The Abdus Salam International Centre for Theoretical Physics

United Nations Educational, Scientific and Cultural Organization

IAEA International Atomic Energy Agency

2033-14

Joint ICTP/IAEA Advanced School on Dosimetry in Diagnostic Radiology and its Clinical Implementation

11 - 15 May 2009

Calibration of an SSDL Facility

Costas Hourdakis

Greek Atomic Energy Agency
Athens
Greece

Joint ICTP-IAEA Advanced School on Dosimetry in Diagnostic Radiology & its Clinical Implementation

Calibration at an SSDL facility

Costas J. Hourdakis

Greek Atomic Energy Commission

Greece

11 – 15 May 2009

Miramare, Trieste, Italy

IAEA

International Atomic Energy Agency

Diagnostic Radiology "sub-groups" :

- Conventional radiology dosimetry standards

  (air kerma K_i & air kerma rate $K_{i,R}$ at 50 – 150 kV)

- Mammography dosimetry standards

  (air kerma K_i at 25 – 35 kV)

- Practical peak voltage

  (tube high voltage at 22 – 150 kV)

What are going to discuss during this session :

- SSDL room design
- Dosimetry equipment
- Irradiation systems – X-ray systems
- Diagnostic radiology standards
    - beam qualities
- Calibration procedures
- Uncertainties

IAEA

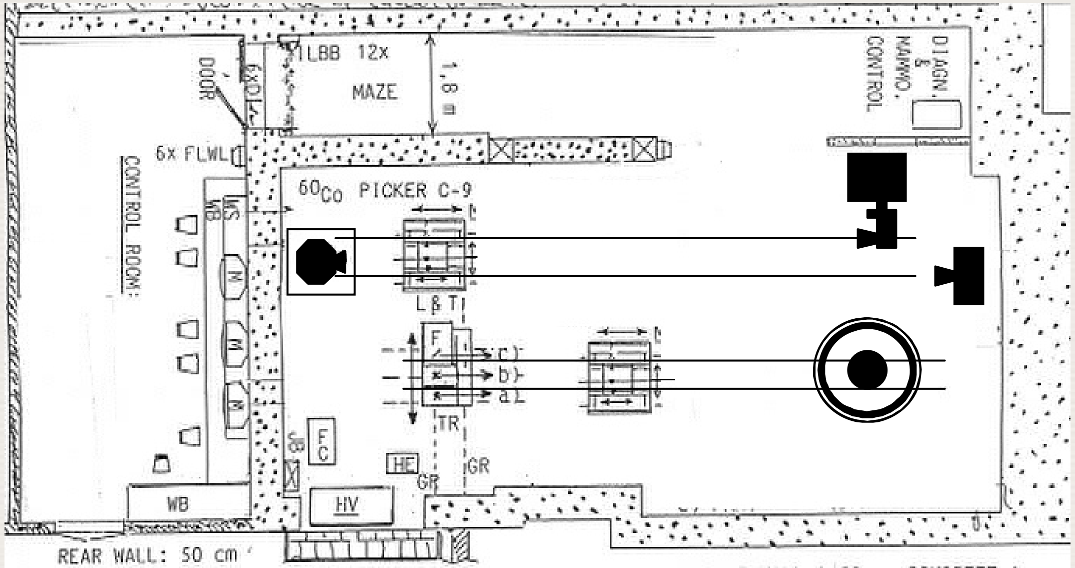
Room design

Dosimetry equipment

X-ray irradiation systems

Room design

- Radiation protection (staff and public)
- Enough space
- Lightning – Air conditioning
- Hygiene
- Electrical power



Room design

•Scattered radiation

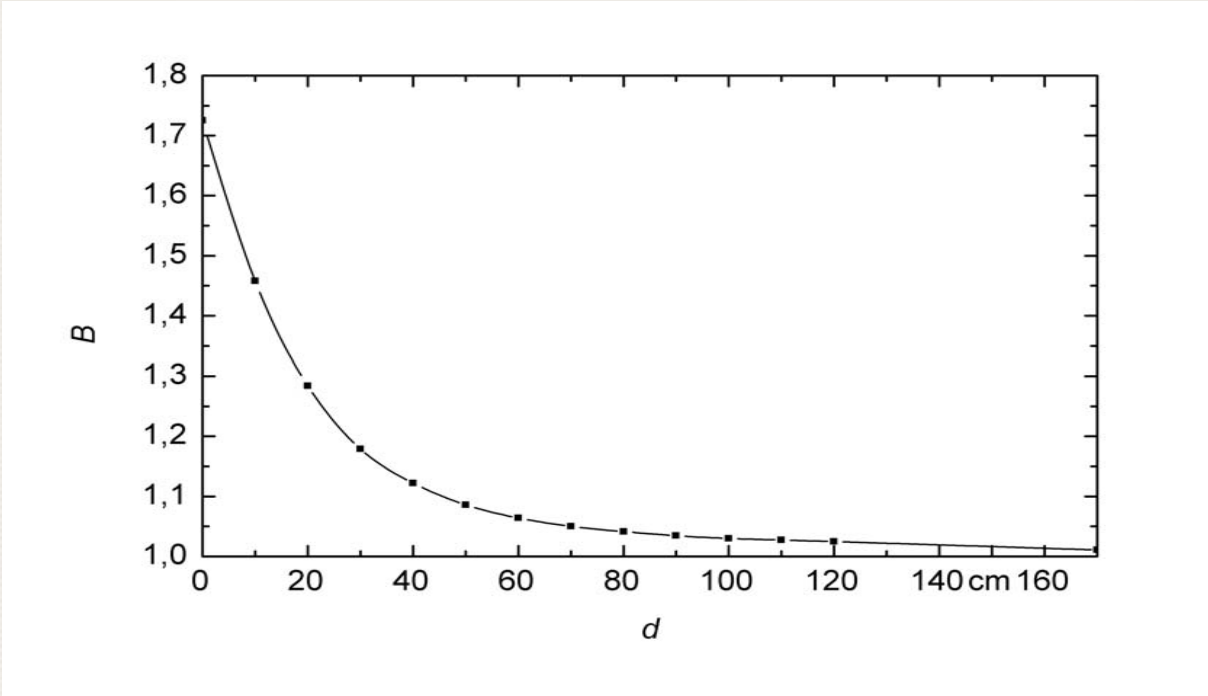
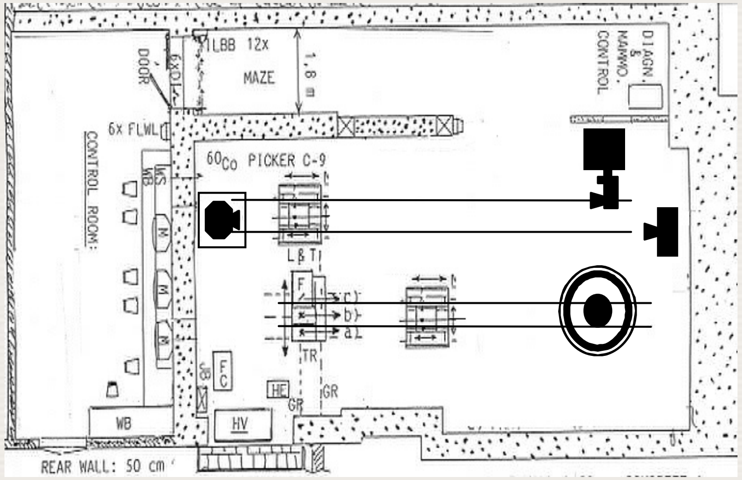
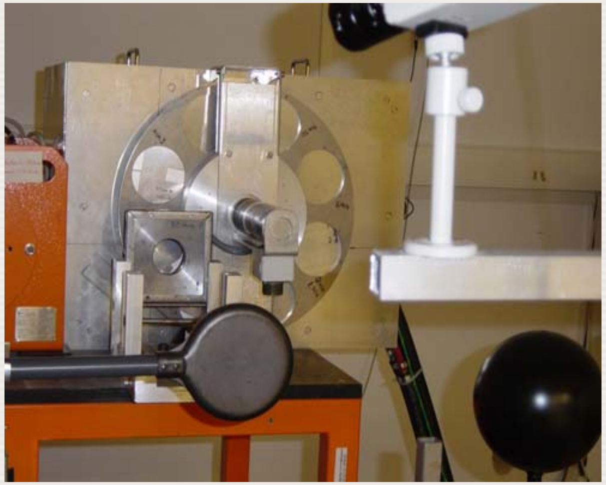


