*H*p(0.07) Photon and Beta Irradiations for the EURADOS Extremity Dosemeter Intercomparison 2015

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Contents

- Introduction to VSL and Ionizing Radiation Department
- Announcement EURADOS IC2015ext
- Irradiation Plan EURADOS IC2015ext
- Determination of *H*p(0.07) for photons and betas
- Conversion coefficients, *h*p(0.07) for photons and betas
- Realizing of $K_{a,ref}$ and $D_{g,ref}$
- Irradiation facilities
- Dosemeter reference point
- Set-up for angle of incidence $\alpha = 0°$ and $\alpha = 60°$
- Uncertainty and results
- Finally…

Dutch Metrology Institute

Introduction to VSL

VSL, located in Delft, near Rotterdam and The Hague, is the Netherlands' National Metrology Institute.

Measurement Standards and Accreditation

Available measurement standards for:

***Chemistry, Electricity, Ionizing radiation, Mass, Pressure & Viscosity, Length, Thermometry & Humidity, Optics, Time & Frequency, Pressure gas and Liquid flow*.**

CIPM MRA

Via the Mutual Recognition Arrangement (MRA), it was established that VSL's measurement standards and the measurement results would be internationally accepted.

KALIBRATIE RvA K 999

Referentie Mat. RvA P 002

K999: Implementation of calibrations (ISO/IEC 17025:2005)

P002: Production and certification of reference materials (ISO Guide 34:2009)

PROF. TESTING RvA R 006

R006: Organisation and implementation of inter-laboratory investigations (ISO/IEC 17043:2010)

Introduction to Ionizing Radiation Department

The Ionizing Radiation Department offers a wide range of services in the field of ionizing radiation.

Primary standard (transportable water-calorimeter) for calibrations in terms of Co-60 absorbed dose to water at 5 g/cm².
Best U = 0.8 % (k = 2)

Calibration of Well-Type ionization chambers in *RAKR* for Ir-192 HDR and PDR sources.
Best U = 2 % (k = 2)

VSL

Introduction Ionizing Radiation Department

A parallel-plate free-air-chamber serves a primary air-kerma standard for x-rays to 320 kV. Radiation qualities available according to ISO 4037 and IEC 61267.
Best U = 1 % (k = 2).

For radiation protection purposes a low scatter facility is available for air-kerma rates from 300 nGy/h to 0.5 Gy/h for Cs-137 and Co-60. Collimated with a conical ring collimator according ISO 4037.
Best U = 1.5 % (k = 2)

At present characterising a well-type ionization chamber and develops methods to serve as a secondary standard . I-125 LDR seeds for Brachytherapy and I-124 for PET-CT purposes.

Announcement of the EURADOS IC2015 extremity dosemeters

European Radiation Dosimetry Group — EURADOS

Announcement of the EURADOS Intercomparison 2015 for extremity dosemeters

Over the last decade EURADOS, through its Working Group 2 (WG2), has been carrying out a programme of work on harmonisation of individual monitoring in Europe. WG2 Subgroup 2 was established specifically to carry out a feasibility study for a programme of self-sustained Individual Monitoring Service (IMS) intercomparisons in Europe with the aims of improving the harmonization of individual monitoring and helping the IMS to comply with ISO 17025. Following the feasibility study, EURADOS established an Organization Group to start the programme. The 2008, 2010, 2012 and 2014 intercomparisons for whole body dosemeters and the 2009 intercomparison for extremity dosemeters have been completed. EURADOS now has the pleasure of announcing the 2015 intercomparison (IC2015ext) for extremity dosemeters.

Scope

The 2015ext intercomparison concerns to extremity dosemeters intended to estimate $H_p(0.07)$. The dosemeters may be of type ring, stall or wrist, designed to be worn on fingers, wrist or ankle, and are used *routinely* in individual monitoring of exposed workers.

Irradiations, restricted to photons and betas, will be performed in European irradiation facilities in terms of $H_p(0.07)$ in the following ranges:

- Photon energy: 16 to 662 keV
- Beta mean energy: 250 to 1000 keV
- Dose: 0,5 mSv to 1 Sv
- Angle of incidence: ± 60°

The dosemeters will be irradiated with both photon and beta sources but the participant may choose to include only the results for photons or betas in the Certificate of Participation by marking this option in the application form.

Intercomparison procedure

IMS wishing to participate will complete the application form which can be accessed after registration on the IC2015ext on-line platform (IOP). The participating IMS will be informed when their application has been accepted.

On acceptance of the application, the participants will receive an invoice from EURADOS and instructions for dosemeter labelling and despatch.

The participation fee is 1250 Euro per dosimetry system. EURADOS sponsors will pay 1125 Euro for one system and 1250 Euro for any additional systems. Fees must be transferred in advance to the EURADOS bank account (free of bank transfer costs) after receiving the invoice from EURADOS. Refunding will only be possible in the unlikely event that the intercomparison is cancelled by EURADOS.

The fees have been calculated on a non-profit base and any surplus money will be used to support the harmonisation of individual monitoring and maintaining expertise in this field within EURADOS.

EURADOS e.V. is registered in the Register of Associations (Amtsgericht Braunschweig, registry number VR 200387) and certified to be of non-profit character (Finanzamt Braunschweig-Altewiekring, notification from 2008-03-03).

Web site: http://www.eurados.org | e-mail: office@eurados.org

Executive board:
Werner Rühm (Chairperson)
Filip Vanhavere (Vice Chairperson)

Version 1.0 – April 2015

Irradiations, restricted to photons and betas, will be performed in European irradiation facilities in terms of *H*p(0.07) in the following ranges:

- Photon energy: 16 to 662 keV
- Beta mean energy: 250 to 1000 keV
- Dose: 0.5 mSv to 1 Sv
- Angle of incidence: ± 60°

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Irradiation Plan: Conditions and Requirements

- The Irradiation Plan were developed by WG2 and described in the EURADOS IC2015ext Irradiation Plan,
- The Coordinator arranged the transit (by car) between Seibersdorf Lab and VSL,
- The irradiation lab did <u>not</u> know the participants,
- Radiation qualities, radiation fields and irradiations according to ISO and IEC standards,
- ISO Rod phantom for finger tip and ring dosemeters,
- ISO Pillar phantom for ankle/wrist dosemeters,
- Per system a random choice of which dosemeters for each irradiation,
- Random varied of delivered *H*p(0.07) within the range of the irradiation plan.

Irradiation plan: Radiation Qualities

Radiation type	Radiation quality	E_{mean} or β_{max} keV	According to	Angle of incidence, α	Number of dosemeters	Range $Hp(0.07)$ mSv
Photon	W-80	57	ISO 4037	0°	4	15 - 25
Photon	RQR 3	33	IEC 61267	0°	2	15 - 25
Photon	RQR 3	33	IEC 61267	60°	2	15 - 25
Photon	RQR 9	57	IEC 61267	0°	2	15 - 25
Photon	RQR 9	57	IEC 61267	0°	2	300 - 600
Photon	S-Cs	662	ISO 4037	0°	2	5 - 10
Photon + Beta	S-Cs + Sr-90/Y-90	662 + 2274	ISO 4037 + ISO 6980	0°	2	2 - 5
Beta	Sr-90/Y-90	2274	ISO 6980	0°	2	5 - 10
Beta	Sr-90/Y-90	2274	ISO 6980	60°	2	5 - 10
Beta	Kr-85	687	ISO 6980	0°	2	5 - 10

Irradiation Plan: ISO and IEC Standards

ISO 6980
Nuclear energy – Reference beta-particle radiation
Part 1 and Part 2

ISO 4037
X and gamma reference radiation for calibrating dosemeters and doserate meters and for determining their response as a function of photon energy; Part 1 and Part 3

ISO 12794
Nuclear energy – Radiation protection – Individual thermoluminescence dosemeter for extremities and eyes

ISO 29661
Reference radiation fields for radiation protection – Definitions and fundamental concepts

IEC 61267
Medical diagnostic X-ray equipment – Radiation conditions for use in the determination of characteristics

Irradiation Plan: ISO Phantoms

For ankle/wrist dosemeters:
The ISO Pillar phantom (center) is a water-filled hollow cylinder with PMMA walls an outer diameter of 73 mm and a length of 300 mm.
The cylinder walls have a thickness of 2.5 mm and the end faces have a thickness of 10 mm.

For ring and finger tip dosemeters:
The ISO Rod phantom (right) is a solid PMMA cylinder of 19 mm diameter and a length of 300 mm.

(The ISO water slab phantom (left) is intended for whole-body dosemeters. Not used in EURADOS IC2015ext.)

