Joint ICTP-IAEA Workshop on Establishment and Utilization of Diagnostic Reference Levels in Medical Imaging (smr3333)
18-22 November 2019, Trieste, Italy

Dose metrics in diagnostic radiology. Calibration and verification of dose data.

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Objectives

To understand:

- What are the requirements of the GSR Part 3 related to the dosimetry and calibration
- What dose metrics should be used in diagnostic radiology
- Calibration procedures and properties of dosimetry instrumentation used
- Quality assurance of dosemeters

Global use of X rays in diagnostic radiology

- 3,6 billion radiological examinations in the period 1997-2007
- Increase of 50% compared to previous decade
- Significant increase of CT practice:
    - Examination frequency
    - Dose per examination
- Interventional procedures

Dose to patient

- Depends on the examination type
- Variations for the same type of procedure

0.02- 0.05 mSv

≅2 mSv
≅ 100CxR

5-20 mSv
400- 1000 CxR

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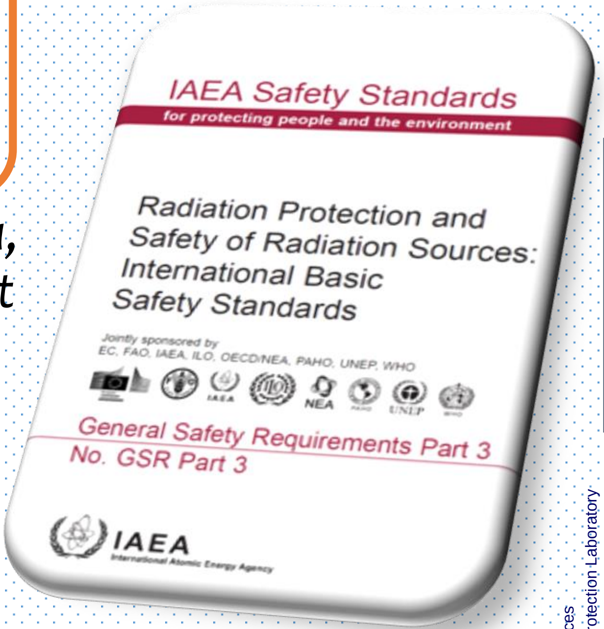
Dosimetry in diagnostic radiology

Diagnostic X ray imaging covers a **diverse range of examination types**, many of which are increasing in frequency and technical complexity.

Development of new dosimetric quantities, measuring instruments, techniques and terminologies.

GSR-Part 3: Calibration (Para 3.167)

- **Source calibration**: *measurement of certain dosimetric quantities which are modality-dependent and should be carried out in reference conditions*
- **Radiography and fluoroscopy:** *incident air kerma, incident air kerma rate and air kerma-area product*
- **CT:**
  - *CT air kerma index, CTDI, weighted CT air kerma index, CTDIw, , volume CT air kerma index, CTDIvol*
  - *CT air kerma-length-product, DLP*
- **Mammography**: *incident air kerma, entrance surface air kerma and mean glandular dose*



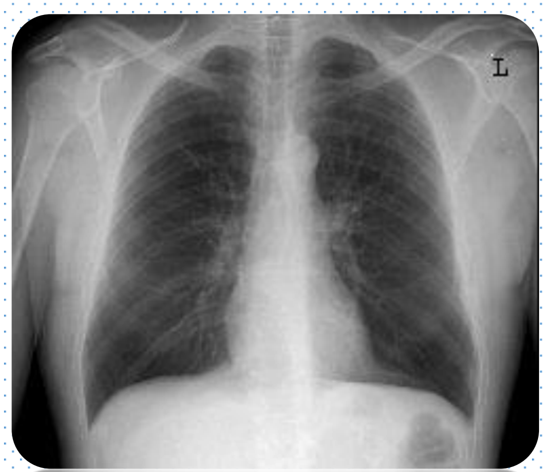
GSR-Part 3: Dosimetry of patients (Para 3.168)

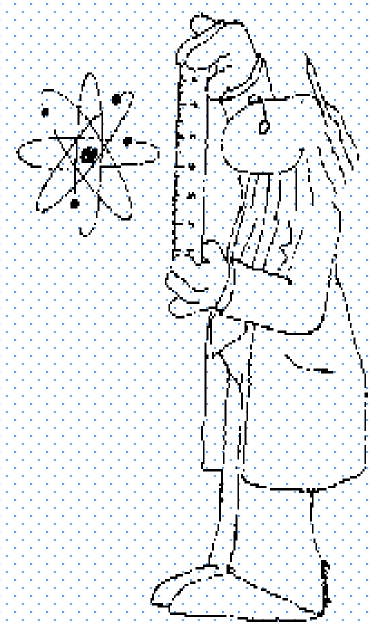
Registrants and licensees shall ensure that **dosimetry of patients** is performed and documented by or under the supervision of a medical physicist, using **calibrated dosimeters** and following internationally accepted or nationally accepted **protocols**, including dosimetry to determine the following:

- For diagnostic radiological procedures, **typical doses to patients** for common procedures;
- For image guided interventional procedures, **typical doses to patients**;
- For therapeutic radiological procedures, absorbed doses to the planning target volume for each patient treated with external beam therapy and/or brachytherapy and absorbed doses to relevant tissues or organs as determined by the radiological medical practitioner;
- For therapeutic radiological procedures with unsealed sources, typical absorbed doses to patients.

Purpose of patient dosimetry

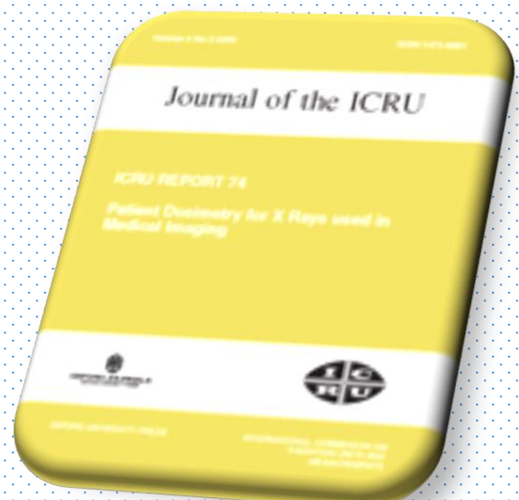
1. Means for setting and checking standards of good practice, as an aid to the **optimization** of the radiation protection of the patient and of image quality
2. Estimates of the absorbed dose to tissues and organs, to assess **radiation detriment** (patient specific dosimetry)
3. Equipment **performance testing**