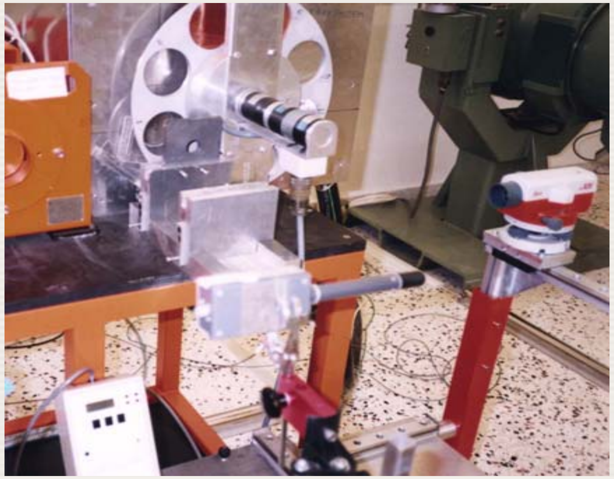
FIG 6.1 (IAEA, CoP, p 58) : Backscatter factor, B, as a function of the distance, d, from the surface of the backscattering wall. Radiation quality RQR 10, field size 600 mm by 600 mm.

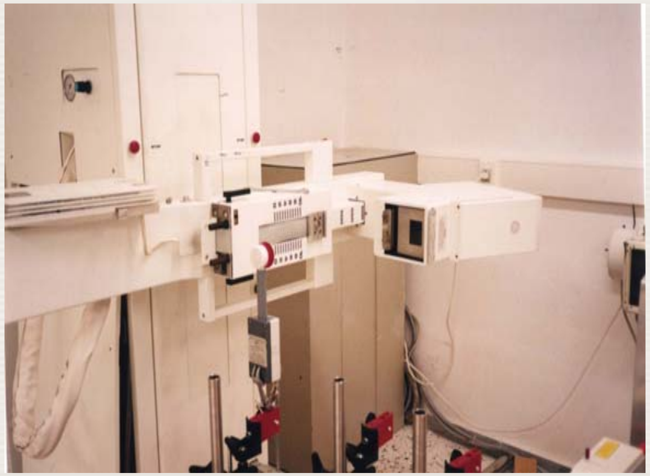
Room design

common & good practice :
horizontal beams
(for air kerma standards & calibrations)









IAEA

Environmental conditions

• stable temperature within the range 18°C to 24°C

• relative humidity should be below 80%

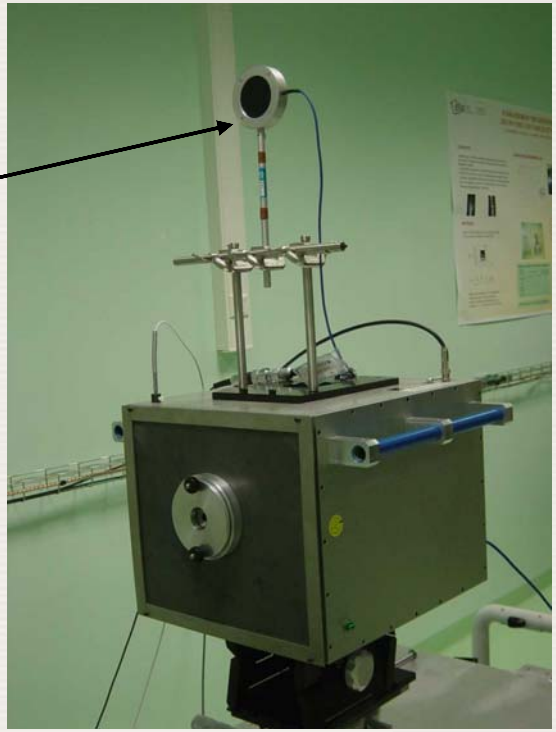
actions for rapid temperature changes

temperature of the air inside any ionization chamber

Dosimetry equipment

The **reference Kair** values at various beam qualities are established at the SSDL, by the transfer – reference **ionization chamber**

The reading of secondary standard is converted to the air kerma or the air kerma rate by means of the **calibration coefficient** as supplied by the PSDL or the IAEA.



$$N^{SSDL}_{K,Q_0,P_0,T_0,cond_{PSDL}} = \frac{K^{PSDL}}{M^{SSDL}_{Q_0,P_0,T_0,cond_{PSDL}}}$$

Ionization chambers

The SSDL should have two reference-class ionization chambers

Table 5.2 Recommended specifications of detectors of a reference class dosimeter, by application (IAEA, CoP, p52)

Application	**Type of detector**	**kV**	**Intrins. error %**	**Respon. Var. %**	**Range of air kerma rate**	
					Unattenuated beam	Attenuated beam
General radiography	Cylindrical, spherical or plane-parallel	60 - 150	3.2	±2.6	1 mGy/s – 500 mGy/s	10 µGy/s – 5 mGy/s
Fluoroscopy	Cylindrical, spherical or plane-parallel (preferable)	50 – 100	3.2	±2.6	10 µGy/s – 10 mGy/s	0.1 µGy/s – 100 µGy/s
Mammography	Plane-parallel	22 – 40	3.2	±2.6	10 µGy/s – 10 mGy/s	