Determination of *H*p(0.07) - Photons

$$Hp(0.07) = K_{a,ref} \cdot h_{p,K}(0.07;E,\alpha) \cdot \Delta t \cdot k_{decay} \cdot k_{attenuation}$$

$Hp(0.07)$	:	is the personal dose equivalent at 0.07 mm tissue, Sv;
$K_{a,ref}$	:	is the reference air-kerma rate, Gy/s;
$h_{p,K}(0.07;E,\alpha)$	:	is the corresponding conversion coefficient for the photon energy *E*, Sv/Gy;
Δt	:	is the irradiation time, s;
k_{decay}	:	is the correction factor for decay (S-Cs);
$k_{attenuation}$	:	is the correction factor for air-attenuation (S-Cs)

Determination of *H*p(0.07) - Betas

$$Hp(0.07) = D_{g,ref} \cdot h_{p,D}(0.07;E,\alpha) \cdot \Delta t \cdot k_{decay}$$

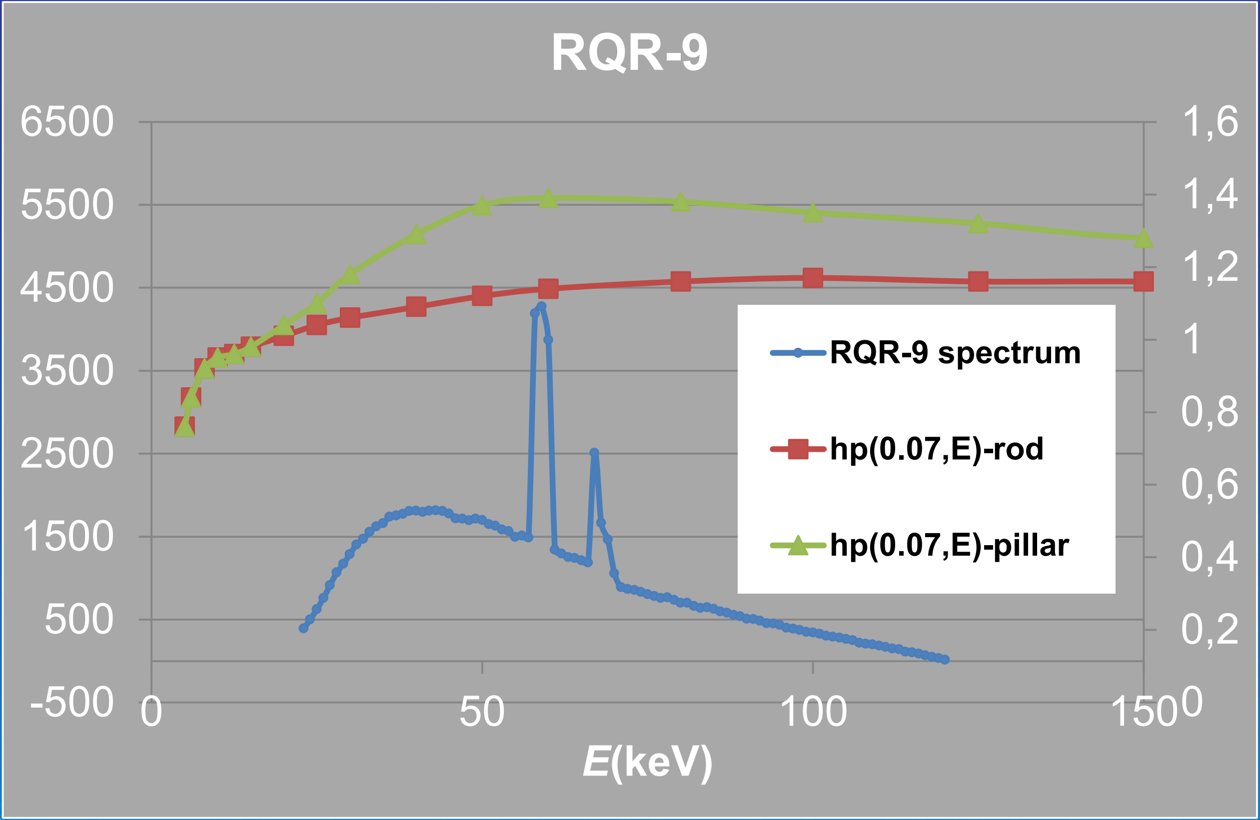
$Hp(0.07)$	:	is the personal dose equivalent at 0.07 mm tissue, Sv;
$D_{g,ref}$	:	is the reference absorbed dose rate at 0.07 mm tissue, Gy/s;
$h_{p,D}(0.07;E,\alpha)$	:	is the corresponding conversion coefficient for the beta energy E, Sv/Gy;
Δt	:	is the irradiation time, s;
k_{decay}	:	is the correction factor for decay.

Used Conversion Coefficients, *h*p

Radiation quality	Angle of incidence, α	Rod $h_{p,K}(0.07;E,\alpha)$ Sv/Gy	Pillar $h_{p,K}(0.07;E,\alpha)$ Sv/Gy	Conversion coefficients adopted from
W-80	0º	1.13 ± 4 %	1.36 ± 4 %	ISO 4037-3
RQR 3	0º 60º	1.07 ± 4 %	1.20 ± 4 %	VSL spectrum
RQR 9	0º	1.12 ± 4 %	1.33 ± 4 %	VSL spectrum
S-Cs	0º	1.12 ± 4 %	1.15 ± 4 %	ISO 12794

Radiation quality	Angle of incidence, α	Rod $h_{p,D}(0.07;E,\alpha)$ Sv/Gy	Pillar $h_{p,D}(0.07;E,\alpha)$ Sv/Gy	Conversion coefficients adopted from
Kr-85	0º	1.00 ± 4 %	1.00 ± 4 %	ISO 6980-3
Sr-90/Y-90	0º 60º	1.00 ± 6 % 1.16 ± 6 %	1.00 ± 4 % 1.16 ± 4 %	ISO 6980-3

$h_{p,K}(0.07;E,\alpha)$ for RQR 3 and RQR 9 (example RQR-9)



Rod:

RQR-3 = 1.07 Sv/Gy

RQR-9 = 1.12 Sv/Gy

Pillar:

RQR-3 = 1.20 Sv/Gy

RQR-9 = 1.33 Sv/Gy

Uncertainty 4 %

Mono energetic conversion factors weighted over the measured spectrum
Data from ISO 4037

Realizing of $K_{a,ref}$ and $D_{g,ref}$

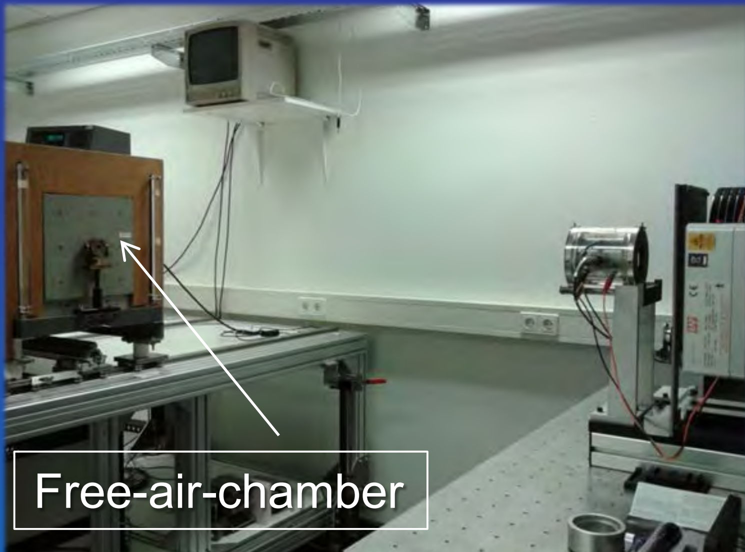
For W-80, RQR3, and RQR9, the quantity air-kerma was realized with the VSL primary air-kerma standard (free-air-chamber) with a standard uncertainty of 0.48 %.

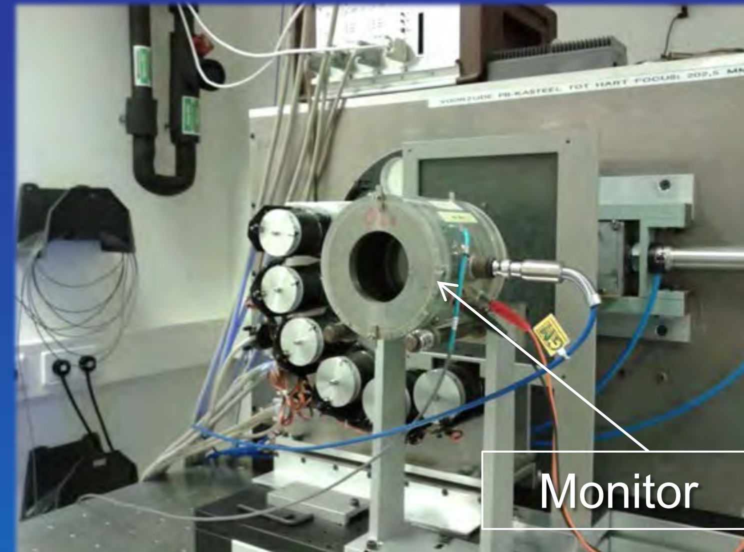
For S-Cs the quantity air-kerma was realized with the VSL primary air-kerma standard (cavity ionization chamber) with a standard uncertainty of 0.75 %.