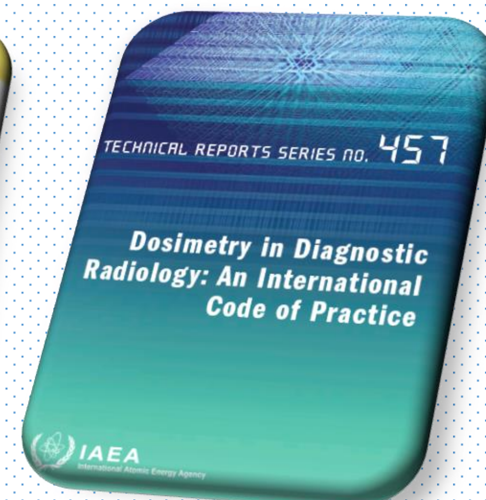




Dosimetry in diagnostic radiology

- Following need to be properly addressed:
  - **Who** (is competent to perform dosimetry)
  - **What** (should be measured/calculated)
  - **How** (is the measurement/calculation made)



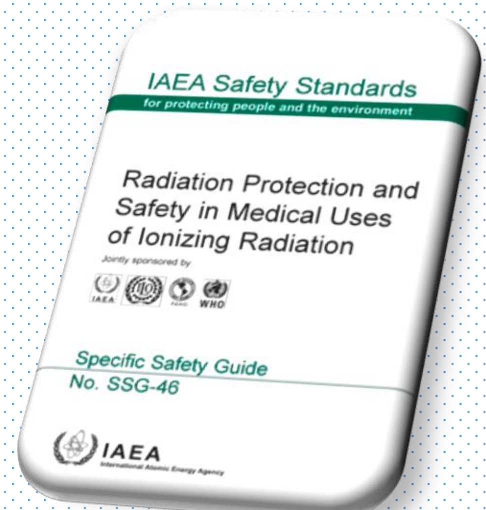


Who is competent to perform dosimetry(GSR-Part 3, Para 3.168) ?

- Registrants and licensees shall ensure thatdosimetry of patients is **performed and documented by or under the supervision of a** **medical physicist** using calibrated dosimeters and following internationally accepted or nationally accepted protocols.

What should be measured/calculated (SSG 46, Para 3.201) ?

- In diagnostic radiology, including medical radiological equipment used for radiation therapy simulation and treatment verification and hybrid imaging systems, and for image guided interventional procedures, **‘source calibration’** is to be interpreted as **the measurement of certain dosimetric quantities** which are modality-dependent and should be carried out in reference conditions.



What should be measured/calculated (SSG 46, Para 3.201) ?

- In diagnostic radiology, including medical radiological equipment used for radiation therapy simulation and treatment verification and hybrid imaging systems, and

Radiography and fluoroscopy: *incident air kerma, incident air kerma rate and air kerma-area product*

CT:

CT air kerma index, CTDI, weighted CT air kerma index, CTDIw, , volume CT air kerma index, CTDIvol

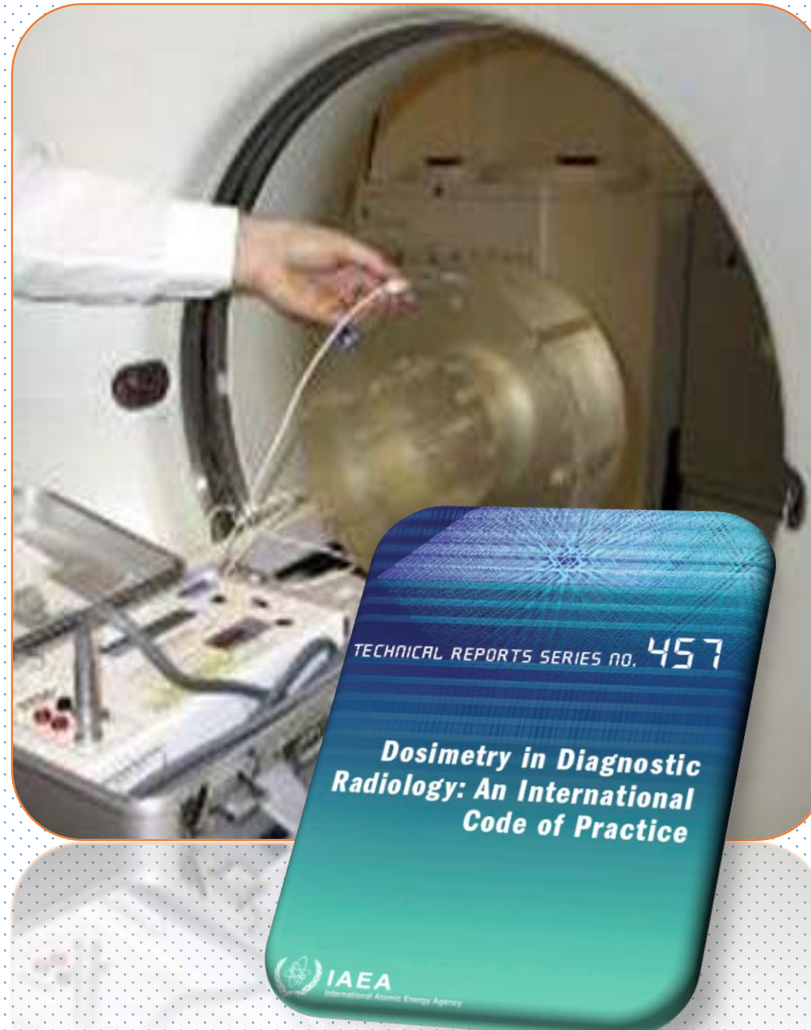
CT air kerma-length-product, DLP

Mammography: *incident air kerma, entrance surface air kerma and mean glandular dose*

How is the measurement/calculation made?

Dosimetry protocol:

- Measured quantities
- Procedure/worksheets
- Phantom measurements
- Patient measurements
- Uncertainty analysis



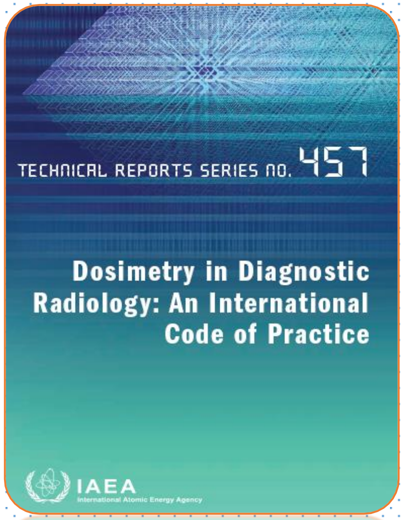
https://www-pub.iaea.org/books/iaeabooks/7638/Dosimetry-in-Diagnostic-Radiology-An-International-Code-of-Practice

Dosimetry for digital modalities (SSG 46, Para 3.218) ?