- Traceability
- Working standard dosimeter

IAEA

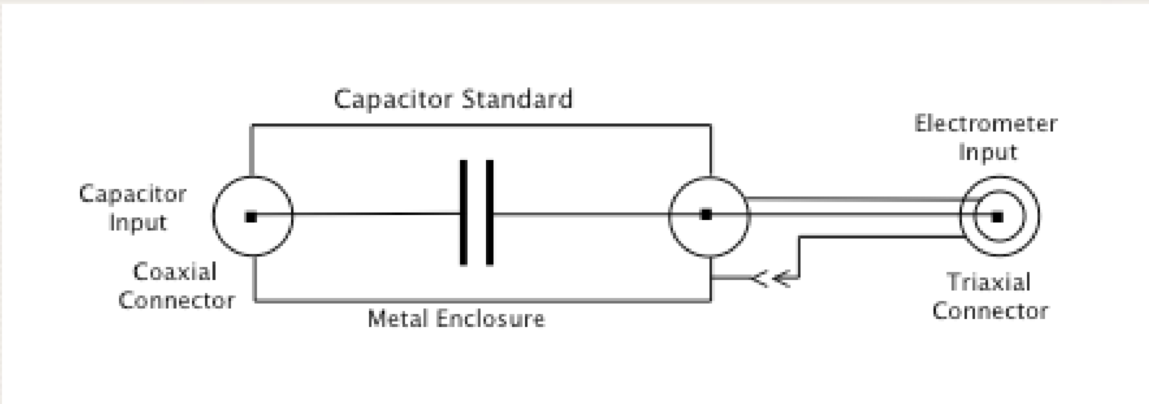
Electrometer and chamber High voltage supply

At least, two electrometers, being capable of measuring charge and current

1. Charge scale calibration

$$N_C = \frac{C\,\Delta V}{\Delta M}$$

where C the capacitor, ΔM is the increment in the reading of the electrometer caused by a voltage increment ΔV



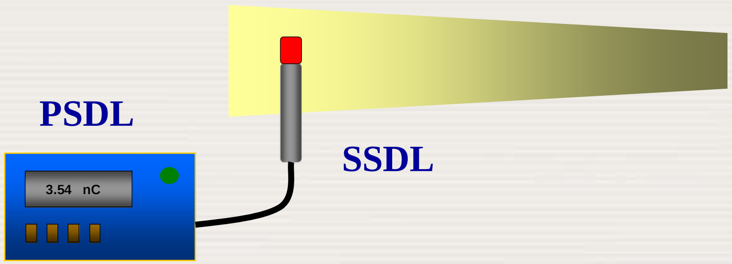
IAEA

Calibration at an SSDL facility : Dosimetry equipment

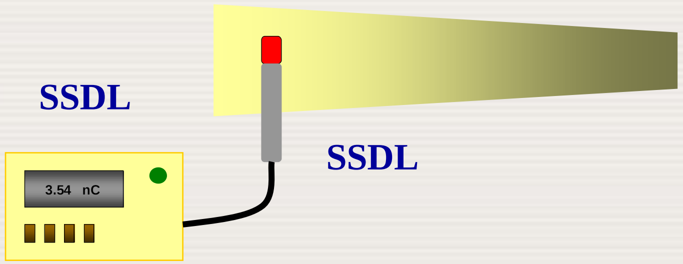
Electrometer and chamber High voltage supply

2. Alternatively : Calibration at PSDL at electrical units

3. Alternatively : Calibration at PSDL at radiation beams



N_K^{ch} : chamber alone



N_K^{el+ch} : electrometer + chamber

$$k_{elec} = N_K^{el+ch} \; / \; N_K^{ch}$$

Calibration at an SSDL facility : X-ray equipment

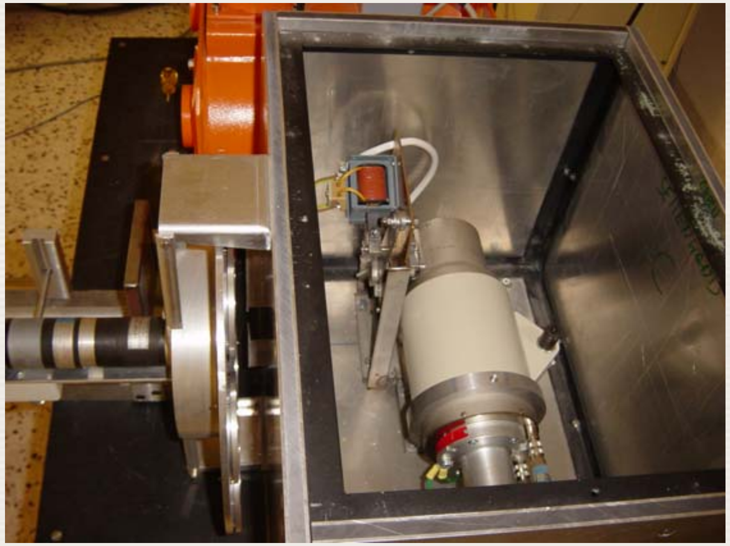
Conventional radiology (40 – 150 kV)

Mammography (20 - 40)

Calibration at an SSDL facility : X-ray equipment

Conventional radiology

- 40 – 150 kV
- Ripple < 10% (CoP), but general <1%
- Display kV @ 1%
- Reflecting anode, < 27o angle
- Anode : Tungsten, W
- Hosting various filters Al, Cu
- IEC 12267 beam series, RQR, RQA, RQT, etc