For ^{90}Sr/^{90}Y beta rays a Buchler BSS-1 was used. The BSS-1 is traceable to PTB. The standard uncertainty in the quantity $D_g(0.07)$ is 1.2 %.

For ^{85}Kr beta rays an ISOTrak BSS-2 were used. The BSS-2 is traceable to PTB. The standard uncertainty in the quantity $D_g(0.07)$ is 0.8 %.

Facility for X-rays 320 kV





HV-generator : Philips MG324 320 kV CP
X-ray tube : Philips MC321, 4 mm Be, W-anode (26^o).
HV calibration : HPGe-spectrometer, uncertainty 1.1 %.

The primary x-ray beam was collimated by two tungsten diaphragms to define a homogeneous circular field. The monitor is an unsealed transmission ionization chamber.

Facility for Cs-137 and Co-60

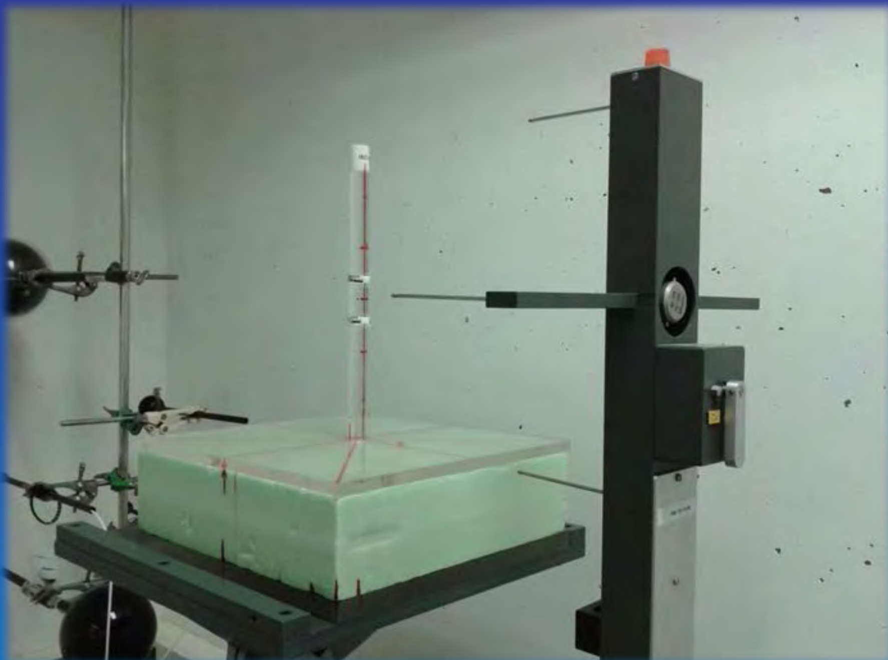
Available air-Kerma rate:
Cs-137: 300 nGy/h – 0.5 Gy/h
Co-60: 300 nGy/h – 0.2 Gy/h

Conversion coefficients for *H*p(d) and *H**(10) adopted from ISO 4037 and ISO 12794.

For the irradiations with S-Cs a low scatter collimated-beam facility from Veenstra Instruments, type DIR-101, was used.
*H*p(0.07) nominal = 150 mSv/h

The primary gamma ray beam is collimated with a conical ring collimator according to ISO 4037.

Buchler/PTB BSS-1 Sr-90/Y-90 Facility

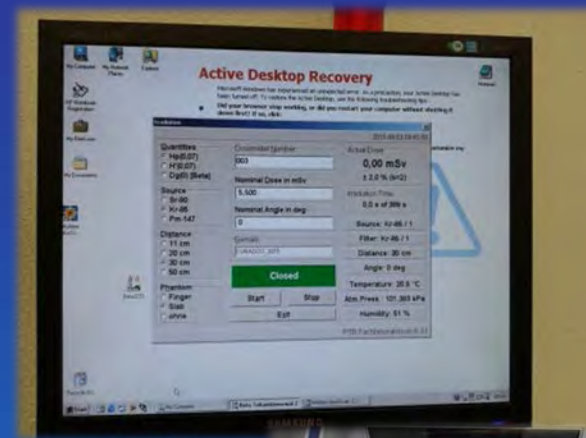


Sr-90/Y-90 source
Nr. 23/50mCi fitted in the source stand. (No beam-flattening filter)

The BSS-1 complies with the recommendations of ISO 6980 for series 2 reference radiation fields.

*D*g(0.07) nominal: 120 mGy/h

ISOtrak/PTB BSS-2 Kr-85 Facility



The BSS-2 complies with the recommendations of ISO 6980 for series 1 reference radiation fields. *D*g(0.07) nominal: 50 mGy/h

The irradiations with Kr-85 were carried out in the laboratory of LCW in Dongen (NL). (Sep 2, 2015 – Sep 9, 2015)

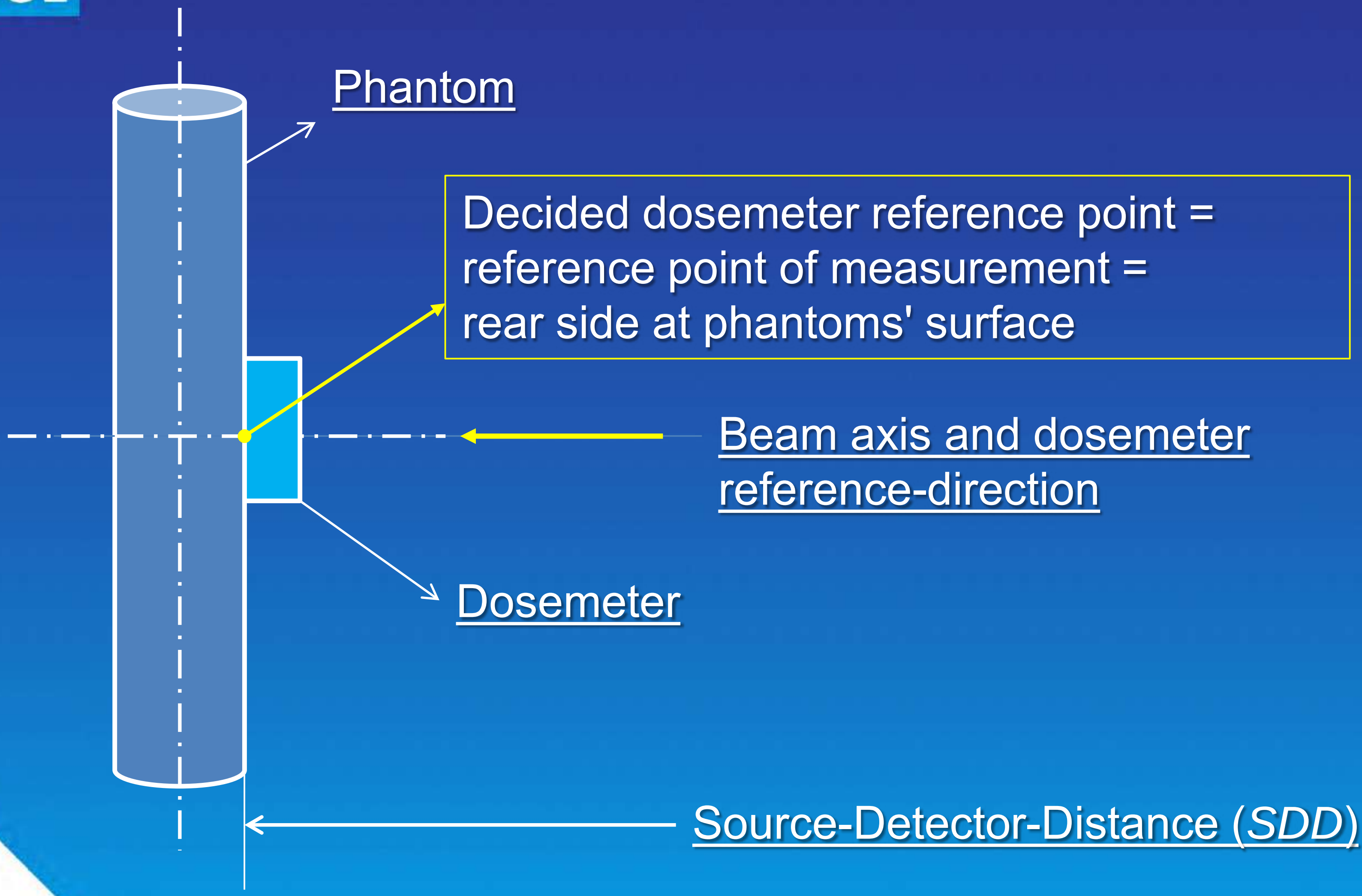
Dosemeter Reference Point

The location of the dosemeter reference point was not always specified by the participant’s application form.