- There are several indirect and direct methods to estimate patient dose in diagnostic radiology and image guided interventional procedures
- ….
- Reported values of dose quantities from **DICOM headers** or the DICOM radiation dose structured reports.
  - The accuracy of the reported dose quantities should have been **validated** in acceptance testing and commissioning and by means of quality assurance procedures as explained in para. 3.244. **This approach is applicable to all digital modalities.**

Dosimetric quantities in units in diagnostic radiology

- Basic dosimetric quantity: Air kerma
  - Easy to measure
- Calibration:
  - Dosimeters calibrated in terms of air kerma
- Clinical application:
  - Quantities derived from air kerma for different imaging modalities



Dosimetric quantities

- Basic dosimetric quantities
- **Application specific dosimetric quantities**

- Quantities for risk assessment

- Conversion coefficient for tissue and organ dose assessment

Basic dosimetric quantities

- Energy fluence
  Unit:J/m²

$$\Psi = \frac{dR}{da}$$

- Kerma
  Unit:J/kg, Gy

$$K = \frac{dE_{tr}}{dm} = \Psi\left(\frac{\mu_{tr}}{\rho}\right)$$

- Absorbed dose
  Unit:J/kg, Gy

$$D = \frac{d\bar{\varepsilon}}{dm} = \Psi\left(\frac{\mu_{en}}{\rho}\right)$$

Kerma vs absorbed dose

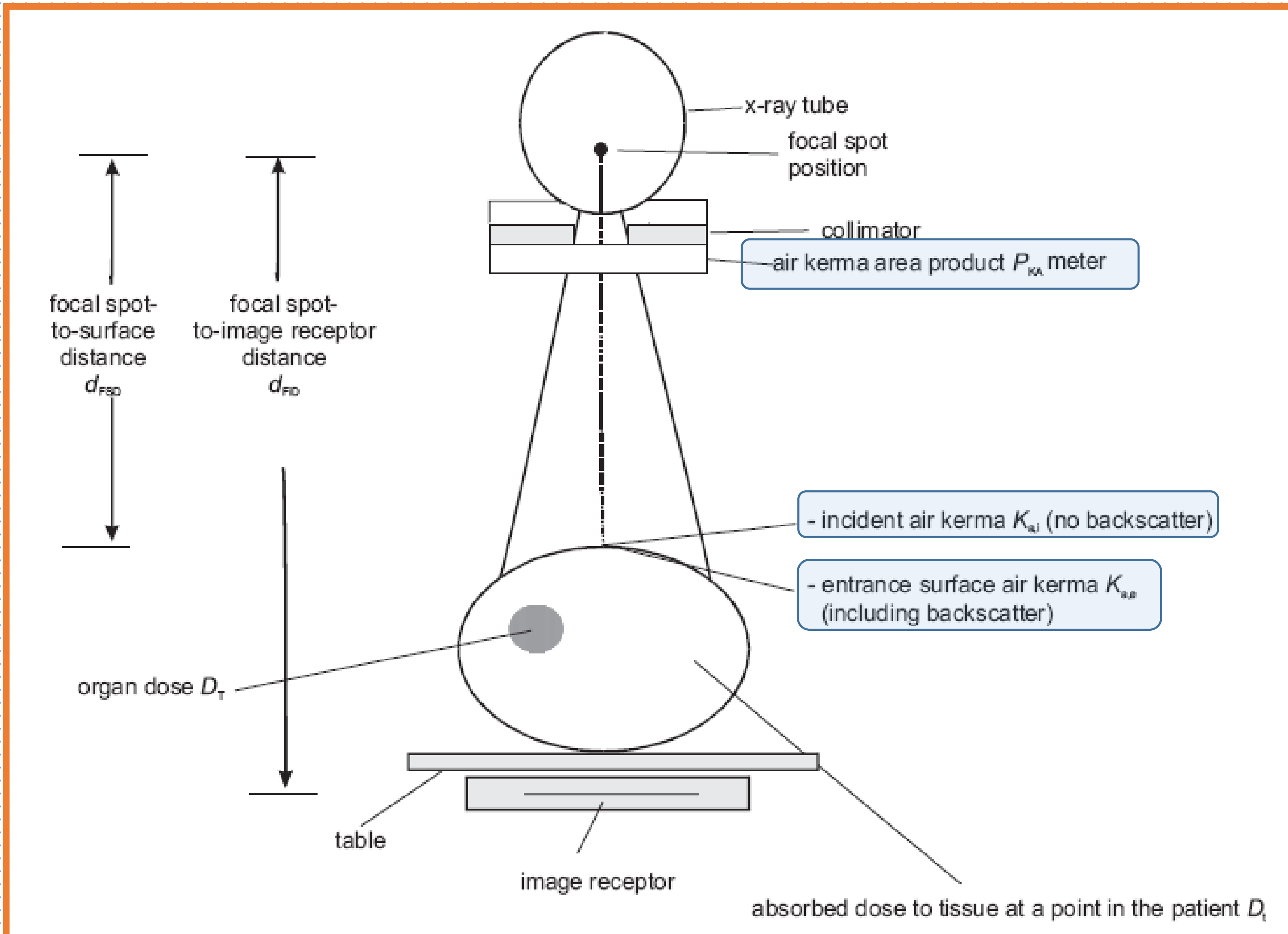
- Charged-particle equilibrium
- Absence of bremsstrahlung losses

$$\boxed{K = D = \Psi\left(\frac{\mu_{en}}{\rho}\right) = \Psi\left(\frac{\mu_{tr}}{\rho}\right)}$$

- Calibrations of dosimeters are made in terms of air kerma free-in-air
- It is often assumed that kerma is expressed only in air
- ICRU (1998): *one can refer to a value of kerma for a specified material at a point in free space, or inside a different material*

Application specific dosimetric quantities

Quantity	Symbol	Unit	Equation
Incident air kerma	Ki	Gy	
Entrance -surface air kerma	Ke	Gy	$K_e = K_i \cdot B$
Air-kerma area product	P_{KA}	Gym^2	$P_{KA} = \int_A K(x,y)dxdy$
Air-kerma length product	P_{KL}	Gym	$P_{KL} = \int_L K_{air}(z)dz$
X-ray tube output	Y(d)	Gy/As	$Y(d) = K_a(d) / P_{It}$



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Application specific dosimetric quantities

- **Measurement of application specific quantities**
  - In some situations it is desirable to make **direct measurements** of the application specific quantities
  - For others it is preferable to make **measurements using a standard phantom** to simulate the patient
    - quality control, the comparison of different systems and optimization studies
- The measurement methodology used depends upon the type of examination

Risk-related quantities

- **Measurements of risk-related quantities**
  - Risk-related quantities are usually **difficult to measure** directly
  - Generally estimated from application specific quantities using tables of dose **conversion coefficients**, determined either
    - by Monte Carlo calculation or
    - measurements using phantoms

See: E. Samei, Form measurable dose quantities to risk metrics

Risk-related quantities

Important note for effective dose

ICRP 103

- "…Effective dose is calculated for a Reference Person and **not for an individual.**"
- "Effective dose is **intended for use as a protection quantity**. The main uses of effective dose are the prospective dose assessment for planning and optimisation in radiological protection, and demonstration of compliance with dose limits for regulatory purposes. **Effective dose is not recommended** for epidemiological evaluations, nor should it be used **for detailed specific retrospective investigations of individual exposure and risk**."