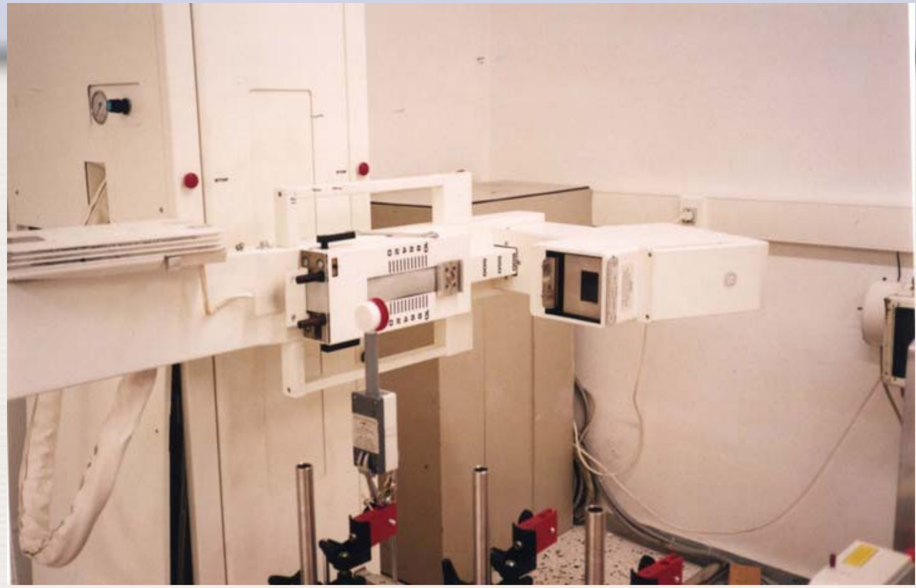


IAEA

Calibration at an SSDL facility : X-ray equipment

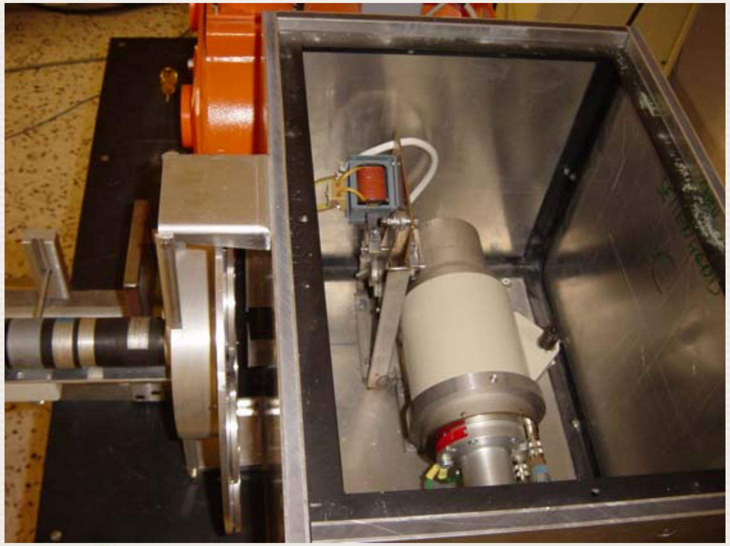
Mammography

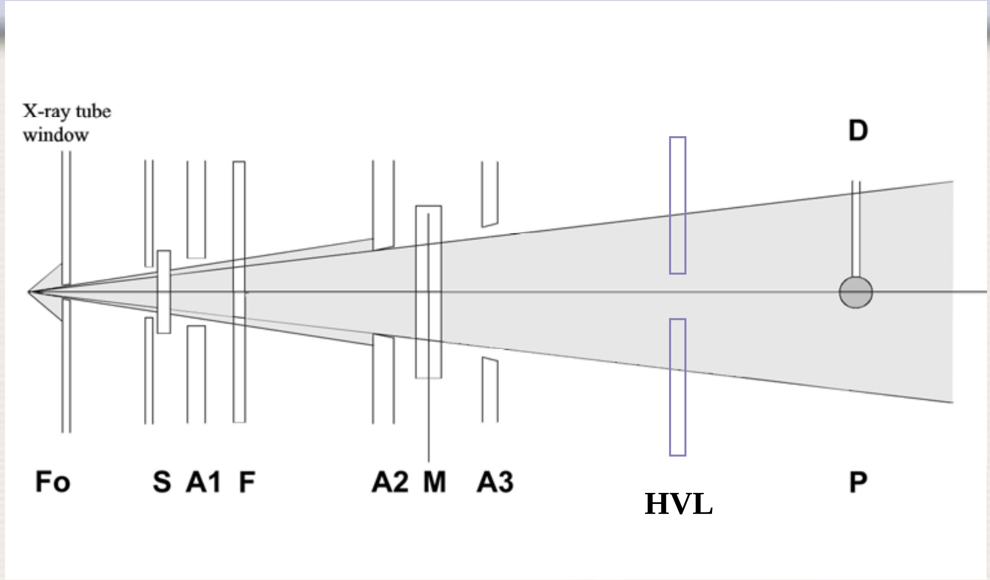
- 22 – 40 kV
- Ripple <1%
- Display kV @ 1%
- Reflecting anode, < 27o angle
- Anode : Mo, Rh
- Hosting various filters Mo, Rh
- IEC 12267 beam series, RQR-M, RQA-M



IAEA

Calibration at an SSDL facility : Shutter & Apertures





Fo : focal spot,
S : X ray beam shutter
A1 : aperture at X ray tube housing
F: added filtration
A2 : field limiting aperture
M : monitor chamber
A3 : further aperture
HVL : aperture and Al holder (not permanent)
P : reference distance from the focus

IAEA

Calibration at an SSDL facility : X-ray equipment

Monitor chamber

Use for :

- as a reference for K_i dermination
- corrections for the non-stability of X-ray output
- verification of X-ray performance (output)
- indication of beam on/off status

!!!

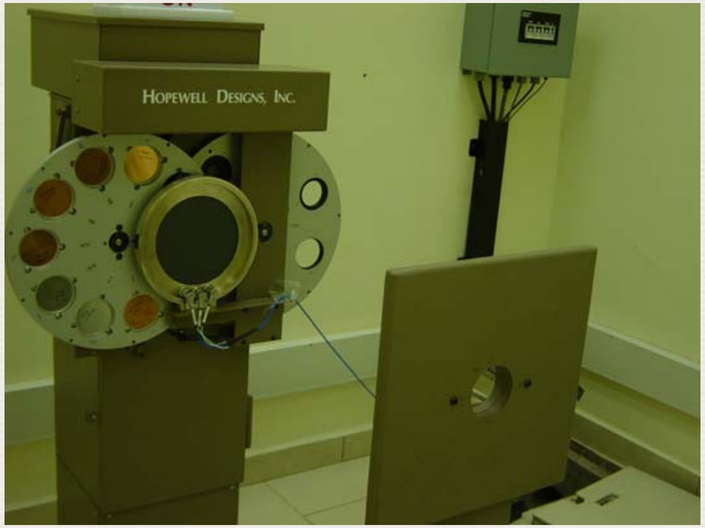
If used as reference of for corrections, sometimes causes more problems than solves : Careful use

Hardens the X-ray beam : included in HVL measurement

The high stability of modern X ray generators does not necessarily require

IAEA

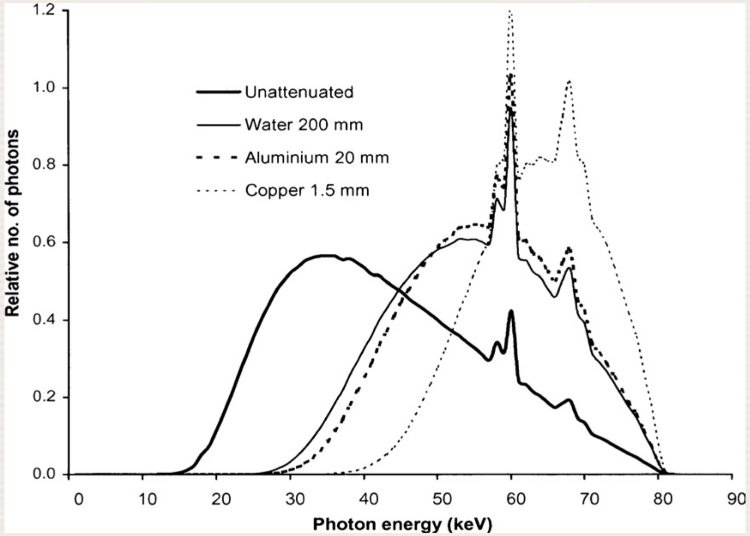
Filters and attenuators



Filters : to modify the X-ray energy spectrum
Measure the HVL
Al and Cu : conventional
Mo, Rh, Al : Mammography
Purity > 99.9%
Various thicknesses
Good homogeneity
Thickness : ± 10µm (conv) & ±5µm (mammo)

!!! Combined filters :

harder material closer to focus (Cu – Al)