Decided: reference point at the rear-side of the dosemeter and position in the point of measurement (= phantoms’ surface at *SDD*).

- Differences are 5 mm at maximum and were considered in the uncertainty budget,
- Adjustments in positioning between irradiations were not necessary.

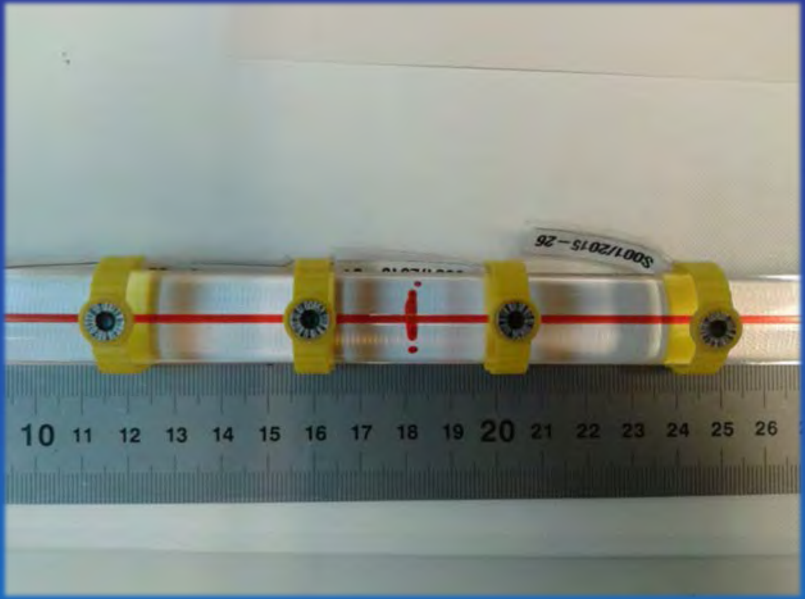
Dosemeter Reference Point

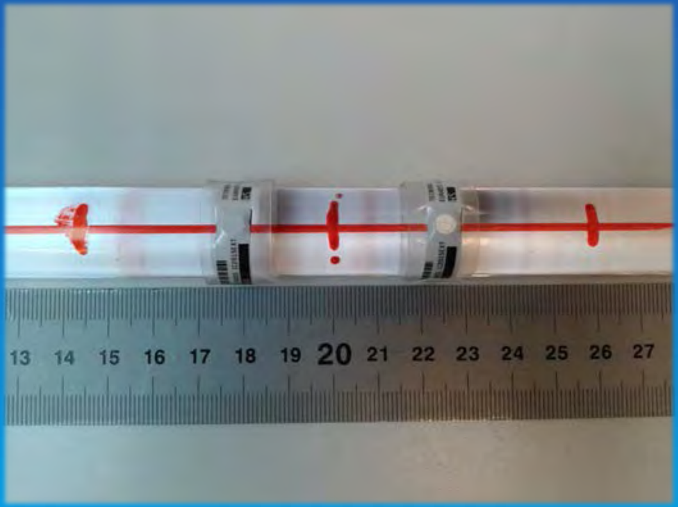


Intensive Care Room

Preparation of the phantoms and dosemeters at VSL and LCW.

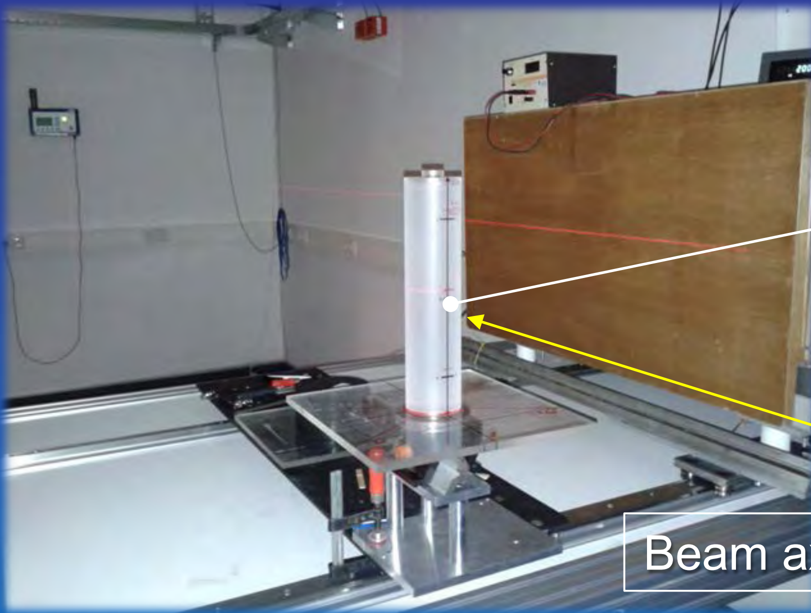
Preparing of the Phantoms

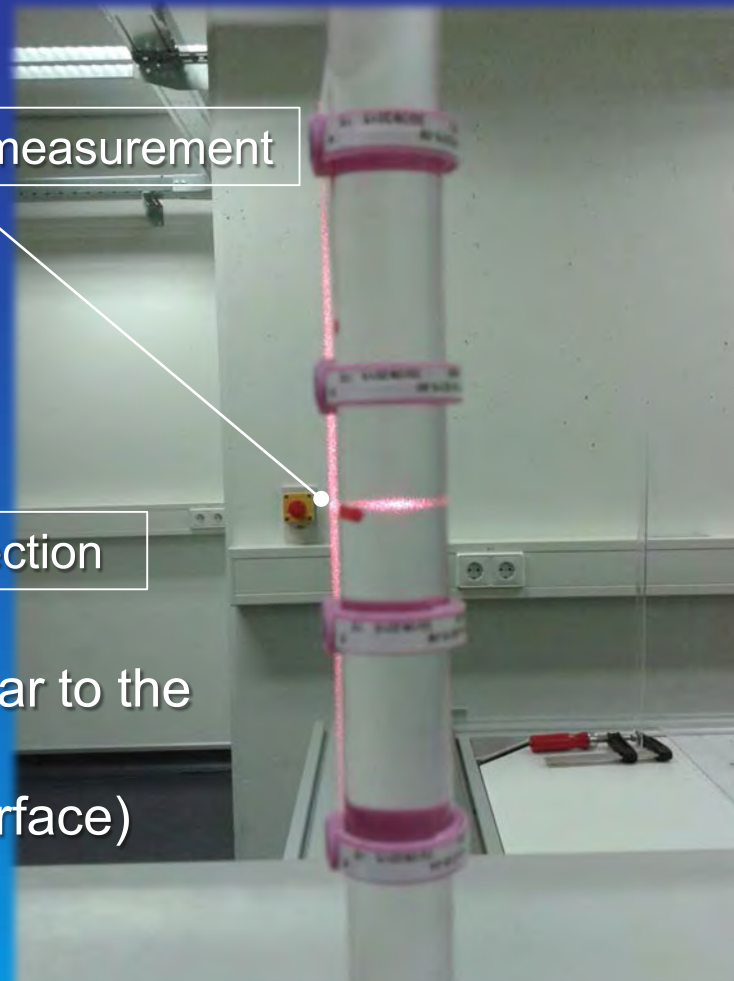




The dosemeters were fixed with a mutual center-to-center distance of approximately 40 mm.

Set-Up for X-rays (0°)





Point of measurement

Beam axis and direction

The phantom was positioned perpendicular to the beam axis.
The point of measurement (phantom's surface) was aligned with cross-lasers.

