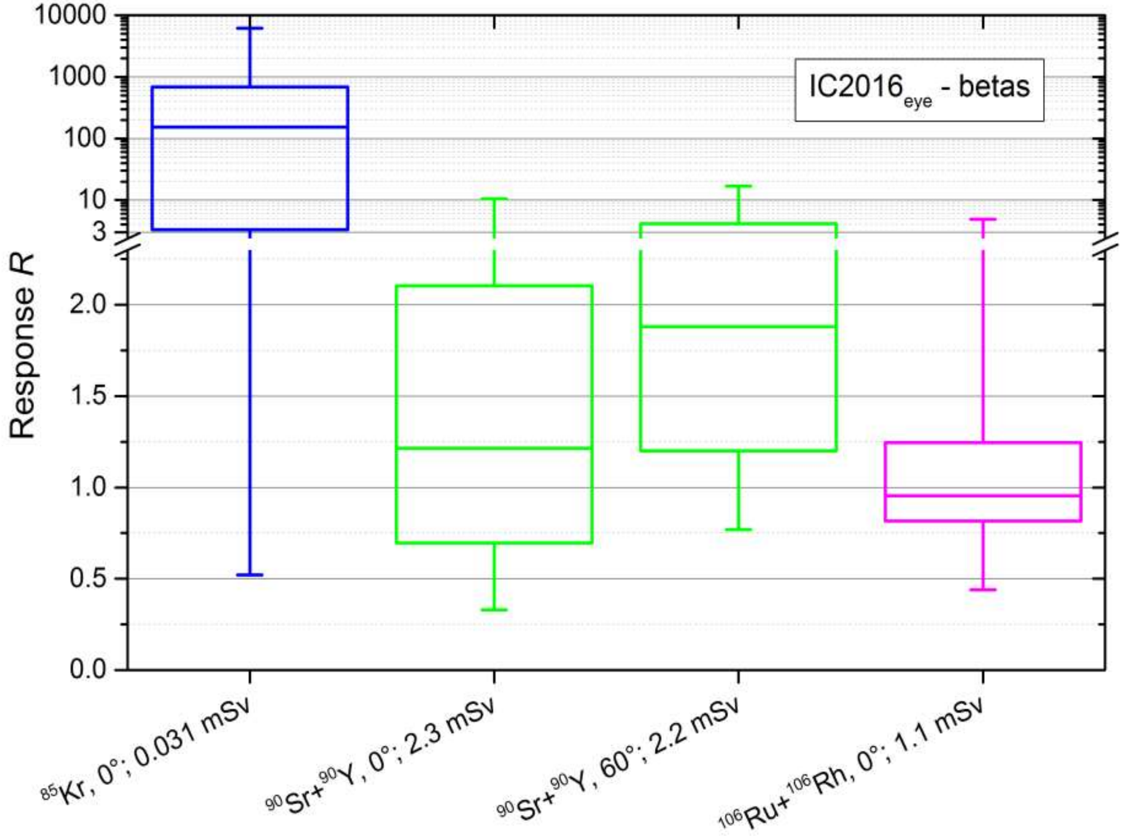
Results – betas (2/5)