Attenuators : HVL measurements

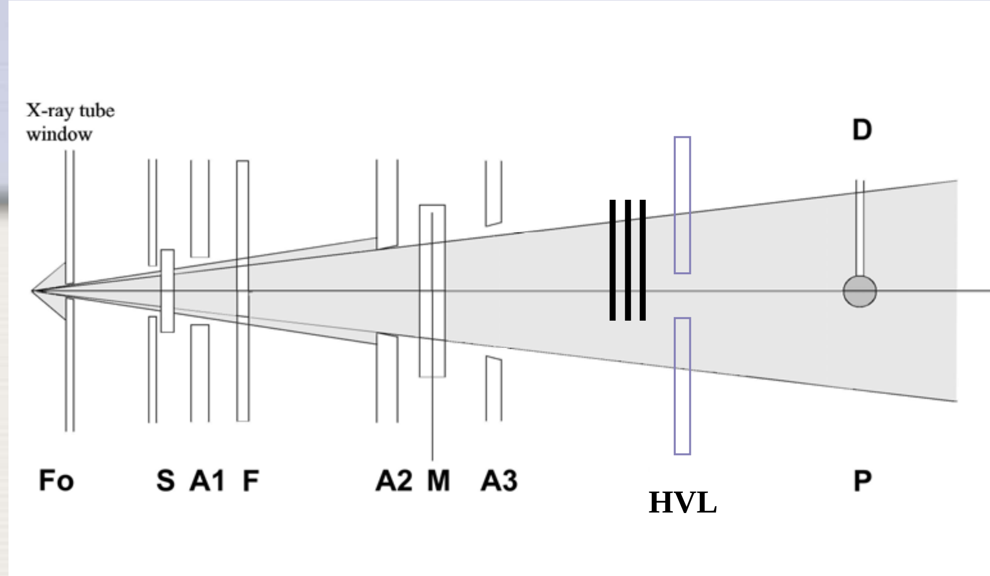
Beam quality : X-ray energy, as characterized by HVL (mm Al)

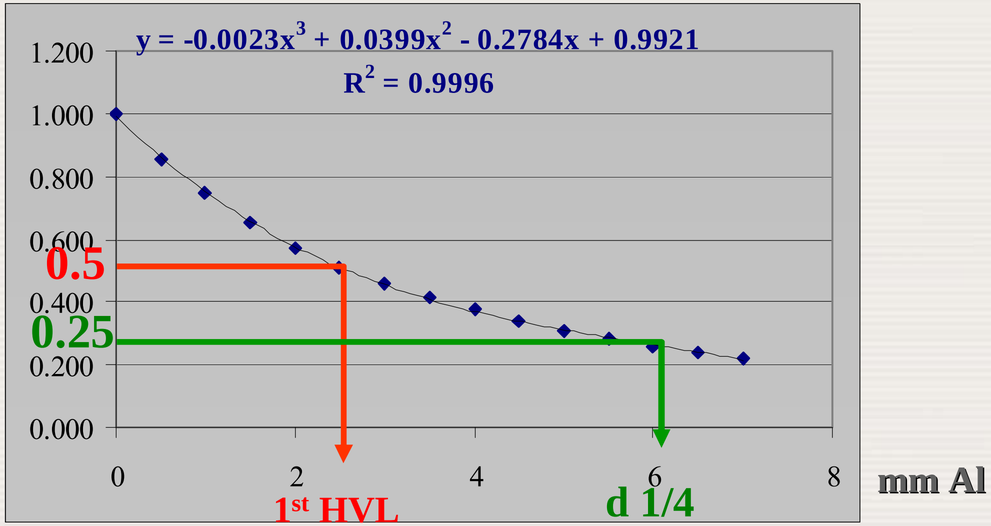
beam quality index
(descriptor)

HVL depends on :

- tube high voltage
- inherent (permanent) tube filtration
- added tube filtration
- X-ray system characteristics (tube ageing, tube anode, converter type, etc)

HVL measurement





Acceptance limits

K_{HVL}/K_0 : [0.485 – 0.515]

HVL : IEC (CoP) value

HVL_{SSDL}/HVL_{IEC} : [0.957 – 1.044]

$h_{measured} - h_{IEC} < 0.03$

2nd HVL = d(1/4) - 1st HVL

h = 1st HVL / 2nd HVL

Beam quality : X-ray energy, as characterized by HVL (mm Al)

beam quality index
(descriptor)

A ***code*** is given to the beam quality describing all above

Example :
RQR 5 means : 70 kV, 3mm Be inherent filtration, 2.70 mm Al added filtration, 1st HVL = 2.58 mm Al, 2nd HVL= 3.63 mm Al, h=0.71

each SSDL establishes its own "beam qualities" according to IEC standards

IAEA

IEC 61267 : 2005 standard provides the radiation qualities for X-ray diagnostic radiology dosimetry

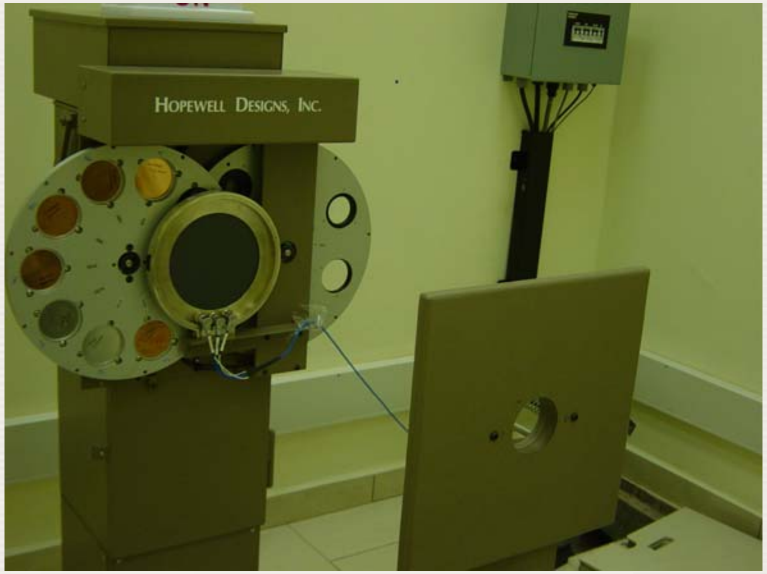
Radiation quality	Radiation origin	Material of an additional filter	Application
RQR	Radiation beam emerging from X ray assembly	no phantom	General radiography, fluoroscopy and dental applications (measurements free in air)
RQA	Radiation beam with an added filter	Aluminium	Measurements behind the patient (on the image intensifier)
RQT	Radiation beam with an added filter	Copper	CT applications (measurements free in air)
RQR-M	Radiation beam emerging from X ray assembly	no phantom	Mammography applications (measurements free in air)
RQA-M	Radiation beam with an added filter	Aluminium	Mammography studies

IEC 61267 : 2005 standard provides the radiation qualities for X-ray diagnostic radiology dosimetry

For the establishing the beam qualities :

- The appropriate kV applied
- The adequate added filtration found

in order for the actual (measured) HVL to comply with IEC values



IAEA

RQR series : Conventional radiology
unattenuated beams – calibrations free in air