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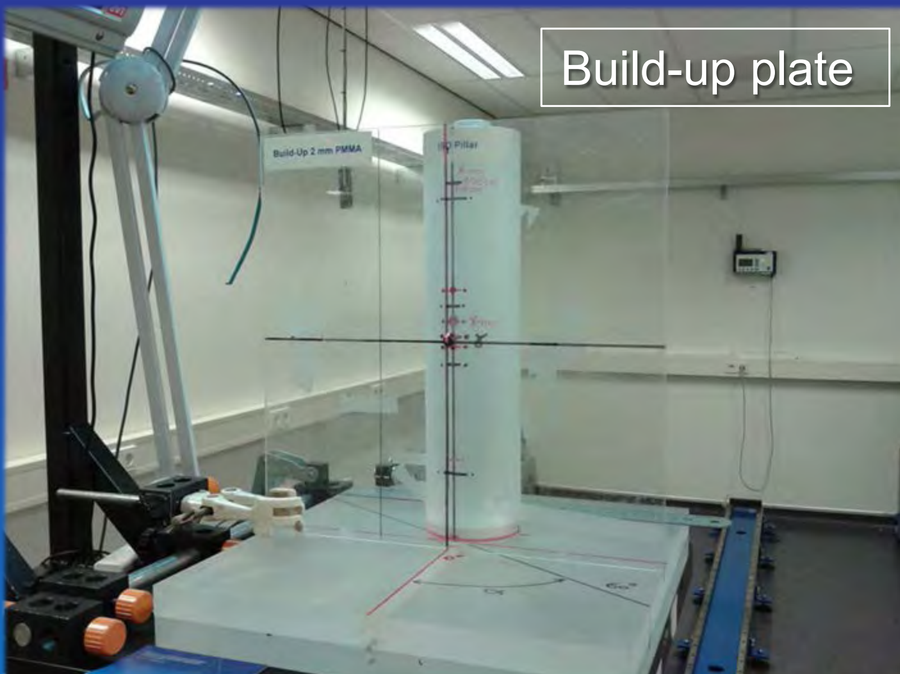
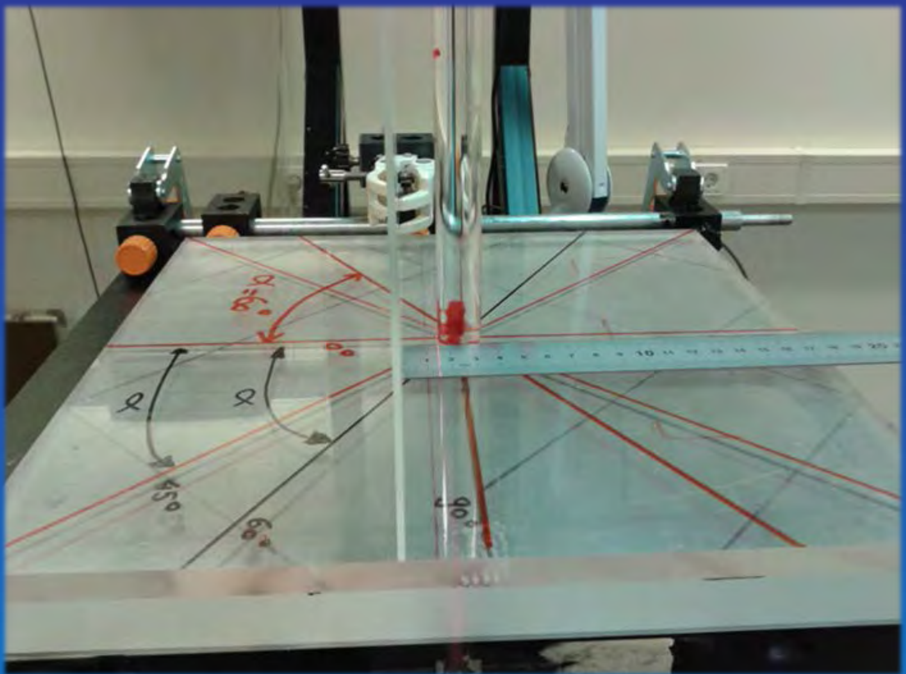
Set-up for S-Cs

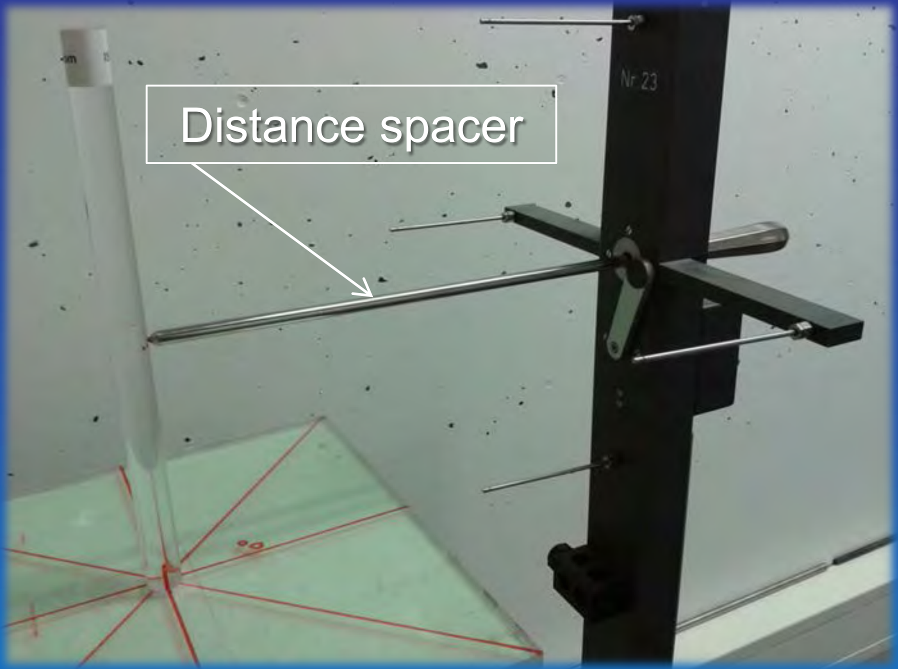


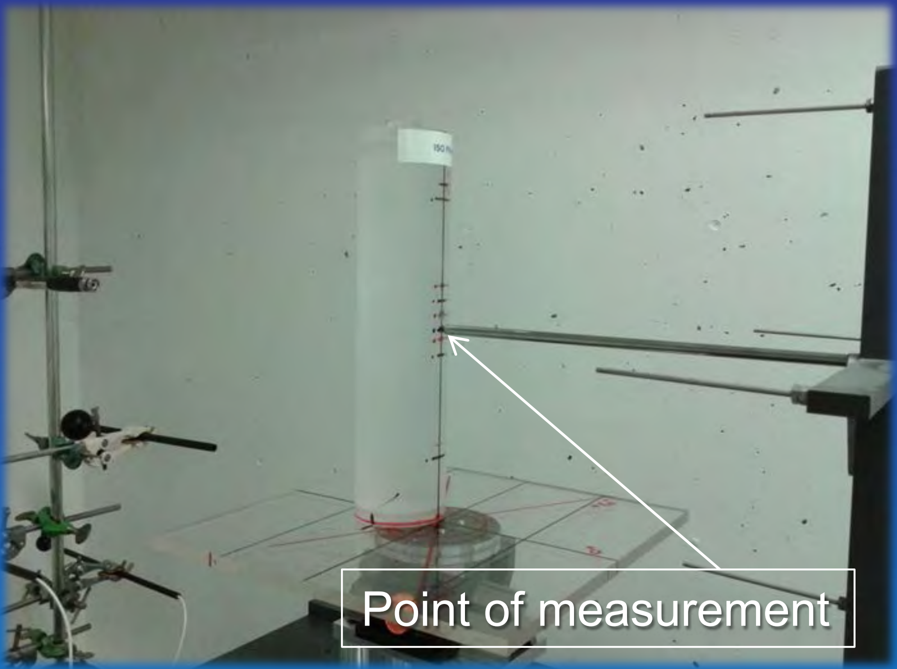


According to ISO 4037 a PMMA build-up plate of 2 mm thickness was used.

The distance between the build-up plate and the front surface of the phantom was approximately 15 mm.

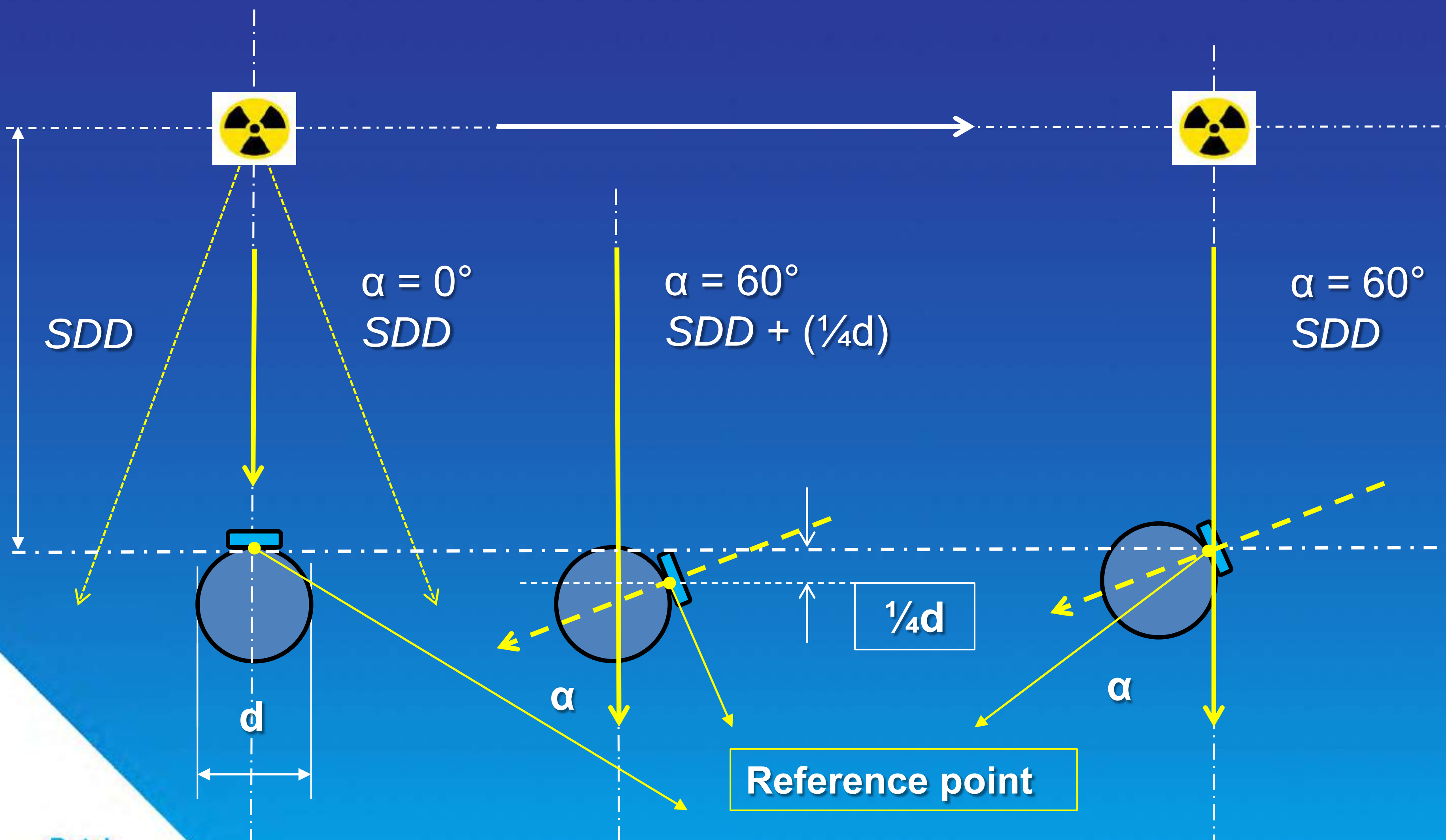
Set-up for Sr-90 and Kr-85 (0°)