ICRU 74

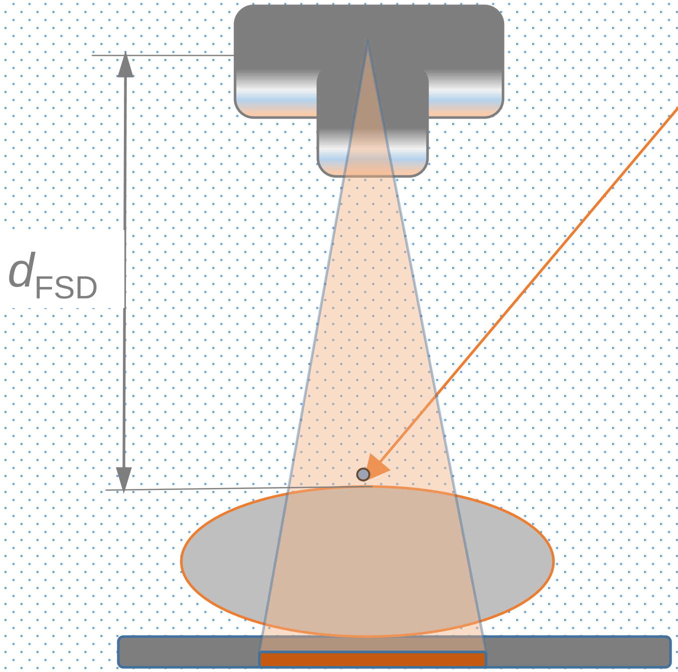
- "…effective dose **should not be used** for the assessment of risk from **medical exposures**."

Application specific dosimetric quantities

Dosimetric quantity for radiography

Modality	DRL quantity	Unit
Radiography	$K_{a,e}$	Gy mGy
	P_{KA} (KAP meter)	$Gy \cdot m^2$ $mGy \cdot cm^2$ $Gy \cdot cm^2$ $\mu Gy \cdot m^2$

Entrance surface air kerma



Incident air kerma, $K_{a,e}$

$K_{a,e} = K_{a,i} \cdot B$

B – Backscatter factor (1.2 – 1.4)

Unit: Gy

Direct measurement

Calculation from the tube output

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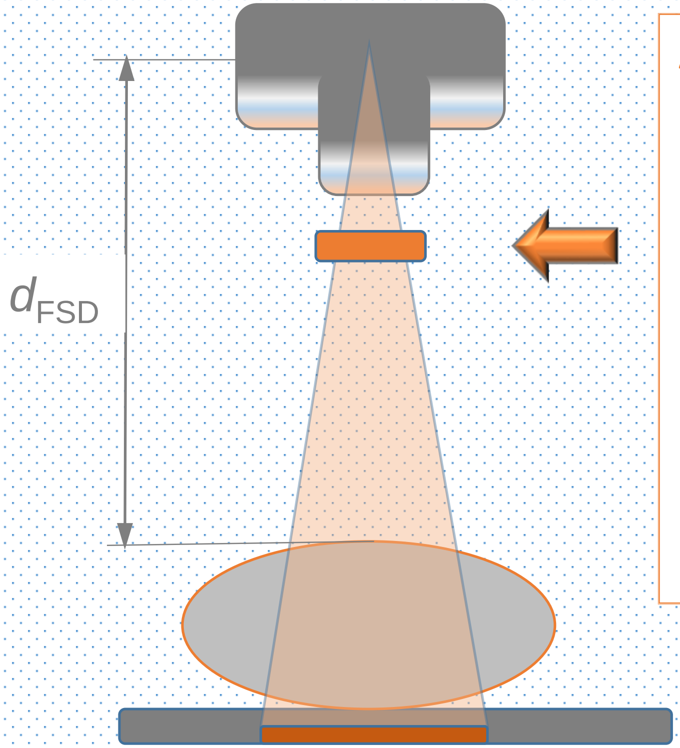
Air kerma-area product



Air kerma-area product (P_{KA})

$P_{KA} = K \cdot A$

K – air kerma

A – area

Unit: $Gy \cdot m^2$, $mGy \cdot cm^2$, $cGy \cdot cm^2$, $\mu Gy \cdot m^2$, $Gy \cdot cm^2$ …

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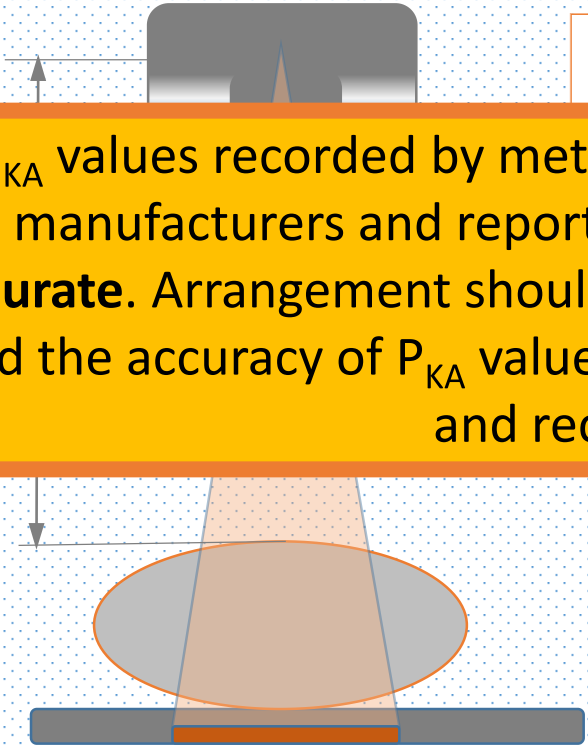
Air kerma-area product



Air kerma-area product (P_{KA})

P_{KA} values recorded by meters, calculated by the equipment, or given by the manufacturers and reported in the DICOM header **should be reasonably accurate**. Arrangement should be in place to **check the calibration** of P_{KA} meters and the accuracy of P_{KA} values calculated and displayed by the X ray equipment and recorded in the DICOM header.

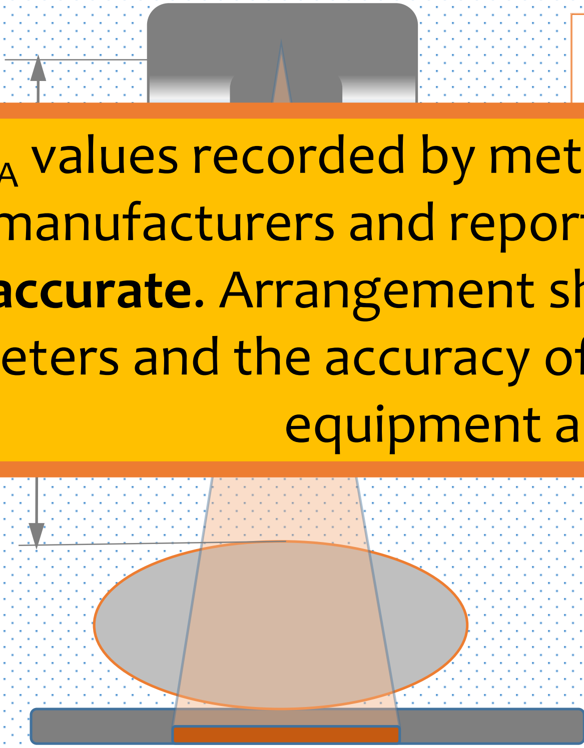
Note: *Standard IEC 60580 specifies acceptable limits of uncertainty in the response of P_{KA} meters when individual exposure vary to the maximum likely extent. According to this, the estimated expanded uncertainty of a measurement with P_{KA} meters is 25% at the 95% confidence interval (k = 2).*