Radiation quality	X ray tube voltage kV	First half-value layer mm Al	Homogeneity coefficient h
RQR 2	40	1.42	0.81
RQR 3	50	1.78	0.76
RQR 4	60	2.19	0.74
RQR 5*	**70**	**2.58**	**0.71**
RQR 6	80	3.01	0.69
RQR 7	90	3.48	0.68
RQR 8	100	3.97	0.68
RQR 9	120	5.00	0.68
RQR 10	150	6.57	0.72

RQR 5 : the reference radiation quality

Calibration at an SSDL facility : Establishing Radiation Qualities

RQT series : CT calibrations

Radiation quality	**X ray tube voltage** **kV**	**Added filtration**	**Nominal first half-value layer** **mm Al**
RQT 8	100	RQR 8 + 0.2 mm Cu	6.9
RQT 9*	**120**	**RQR 9 + 0.25** mm Cu	**8.4**
RQT 10	150	RQR 10 + 0.3 mm Cu	10.1

RQT 9 : the reference radiation quality

IAEA

RQA series : Conventional radiology
Attenuated beams – behind the patient

Radiation quality	X ray tube voltage	Added filtration	Nominal first half-value layer
	kV	mm Al	mm Al
RQA 2	40	4	2.2
RQA 3	50	10	3.8
RQA 4	60	16	5.4
RQA 5*	**70**	**21**	**6.8**
RQA 6	80	26	8.2
RQA 7	90	30	9.2
RQA 8	100	34	10.1
RQA 9	120	40	11.6
RQA 10	150	45	13.3

RQA 5 : the reference radiation quality

Calibration at an SSDL facility : Establishing Radiation Qualities

RQR-M series : Mammography
unattenuated beams – calibrations free in air

Mo Anode, Mo added tube filtration (Mo/Mo)

Radiation quality	X ray tube voltage kV	Nominal first half-value layer mm Al
RQR-M 1	25	0.28
RQR-M 2*	**28**	**0.31**
RQR-M 3	30	0.33
RQR-M 4	35	0.36

RQR-M 2 : the reference radiation quality

TABLE 6.7 (CoP, p 78) : MAMMOGRAPHY RADIATION QUALITIES WITH A RHODIUM FILTER AT THE IAEA DOSIMETRY LABORATORY.

Radiation quality	Tube potential	Added filtration	First half-value layer	Homogeneity coefficient
	kV	mm	mm Al	
Mo anode				
Mo/Rh-28	28	0.025 Rh	0.417	0.82
Mo/Rh-32	32	0.025 Rh	0.449	0.84
Rh anode				
Rh/Rh-25	25	0.025 Rh	0.362	0.78
Rh/Rh-30	30	0.025 Rh	0.444	0.76
Rh/Rh-35	35	0.025 Rh	0.504	0.78
Rh/Rh-40	40	0.025 Rh	0.548	0.78
Rh/Rh-30x	30	0.025 Rh + 2 Al	0.814	0.94
Rh/Rh-35x	35	0.025 Rh + 2 Al	0.883	0.92

Calibration at an SSDL facility : Establishing Radiation Qualities

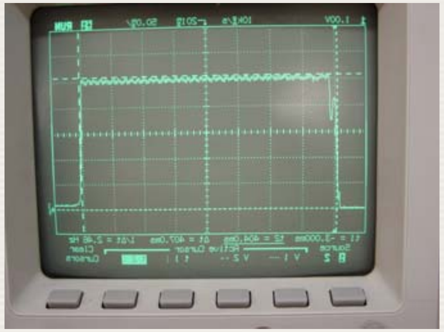
RQR-M series : Mammography
Attenuated beams – behind a phantom

Radiation quality	X ray tube voltage kV	Added filtration mm Al	Nominal first half-value layer mm Al
RQA-M 1	25	2	0.56
RQA-M 2	28	2	0.60
RQA-M 3	30	2	0.62
RQA-M 4	35	2	0.68

Calibration at an SSDL facility : Tube voltage (kV) calibration

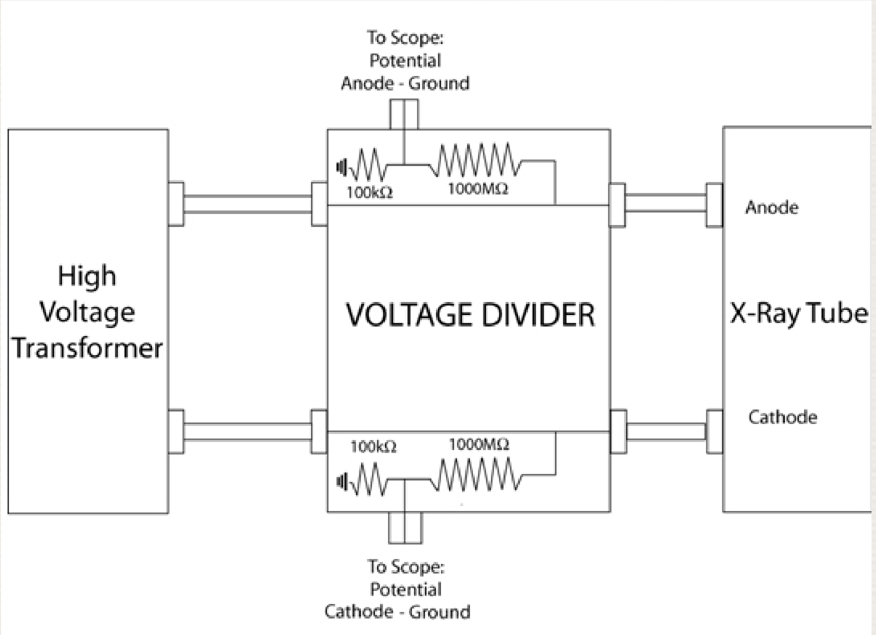
Standards for calibration of
non invasive X-ray tube voltage
measuring instruments (kVp-meter)