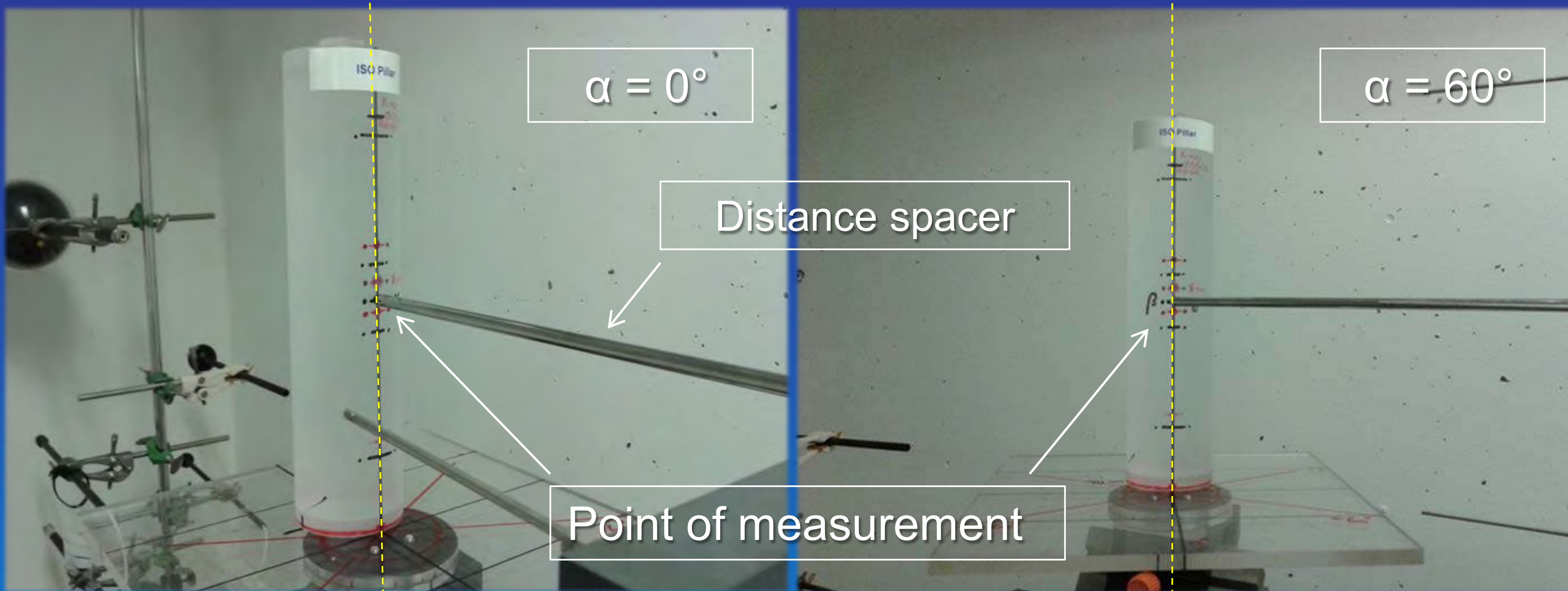


Alignment of the point of measurement (phantom's surface) at the source-detector-distance (*SDD*) of 30 cm with the distance spacer.

Set-Up for Angle of Incidence, α = 60°

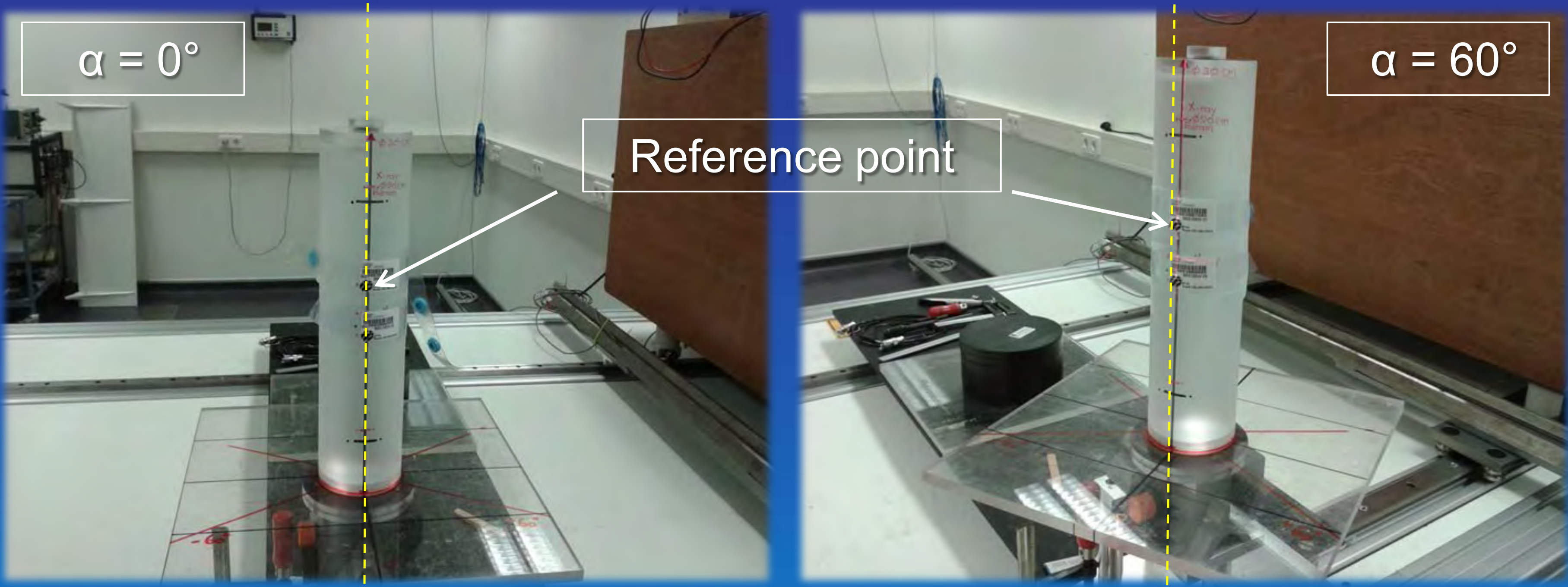


Set-Up for Sr-90/Y-90 and α = 60°



Moving from 0° to 60° and aligned the reference point at the point of measurement using the distance spacer at *SDD.* (Same for the Rod phantom).