References: IAEA TRS 457, IAEA, Vienna, 2007 and Lin, PJ, et. al. Accuracy and calibration of integrated radiation output indicators in diagnostic radiology: A report of the AAPM Imaging Physics Committee Task Group 190, Med Phys, 42: 6815-6829 (2015)

Dosimetric quantity for fluoroscopy and IGFP

Modality	DRL quantity	Unit
Diagnostic fluoroscopy and interventional procedures	P_{KA}	mGy cm^2
	$K_{a.r}$	Gy
	Fluoroscopy time	s
	Number of images in cine or digital subtraction angiography	Number

Air kerma-area product



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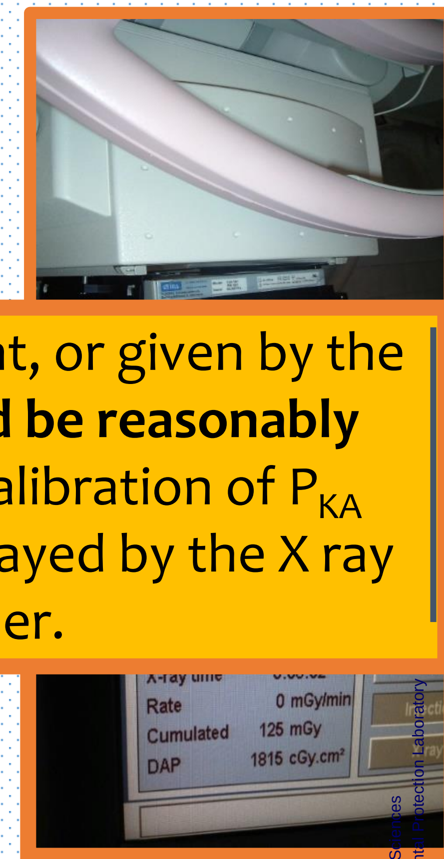

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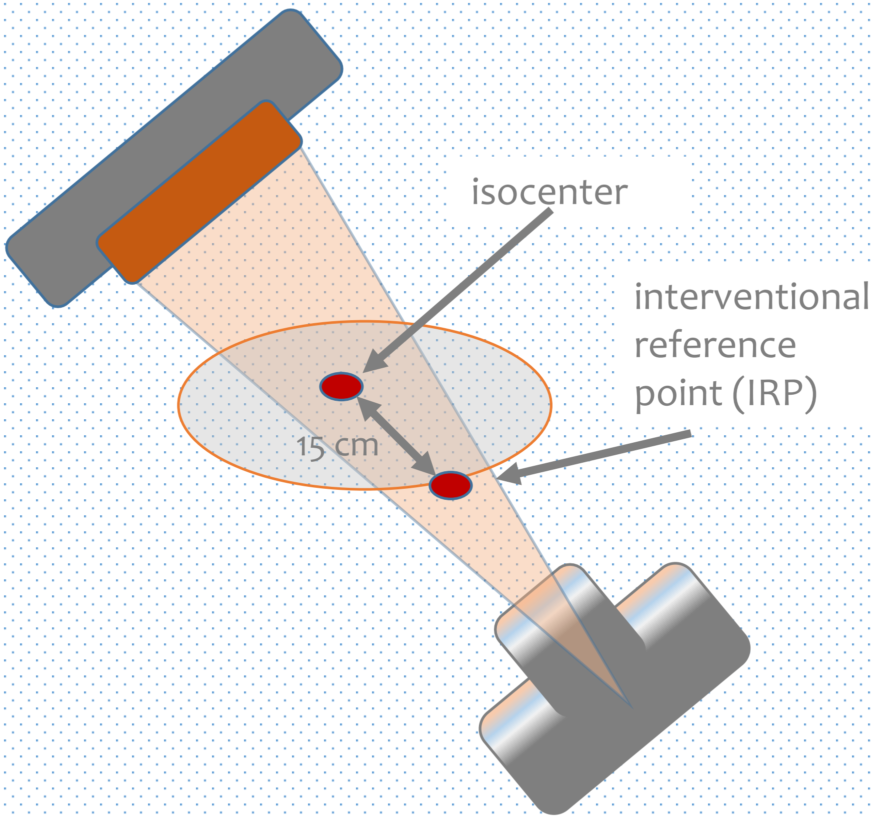
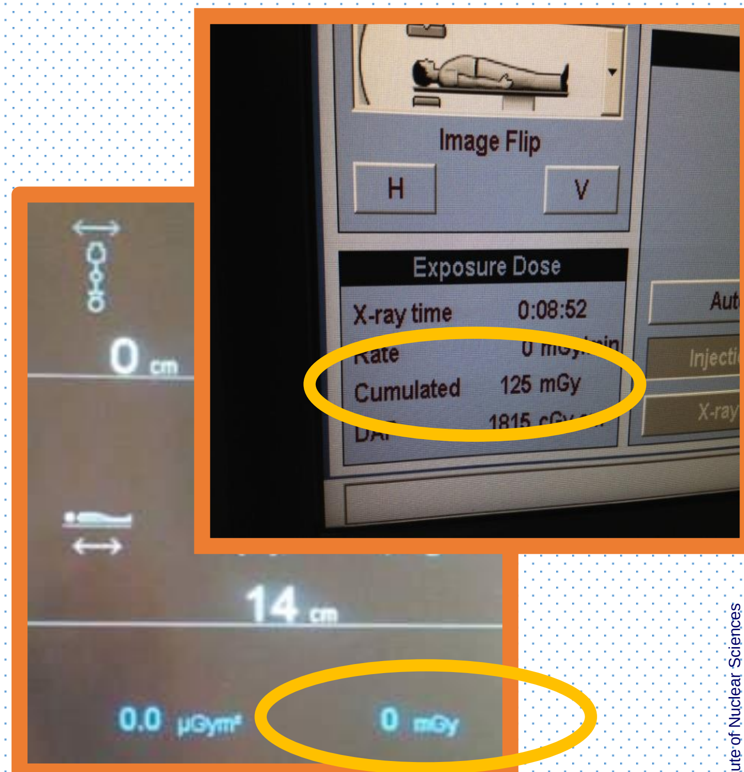
Air kerma in the intevenational reference point ($K_{a,r}$)





Dose quantities in computed tomography

TABLE 4. COMPARISON OF IAEA AND INTERNATIONAL ELECTROTECHNICAL COMMISSION DOSIMETRY TERMINOLOGY USED IN COMPUTED TOMOGRAPHY