High voltage divider



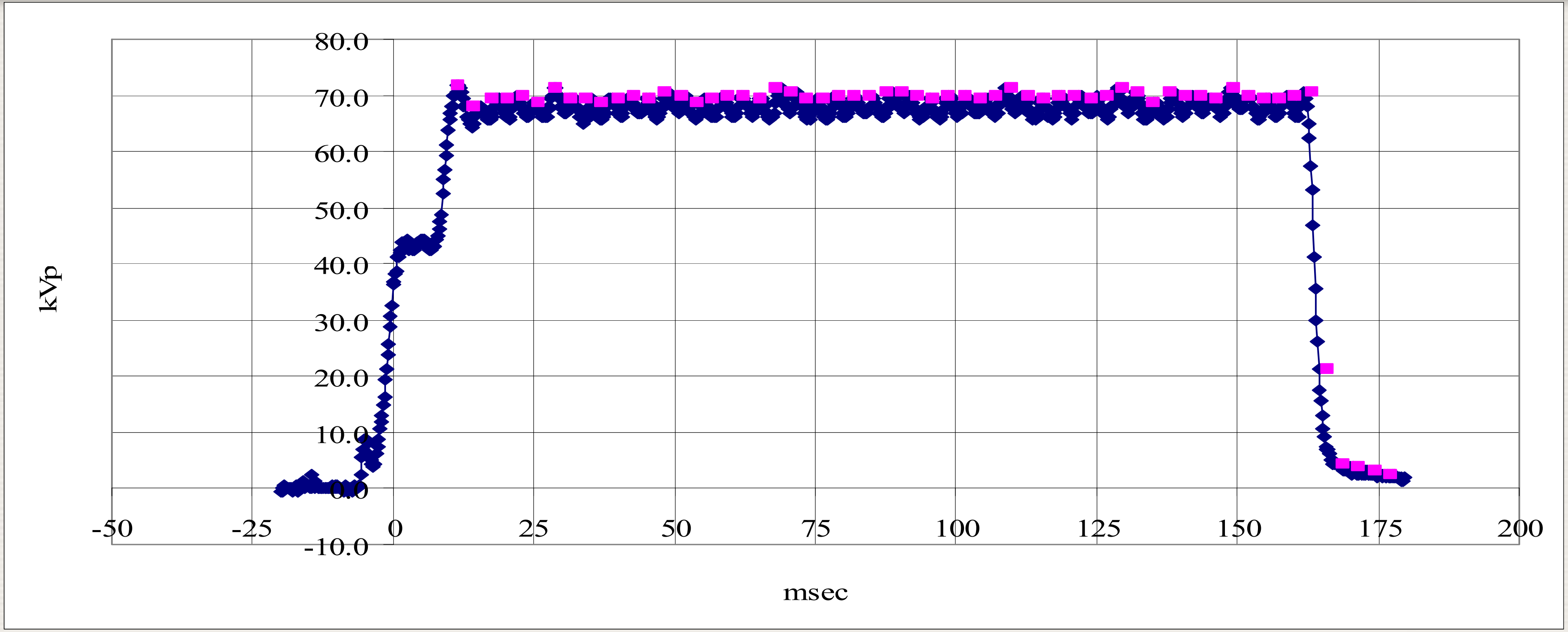
Simultaneous exposure of kVp-meter

& divider measurement



IAEA

Calibration at an SSDL facility : Tube voltage (kV) calibration



Practical Peak Voltage, PPV

$$\hat{U} = \frac{\sum_{i=1}^{n} p(U_i) \cdot w(U_i) \cdot U_i}{\sum_{i=1}^{n} p(U_i) \cdot w(U_i)}$$

KRAMER, H.-M., SELBACH, H.-J., ILES, W.J., The practical peak voltage of diagnostic x-ray generators, Br. J. Radiol. **71** (1998) 200-209.

Alternative options :

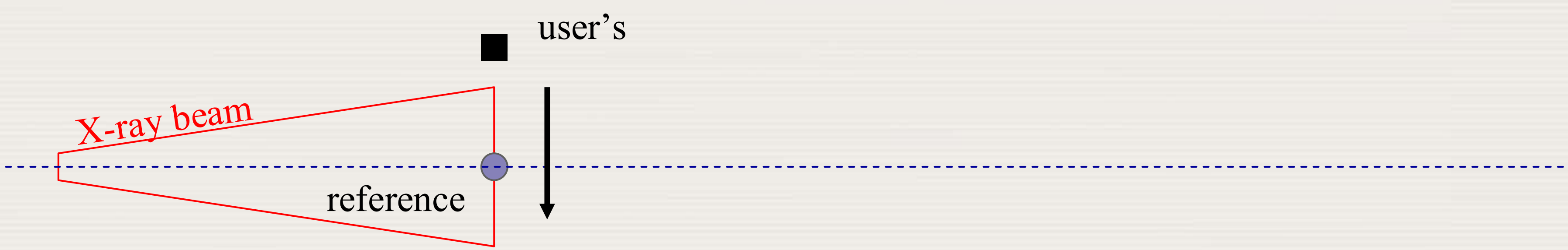
A non-invasive device is employed, which measures the practical peak voltage and has been calibrated by another SSDL or other laboratory

Use of a non-invasive high-voltage measuring device possessing an analogue and/or a digital output : kV vs time

Calibration Procedures

This section applies to all diagnostic dosimeters
except those with a CT ionization chamber and KAP ionization chamber

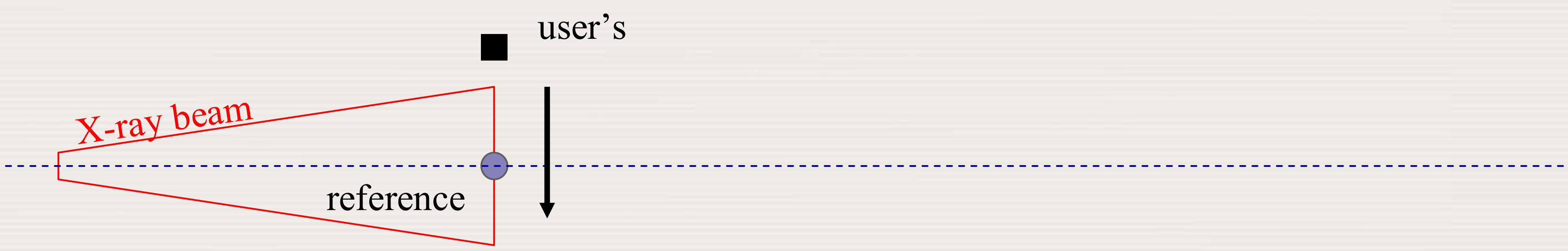
Calibration at an SSDL facility : CoP for calibrations



Prior the calibration :

- Acclimatization
- Warm-up and polarizing voltage application
- Positioning both chambers at the same distance
- Pre-irradiation
- Zeroing
- Measurement of leakage current

Calibration at an SSDL facility : CoP for calibrations



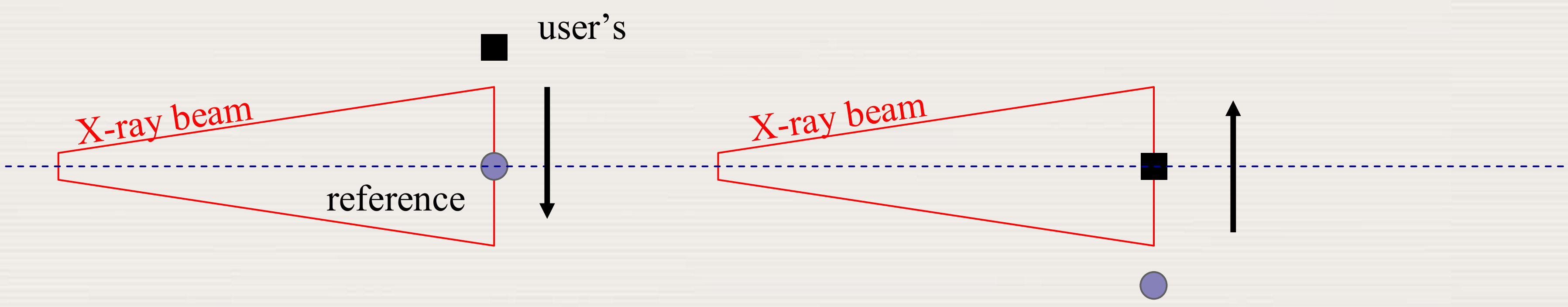
Reference point of detector

Focus to Reference point distance = 1000 mm (1 m)