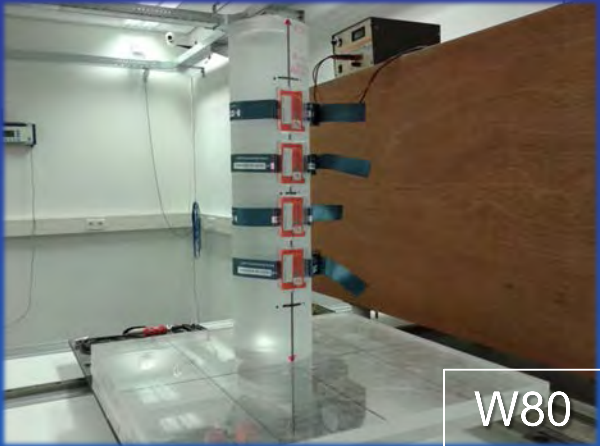
Set-Up for RQR3 and α = 60°

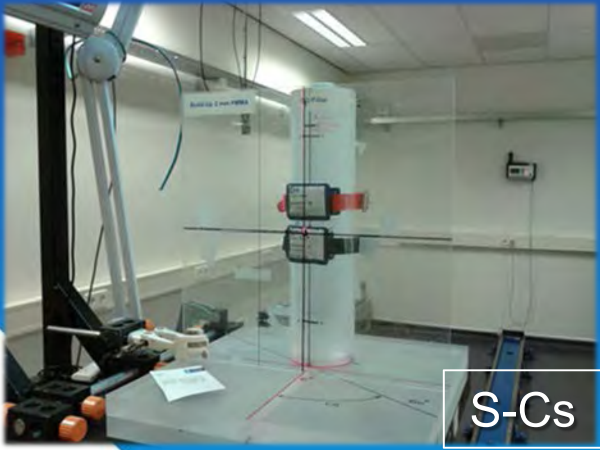


Moving the pillar from 0° to 60° and aligned the reference point with a X- and Y-translation and cross-lasers at the point of measurement.

VSL

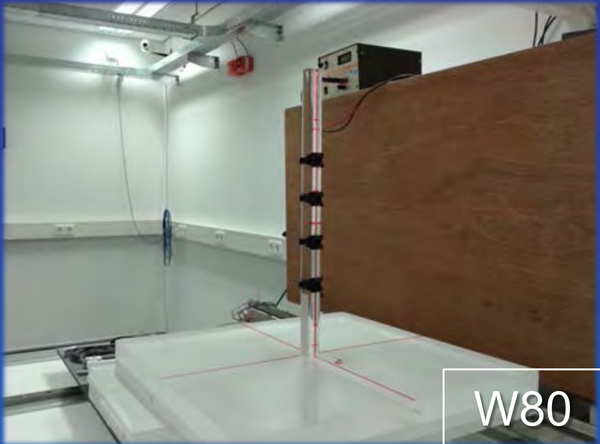
Impression of the Irradiations
Pillar

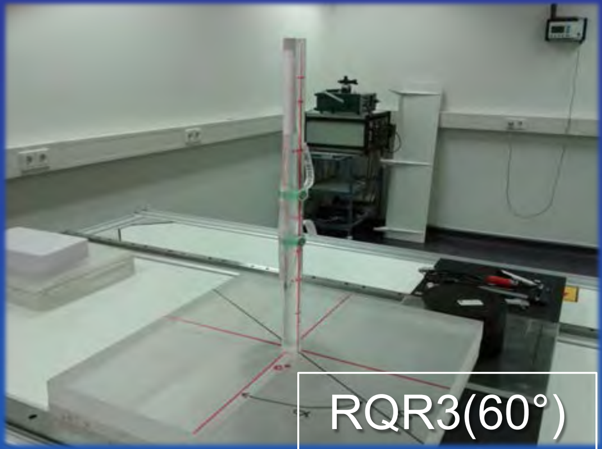




(Random picture choice)

Impression of the Irradiations
Rod





(Random picture choice)

Uncertainty in *H*p(0.07)

Mainly:

- Standard uncertainty of the conversion coefficients; 2 % for photons to 3 % for Sr-90/Y-90 and the rod.
- Set-up at the *SDD* for betas: standard uncertainty of 2 %.
- Use of a PMMA build-up plate for S-Cs; standard uncertainty of 1 %.

Neglected:

- The mutual influence of dosemeters (two or four) in a simultaneous irradiation.

Determined:

- In accordance with the GUM ’Evaluation of measurement data – Guide to the expression of uncertainty in measurement’.

Reported Uncertainty in *H*p(0.07)

Irradiation	Phantom	Uncertainty at *k* = 2
W80	pillar and rod	4.6 %
RQR3	pillar and rod	4.6 %
RQR3(60°)	pillar and rod	4.6 %
RQR9-L	pillar and rod	4.6 %
RQR9-H	pillar and rod	4.6 %
S-Cs	pillar and rod	5.0 %
Mix	pillar	4.2 %
Mix	rod	4.8 %
Sr-90	pillar	6.8 %
Sr-90	rod	8.1 %
Sr-90(60°)	pillar	6.8 %
Sr-90(60°)	rod	8.1 %
Kr-85	pillar and rod	6.0 %

Period of Irradiation and Storage

July 12, 2015 : arrival first batch from Seibersdorf Lab,
August 28, 2015 : arrival second batch from Seibersdorf Lab,
September 18, 2015 : return to Seibersdorf Lab.

All dosemeters were stored in the control room of the laboratory.
Background radiation varied between 90 nSv/h and 120 nSv/h.
EPD measurement (almost 70 days): 0.12 mSv

During storage and irradiation:

Temperature	: 19 ^{o}C and 22 ^{o}C,
Atmospheric pressure	: 99 kPa and 103 kPa,
Relative humidity	: 45 % and 55 %.

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Finally…

I know what I did last summer…

receiving 2190 dosemeters,

803 irradiations (and pictures),

1606 irradiated dosemeters,

Consuming of a few rolls of Scotch adhesive tape,

tie wraps and elastic bands,

a lot of patience,

and lessons to learn…

Unfortunately wrong irradiated:

2 systems: 2 dosemeters

1 system: 6 dosemeters

…73 Certificates of Irradiation

VSL

CERTIFICATE OF IRRADIATION

Number 3320674.Sxxx-2015
Page 1 of 1

Applicant European Radiation Dosimetry Group e.V.
IC2015$_{ext}$ organisation group

Participant System identification: Sxxx/2015

Subject EURADOS Intercomparison IC2015$_{ext}$
Photon and beta irradiation of personal extremity dosemeters in the quantity personal dose equivalent, *Hp*(0.07).

Submitted 30 passive personal extremity dosemeters delivered by the participant.
Dosemeter identification: Sxxx/2015-01 to Sxxx/2015-30.

Irradiation plan and period of storage The personal extremity dosemeters were irradiated in the quantity personal dose equivalent, *Hp*(0.07), according to the EURADOS IC2015$_{ext}$ irradiation plan. A detailed explanation of the irradiation plan and the method of irradiation are described on the following pages of this certificate. Between July 12, 2015 (date of arrival first batch) and August 28, 2015 (date of arrival second batch) and September 18, 2015 (date of dispatch) all dosemeters were stored in the control room of the laboratory. During storage and irradiation the environmental conditions were as follows: temperature between 19 °C and 21 °C, atmospheric pressure between 99 kPa and 103 kPa and relative humidity between 45 % and 55 %. During storage the background radiation dose rate (Cs-137 ambient dose equivalent) in the control room varied between 90 nSv/h and 120 nSv/h.

Date of irradiation See table 4 of this certificate.

Result The results of the irradiations are shown on page 5 of this certificate.
The reported uncertainty of measurement is based on the standard uncertainty of measurement multiplied by a coverage factor k = 2, which for a normal distribution corresponds to a coverage probability of approximately 95 %. The standard uncertainty of measurement has been determined in accordance with the GUM 'Evaluation of measurement data - Guide to the expression of uncertainty in measurement'.

Traceability The results of the irradiation services are traceable to primary and/or (inter)nationally accepted measurement standards.

Delft, 25 January 2016
VSL B.V.