Quantity	IAEA	International Electrotechnical Commission
Measured free-in-air:		
Computed tomography air kerma index	$C_{a,100} = \frac{1}{N \cdot T} \int_{-50}^{+50} K(z)\,dz$	$\mathrm{CTDI}_{air} = \frac{1}{N \cdot T} \int_{-\infty}^{+\infty} K_a(z)\,dz$
Measured in standard phantom:		
Weighted computed tomography air kerma index	$C_W = \frac{1}{3}(C_{PMMA,100,c} + 2C_{PMMA,100,p})$	$\mathrm{CTDI}_W = 1/3\mathrm{CTDI}_{100,c} + 2/3\mathrm{CTDI}_{100,p}$
Normalized weighted computed tomography air kerma index	${}_nC_W$	${}_n\mathrm{CTDI}_W$
Volume computed tomography air kerma index	C_{VOL}	CTDI_{VOL}
Computed tomography air kerma length product	$P_{KL,CT} = \sum_j {}_nC_{VOL_j} l_j P_{It_j}$	$\mathrm{DLP} = \mathrm{CTDI}_{VOL} L$

Displayed dose quantities in CT

CTDIvol

- Calculated from measurements at the centre and periphery of a standard PMMA CT head or body phantom
- Phantom size is displayed on the CT
- Represents the average dose within a slice
- Does not represent the actual patient dose

DLP

- Calculated from the CTDIvol
- Represents dose over the entire scan area
- Does not represent the actual patient dose

See: S. Edyvean, DRLs and exposure monitoring in CT

Post-scan dose display

- Dose information page
  - Different for different CT vendors
  - Image capture of mathematical data
- DICOM Radiation Dose Structured Report (RDSR)
  - In downloadable format

Calibration of dose display

Calibrations of displays should be verified, preferably at intervals of no more than 1–2 years. Calibration of instruments used to confirm the accuracy CT scanner displays of volume CTDI and DLP should be performed regularly and should be traceable to a national or international standard.

The difference between displayed and measured: <±20%

If any of the values be outside the tolerances, service is required.

It is important to verify if the CTDI displayed for paediatric use are based on a 32 cm, 16 cm or other diameter dose phantom

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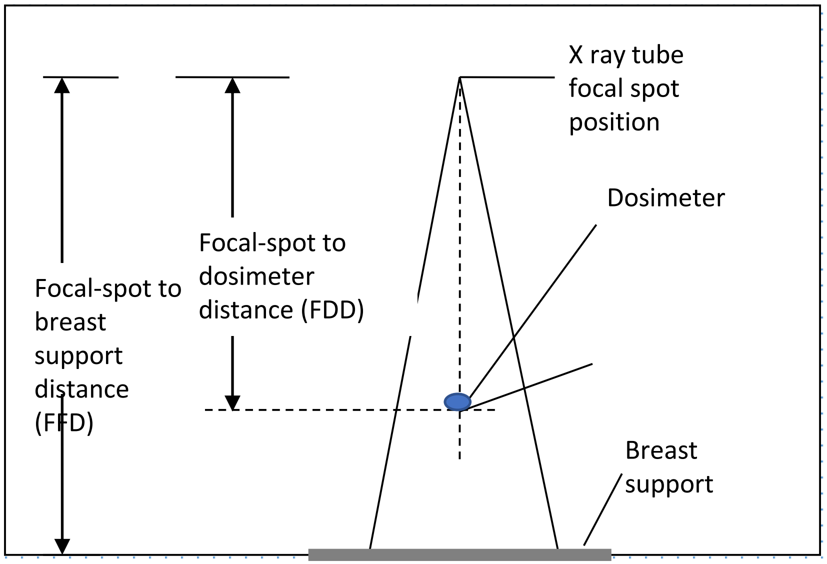
DRL quantity for mammography

Modality	DRL quantity	Unit
Mammography	$K_{a,e}$	mGy
	$K_{a,i}$	mGy
	D_G	mGy

See: O Ciraj Bjelac, Estabilishing and using DRLs for optimization in mammography

Incident air kerma

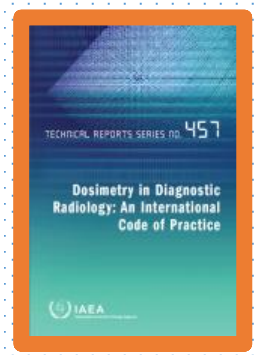


$$K_{a,i}(FDD) = M \cdot N_K \cdot k_Q$$

Incident air kerma

$$Y(U_0, FDD) = K_{a,i} / It_0$$

X ray tube output



For detailed information, please refer to IAEA TRS 457, https://www-pub.iaea.org/MTCD/publications/PDF/TRS457_web.pdf

Mean glandular dose

Incident air kerma

$$K_i = Y_{ref}\left(\frac{d_P - d_{ref}}{d_P - d_B}\right)^2 P_{It,pat}$$

d_P is the distance from the tube focus to the top of the breast support platform
d_{ref} and d_B are the distances from this platform to the reference point and the top of the breast (the breast thickness), respectively
$P_{It,pat}$ is the recorded tube loading for the patient exposure

Dance DR, Sechopoulos I. Dosimetry in x-ray-based breast imaging. Phys Med Biol. 2016 Oct 7;61(19):R271-R304

Mean glandular dose

$$D_G = c_{D_{G50},K_i}\, c_{D_{Gg},D_{G50}}\, s K_i$$

Conversion of the incident air kerma to the mean glandular dose for a breast of 50% glandularity

Conversion of the mean glandular dose for a breast of 50% glandularity to that for a breast of glandularity

Spectral correction factor

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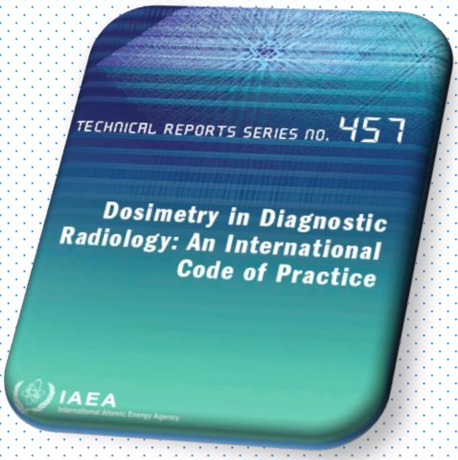
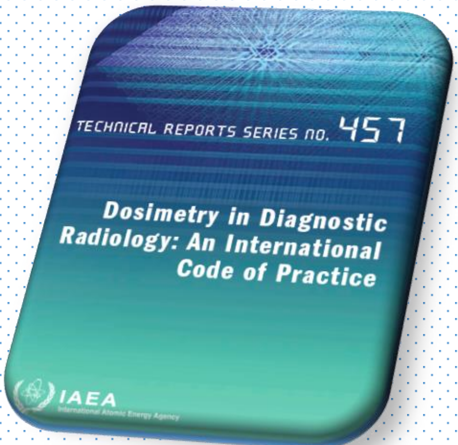
Clinical dosimetry: IAEA TRS 457



Modality	Measurement subject	Measured quantity	Comments
General radiography	Phantom	Incident air kerma	Methodology for using chest and abdomen/lumbar spine phantoms is described.
	Patient	Incident air kerma	Calculated from exposure parameters and measured tube output.
		Entrance surface air kerma	Measurements on patient's skin.
		Air kerma–area product	Methodology same as for fluoroscopy.
Fluoroscopy	Phantom	Entrance surface air kerma rate	Measured directly on a phantom or calculated from the incident air kerma rate using backscatter factors.
	Patient	Air kerma–area product	Maximum skin dose is also measured. As the methods are not standardized they are not included in this Code of Practice.