X-ray beam must cover the detector totally

Field size at least 1,5 times larger than the cross-section of detector BUT not too wide to hit room's walls and floor

"substitution method"



repetitive measurements at inter-changed positions

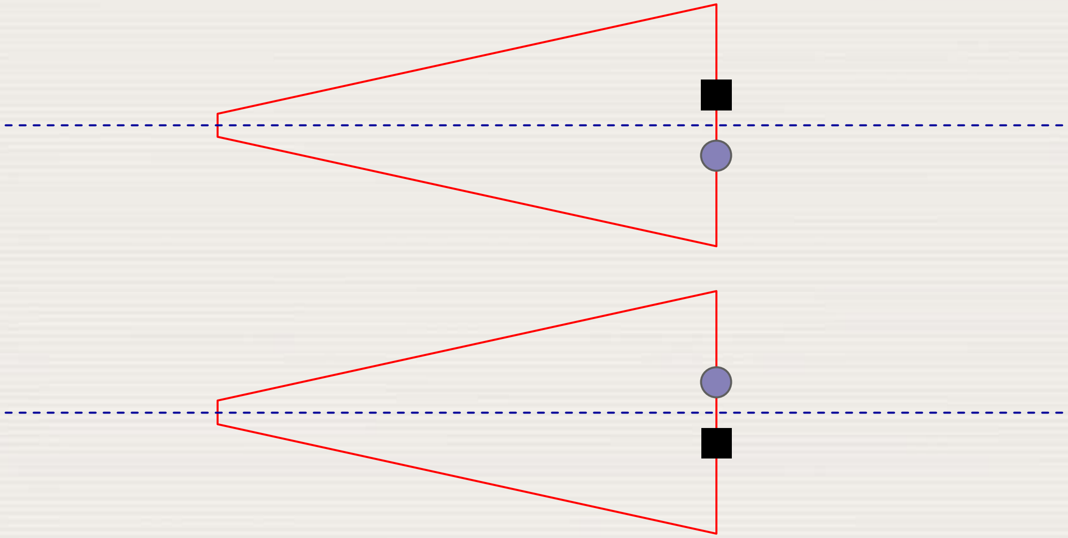
Example :

3 readings with reference & then 3 with the user's
3 readings with reference & then 3 with the user's
3 readings with reference & then 3 with the user's

10 readings of each chamber

any tube output, temperature, or other variations to be spread at both chambers

Calibration at an SSDL facility : CoP for calibrations



!!! the **Side by Side method**

is **NOT** recommended by the IAEA CoP **!!!**

- heal effect
- inhomogeneities of X-ray beam
- scattered radiation
- radiation incident angles
- etc

Calibration at an SSDL facility : CoP for calibrations

For calibration …

1st step : the reference value of air kerma is determined with the SSDL reference ionization chamber

2nd step : the user's detector is exposed to identical conditions

3rd step : the calibration coefficient calculated as the ratio of air kerma K to user detector's readings (corrected)

IAEA

Calibration at an SSDL facility : CoP for calibrations **with monitor chamber**

reference chamber

$$K_i^{ref} = M_Q^{ref} \cdot \mathrm{k_{TP}} \cdot N_{K,Q_0} \cdot k_{Q,Q_0}$$

$$\frac{K_i^{ref}}{m^{mon} \cdot k_{TP}}$$

$$\overline{\left(\frac{K_i^{ref}}{m^{mon} \cdot k_{TP}}\right)}^{ref}$$

user's chamber

$$\frac{M_Q^{user} \cdot k_{TP}}{m^{mon} \cdot k_{TP}}$$

$$\overline{\left(\frac{M_{Qi}^{user} \cdot k_{TP}}{m^{mon} \cdot k_{TP}}\right)}^{user}$$

$$N_{K,Q}^{user} = \frac{\overline{\left(\frac{K_i^{ref}}{m^{mon} \cdot k_{TP}}\right)}^{ref}}{\overline{\left(\frac{M_Q^{user} \cdot k_{TP}}{m^{mon} \cdot k_{TP}}\right)}^{user}}$$

$$N_{K,Q}^{user} = N_{K,Q}^{ref} \left(\frac{(M\ k_{\mathrm{TP}})_Q^{ref}}{(m\ k_{\mathrm{TP}})_Q^{ref}}\right)\left(\frac{(m\ k_{\mathrm{TP}})_Q^{user}}{(M\ k_{\mathrm{TP}})_Q^{user}}\right)$$

IAEA

Calibration at an SSDL facility : CoP for calibrations **without** a monitor chamber

reference chamber

$$K_i^{ref} = M_Q^{ref,mean} \cdot \mathrm{k}_{\mathrm{TP}} \cdot N_{K,Q_0} \cdot k_{Q,Q_0}$$

user's chamber

$$M_Q^{user,mean} \cdot k_{TP}$$

$$N_{K,Q}^{user} = \frac{K_i^{ref}}{M_Q^{user,mean} \cdot k_{TP}}$$

In both cases (with or without monitor chamber)

$$\boxed{k_Q^{user} = \frac{N_{K,Q}^{user}}{N_{K,Q_0}^{user}}}$$

IAEA

Calibration at an SSDL facility : Uncertainties

Calibration uncertainties consists of two parts :

- Measurements with the reference chamber for K_i^{ref} calculation
- Measurements with the user’s chamber

Example :

Diagnostic dosimeters - Nk	Type A	Type B
	%	%
Measurements of Kair by SSDL chamber		
Nk from PTB	NR	0.99
Nk stability	0.50	NR
Electrometer accuracy	NR	0.00
Scale reading / resolution	NR	0.00
Current measurements	0.01	0.02
Uniformity of Xray beam	0.02	0.58
Difference in X ray spectra (HVL)	NR	0.50
Positioning in same distance	0.02	0.12
Temperature & Pressure	0.07	0.08
Electrometer Built-In timer	*	*
Leakage current	NR	0.00
Recombination loss	NR	0.00

Measurements with User's chamber		
Shuter timer accuracy	*	
Shutter timer reproducibility	*	
Ionization / Dose measurements stability	*	
Positioning in same distance	NR	0.35
Uniformity of radiation beam (for different chamb)	0.00	0.00
Temperature & Pressure	0.17	0.38
Difference in Temperature at two places	NR	0.00
Leakage current	NR	0.00
Radiation background	NR	0.00
Electrometer accuracy	NR	NR
Humidity	NR	0.00
Recombination loss	NR	0.00

Reproducibility of Kair meas with SSDL instrument	0.30	
Reproducibility of meas with USER instrument	0.50	
Scale reading / resolution for USER instrument	*	0.01
Kair to R (exposure) relation		0.00

QUADRATIC SUM	0.80	1.78
COMBINED UNCERTAINTY	1.95	%
EXPANDED UNCERTAINTY	3.90	%

IAEA