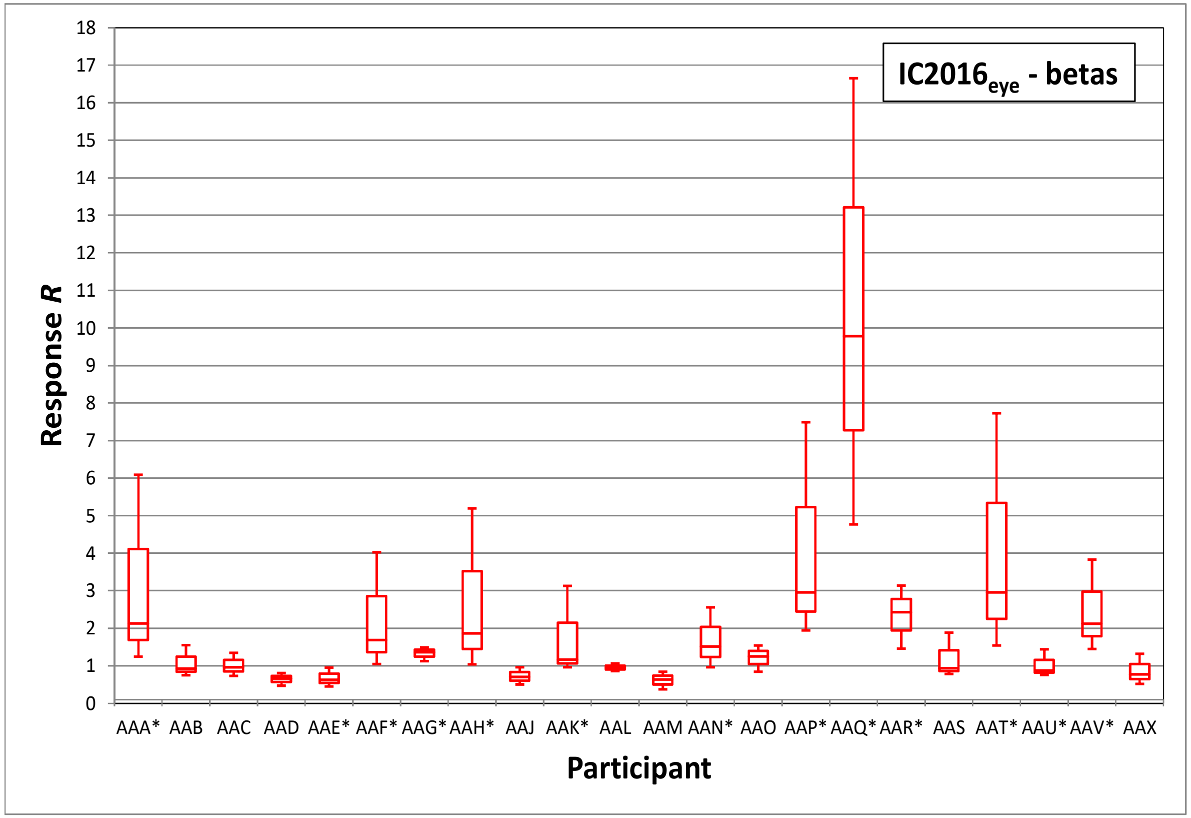
***Box plots** showing the minimum, 1st quartile, median, 3rd quartile and maximum responses **per irradiation setup <u>for beta qualities</u>**.*

The median of responses ranges from **0.96 to 1.9 for all betas setups except for ^{85}Kr** for which large overresponses are observed with a median equal to **154.**

Results - betas (3/5)

- $^{106}Ru+^{106}Rh$: **20 participants** are within the trumpet curves
- $^{90}Sr+^{90}Y$; **0°: 10 participants** within the trumpet curves
- $^{90}Sr+^{90}Y$; **60°: 8 participants** within the trumpet curves
- ^{85}Kr: **4 participants** within the limits + 5 with data below the LLD.

- Only 1 participant has 100% of results within the limits for **all setups with beta qualities**



*Box plots showing the minimum, 1st quartile, median, 3rd quartile and maximum responses **for each participant for beta qualities excluding results for ^{85}Kr**. Participants marked with * gave results outside of the trumpet curves for ^{85}Kr.*

➡ A relatively large variability is observed among participants, the median of responses ranges from 0.6 to 9.8 (to 13.5 if ^{85}Kr included).

Results - betas (4/5)

- Regarding the participants with responses outside the trumpet curves for beta beam qualities – except ^{85}Kr: **no obvious link was found with the type of dosemeter**, according to the information given by the participants.