Clinical dosimetry: IAEA TRS 457



Mammography	Phantom	Incident air kerma	Mean glandular dose is the primary quantity of interest. It is calculated from measured incident air kerma.
		Entrance surface air kerma	When this is measured (using TLDs) the backscatter factors are used to calculate the incident air kerma.
	Patient	Incident air kerma	Mean glandular dose is the primary quantity of interest. It is calculated from the incident air kerma estimated from measurements of tube output by using the exposure parameters for the examination.
CT	Phantom	CT air kerma indices	Measurements in air or in PMMA head and body phantoms.
	Patient	CT air kerma–length product	Direct measurements on patients are not described in this Code of Practice. Instead, a CT air kerma–length product is calculated from patient exposure parameters and results of phantom measurements.
Dental radiography	Patient	Incident air kerma	Calculated from exposure parameters and measured tube output for bitewing projection.
		Air kerma–length product	Used for calculation of the air kerma–area product for a panoramic projection.

Calibration and accuracy

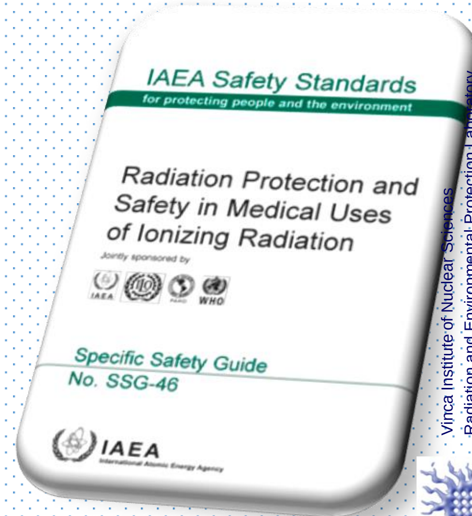
- All dosimeters used for dosimetry of patients
- To confirm the accuracy of:
  - P_{KA} meters
  - CT scanner displays of CTDIvol and DLP
  - Thermoluminescent dosimeters
  - Dosimetric quantity transferred from a X ray system
  - …

Calibration in the IAEA GSR-Part 3

- 3.167. In accordance with para. 3.154(d) and (e), the **medical physicist** shall ensure that:
- …..
- (d) **Calibration of all dosimeters** used for dosimetry of patients and for the calibration of sources is **traceable to a standards dosimetry laboratory**.

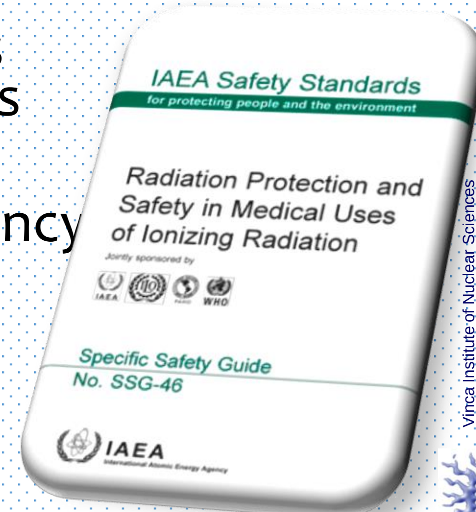
Calibration in the IAEA SSG 46

- 3.206. Dosimetry instrumentation used at a radiology facility should be calibrated at appropriate intervals. **A period of not more than two years is recommended.** See also para. 3.244 on associated quality assurance guidance.
- 3.207. … However, since **dosimetry accuracy is not as critical in diagnostic radiology as in radiation therapy**, calibrations with comparable radiation qualities should be sufficient. Alternatively, the regulatory body may accept instrument **manufacturers' "calibrations" as spelled out in the "certificate of calibration"** issued by the instrument manufacturer, provided that the manufacturer operates or uses a calibration facility that is itself **traceable to a SDL** and appropriate calibration conditions have been used. This certificate should state the overall uncertainty of the calibration coefficient.



Calibration in the IAEA SSG 46

- 3.209. There is a role for **cross-calibration** of dosimeters, where the radiology facility's **dosimeters that have been officially calibrated are used to check or compare with other dosimeters**
- This is particularly important for field air kerma product meters which should be calibrated (or cross-calibrated) against a reference air kerma product meter or air kerma dosimeter in situ in the clinical rather than in a SDL environment
- It might also occur when a radiology facility has many dosimeters, and to calibrate all dosimeters could be too costly
- Cross-calibration can also be utilized as a constancy check, as part of periodic quality control tests.



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Calibration in the IAEA TRS 457

Calibration.

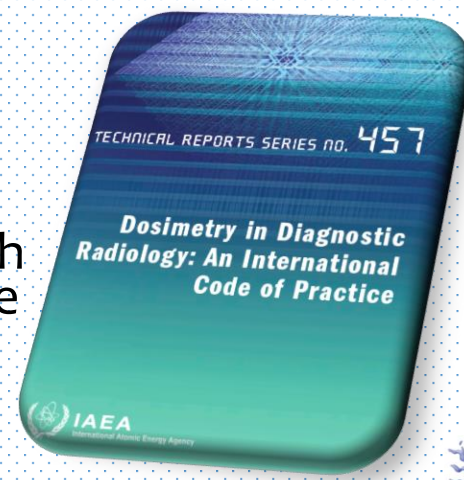
- A set of operations that establish the relationship between values of quantities indicated by the instrument under reference conditions and the corresponding values realized by standards.

Calibration of a diagnostic dosimeter.

- The comparison of the indication of the instrument under test with the conventional true value of the air kerma or air kerma rate with the objective of determining the calibration coefficient.

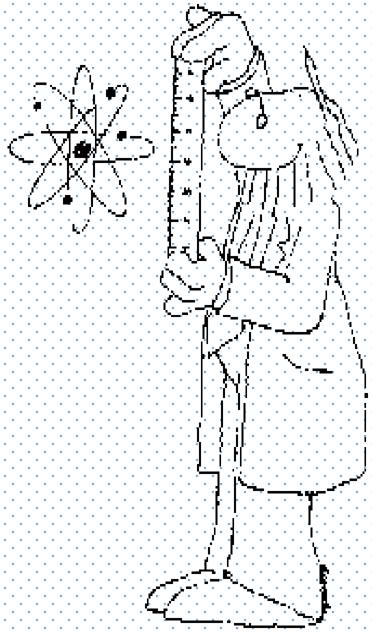
Traceability.