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CERTIFICATE OF IRRADIATION

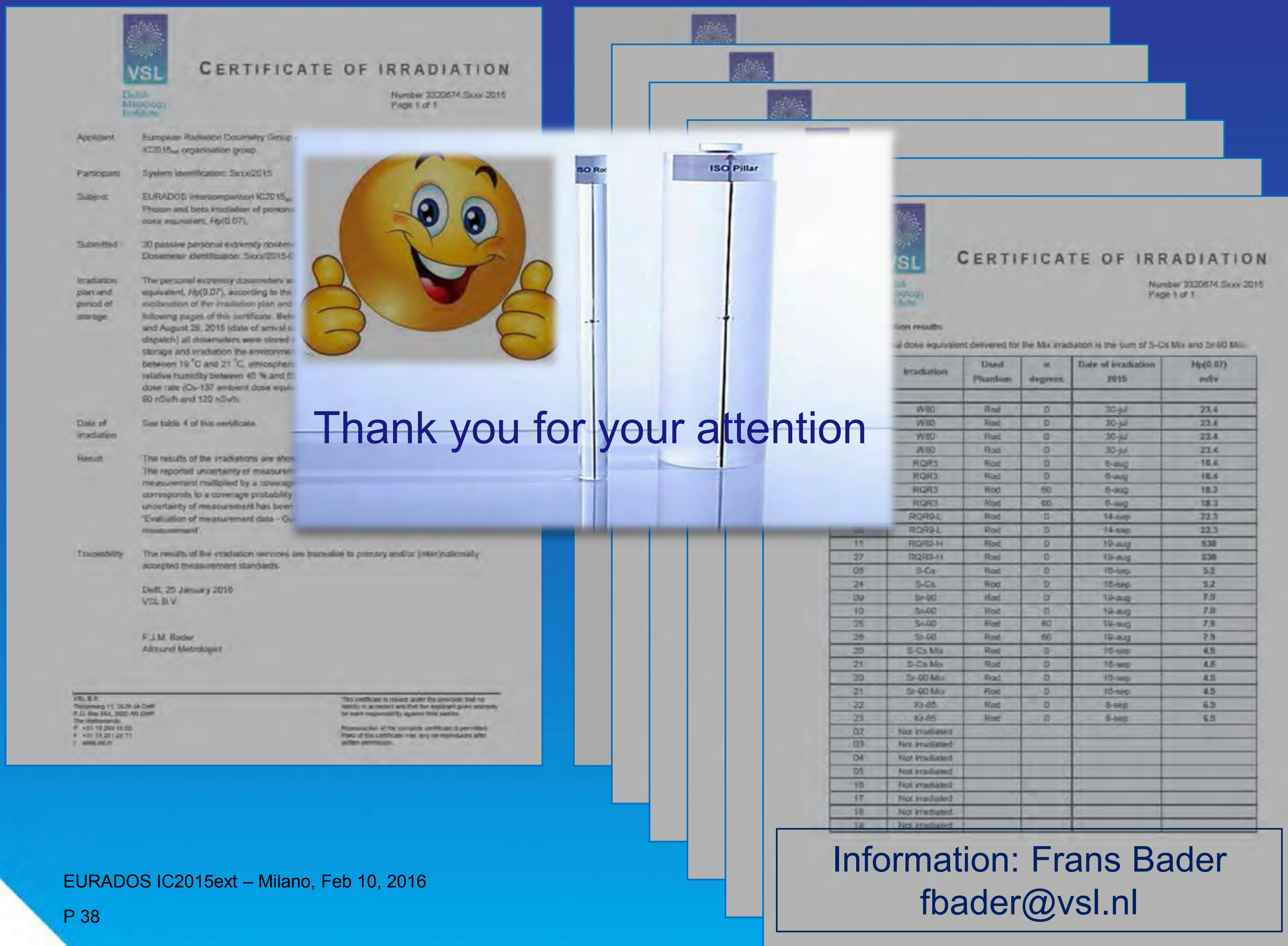
Number 3320674.Sxxx-2015
Page 1 of 1

Table 4: Irradiation results

The total personal dose equivalent delivered for the Mix irradiation is the sum of S-Cs Mix and Sr-90 Mix.

Dosemeter #	Irradiation	Used Phantom	α degrees	Date of irradiation 2015	Hp(0.07) mSv
Sxxx					
01	W80	Rod	0	30-jul	23.4
14	W80	Rod	0	30-jul	23.4
15	W80	Rod	0	30-jul	23.4
30	W80	Rod	0	30-jul	23.4
29	RQR3	Rod	0	6-aug	18.4
13	RQR3	Rod	0	6-aug	18.4
28	RQR3	Rod	60	6-aug	18.3
12	RQR3	Rod	60	6-aug	18.3
07	RQR9-L	Rod	0	14-sep	22.3
08	RQR9-L	Rod	0	14-sep	22.3
11	RQR9-H	Rod	0	19-aug	538
27	RQR9-H	Rod	0	19-aug	538
06	S-Cs	Rod	0	16-sep	5.2
24	S-Cs	Rod	0	16-sep	5.2
09	Sr-90	Rod	0	19-aug	7.0
10	Sr-90	Rod	0	19-aug	7.0
25	Sr-90	Rod	60	19-aug	7.9
26	Sr-90	Rod	60	19-aug	7.9
20	S-Cs Mix	Rod	0	16-sep	4.5
21	S-Cs Mix	Rod	0	16-sep	4.5
20	Sr-90 Mix	Rod	0	16-sep	4.5
21	Sr-90 Mix	Rod	0	16-sep	4.5
22	Kr-85	Rod	0	8-sep	6.5
23	Kr-85	Rod	0	8-sep	6.5
02	Not irradiated				
03	Not irradiated				
04	Not irradiated				
05	Not irradiated				
16	Not irradiated				
17	Not irradiated				
18	Not irradiated				
19	Not irradiated				

…73 Certificates of Irradiation



Thank you for your attention

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Relative Measurements Sr-90/Y-90 and Kr-85

For Sr-90/Y-90

$$D_{(Sr,LCW)} / D_{(Sr,VSL)} = M_{(Sr,LCW)} / M_{(Sr,VSL)} =$$

For Kr-85

$$D_{(Kr,LCW)} / D_{(Sr,LCW)} = M_{(Kr,LCW)} / M_{(Sr,LCW)} =$$

$$D_{(Kr,LCW)} / D_{(Sr,VSL)} = M_{(Kr,LCW)} / M_{(Sr,VSL)} =$$

} ≤ 1.5 %

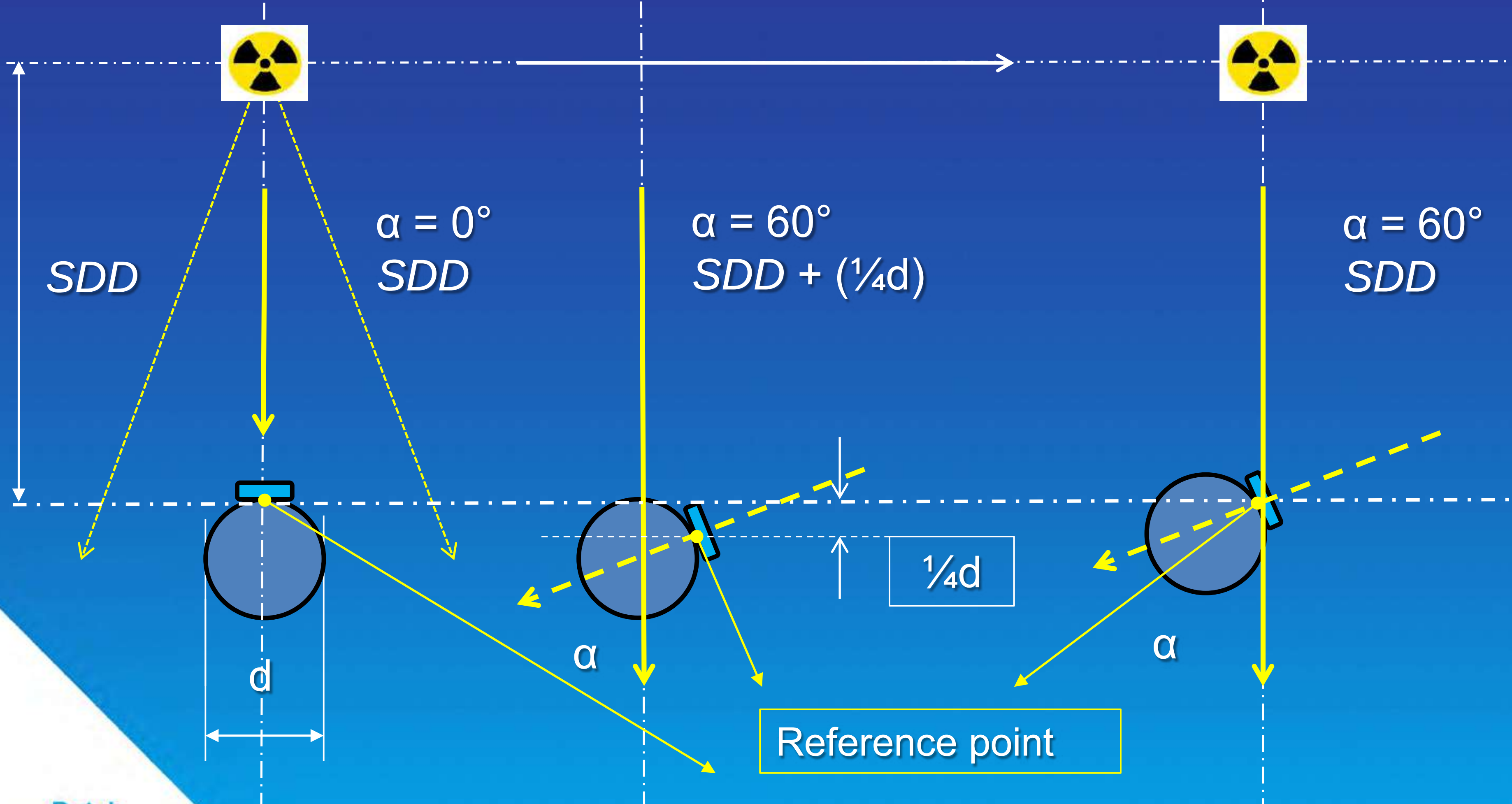
D is according to PTB certificate

M is ion-chamber measurement

VSL

Set-Up for Angle of Incidence, α = 60°

d(pillar) = 73 mm => ¼d = 18.25 mm
d (rod) = 19 mm => ¼d = 4.75 mm



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