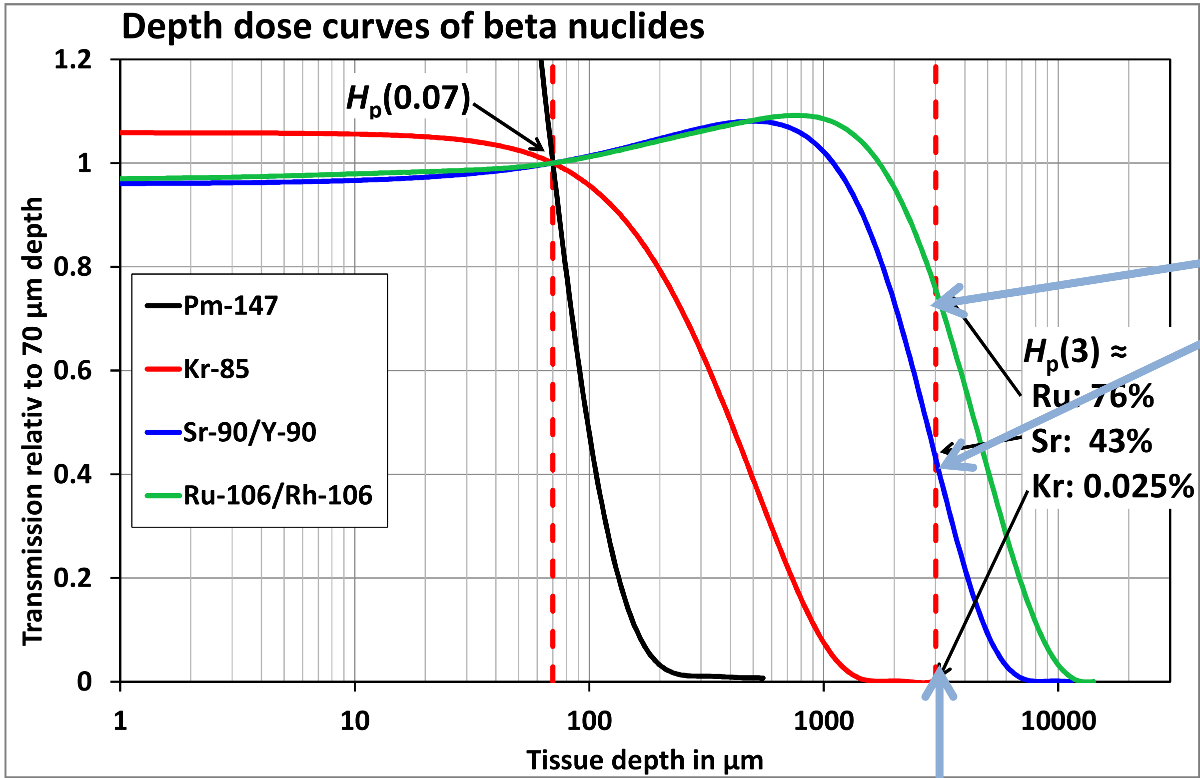
  ➡ *A deeper analysis cannot be carried out because of the obligation to maintain the anonymity of results.*

- **For ^{85}Kr radiation large overresponses are observed.**
- **All dosemeters** (except for one participant) **with an overresponse to ^{85}Kr are designed for the measurement of H_p(0.07),** this can be explained by an insufficient filter in front of the detector.

  ➡ ^{85}Kr has a beta maximum energy of about 0.69 MeV, which does not contribute to the delivered H_p(3) dose.

  ➡ For ^{90}Sr+^{90}Y and ^{106}Ru+^{106}Rh, the overresponses are lower, because betas contribute significantly to H_p(3) compared to ^{85}Kr.

Results - betas (5/5)



betas of ^{90}Sr+^{90}Y and ^{106}Ru+^{106}Rh contribute partially to $H_p(3)$

betas of ^{85}Kr do not contribute to $H_p(3)$

Behrens, JINST 6, P11007 (2011)
Behrens, JINST 6, P09006 (2011)

Conclusion

These two intercomparisons gave an overview of the different dosimetry systems currently available for eye lens dose monitoring

Results are globally satisfactory for photon qualities, whatever the type of dosemeters, since **90% of the results are in accordance to the ISO 14146 standard requirements.**
For a minority of participants, some discrepancies between the results and reference doses were observed in the case of the irradiation setups characterized by large angles and/or low energies.

Results for betas are less satisfactory and illustrate the difficulties in measuring beta radiation. The main observed problem was an over-estimate of $H_p(3)$ for low beta energy.
This intercomparison demonstrates that dosemeters designed for $H_p(0.07)$ are, in general, not suitable to monitor the dose to the eye lens in case of betas because the filter placed in front of the detector is too thin.

⇨ An intercomparison for eye lens dosemeters (and extremity dosemeters) organised by EURADOS is currently in progress: the final results will be presented during the IM conference in Budapest in April 2020.

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