- The property of a result, measurement or standard whereby it can be related to a stated reference (usually a national or international standard) through an unbroken chain of comparisons, all of which have stated uncertainties.



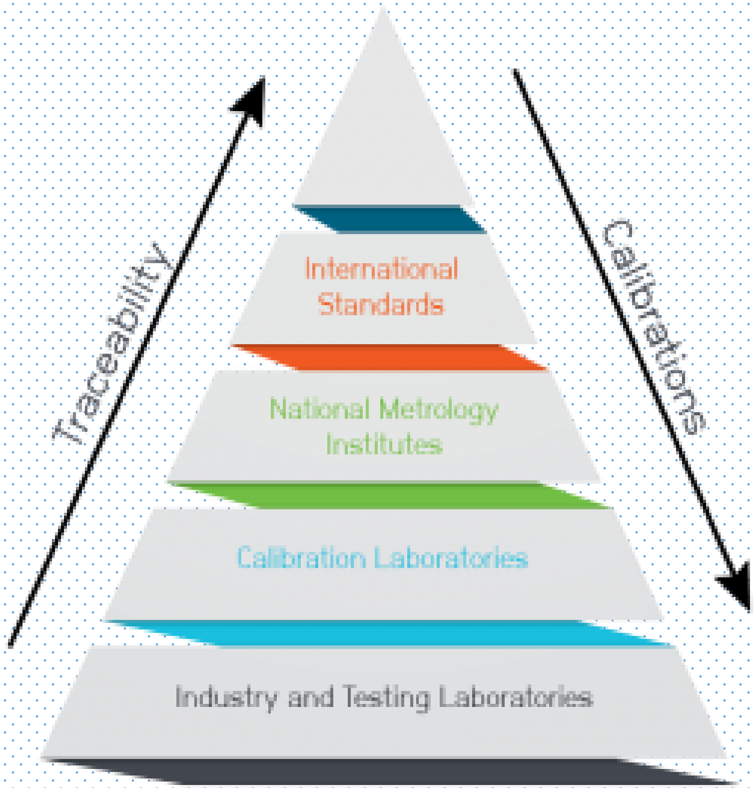
Basic metrology elements

- International Measurements System (IMS)
- Framework for dosimetry in diagnostic radiology
- Consistency in radiation dosimetry



International Measurements System (IMS)

- Bureau International des Poids et Mesures (BIPM)
- National Primary Standard Dosimetry Laboratories (PSDL)
- Secondary Standards Dosimetry Laboratories (SSDL)
- Users performing measurements (hospitals)



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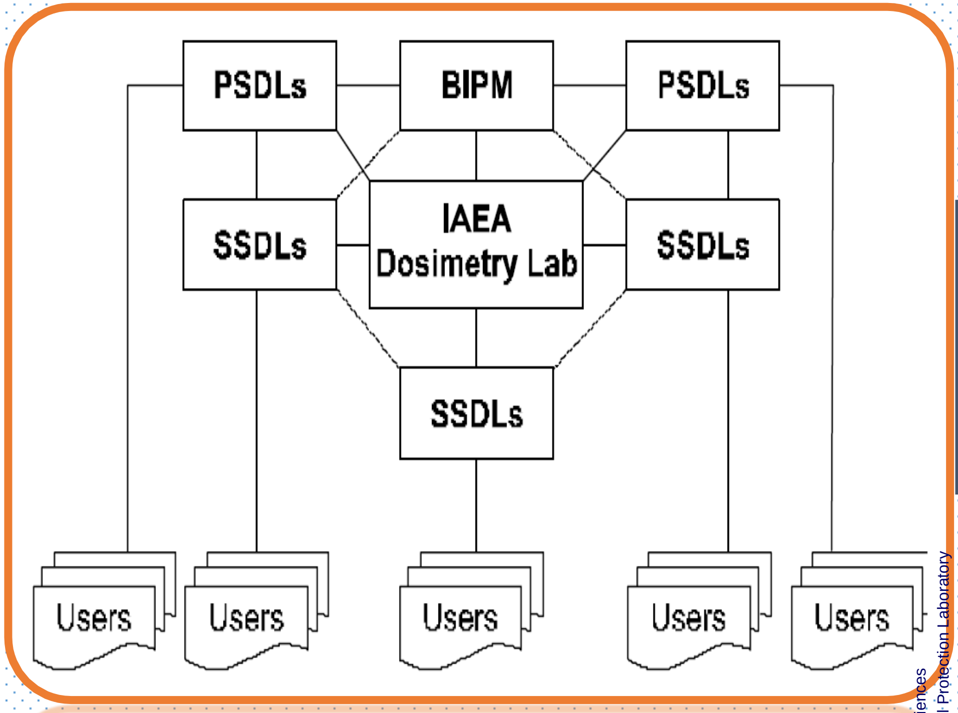
Metrology and traceability

- Measurements need to be traceable though an ***unbroken chain of comparisons*** to national and international standards
- Traceability is needed **to ensure accuracy** and reliability



Role of the SSDL

- The prime function: ***to provide a service in metrology***
- Designated by the competent national authorities
- SSDL-Secondary standards, calibrated against the primary standards of laboratories participating in the IMS

Dosimeters in diagnostic radiology

Tube voltage 20-150 keV, various A/F combinations, various modalities

Ionization chambers	Semiconductor dosimeters	Others
Accurate	Compact	TLD
Good energy dependence	Energy dependant	OSL
Design for different application (cylindrical, parallel-plate, different volumes..)		Film (radiochromic)
		Scintillation
		(kVp meters)

PSDL/SSDL

user

Dosimetry standards in diagnostic radiology

- IEC 61674: Dosimeters with ionization chambers and/or semi-conductor detectors as used in X-ray diagnostic imaging
  - *Diagnostic dosimeter: detector and measuring assembly*
- IEC 60580: Dose area product meters

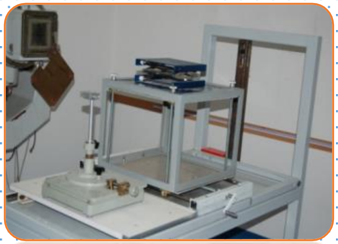
Calibrations in diagnostic radiology

- Air kerma:
  - *Radiography and mammography*
- Kerma-length product
  - *Dosimeters in CT*
- Kerma-area product
  - *Radiography and fluoroscopy*
- PPV: kVp meters

- Frequency: according to national regulations

Calibration in diagnostic radiology

- SSDL with relevant measurement capabilities
- General requirements: beam qualities, tube voltage and filtration measurements
- Dosimeter of reference class (with electrometer)
  - Calibrated
  - Quality control
  - Traceability for all beam qualities
- Auxiliary equipment: electrometers, thermometers, barometers…
- Environmental conditions



Equipment

Dosimetry

- Ionization chambers
- Position system
- HV supply for monitor and reference class ionization chamber
- Electrometer

Radiation source

- X-ray generator, 50-150 kVp, 20-40 kVp
- Ripple less than 10% for radiography and less than 4% for mammography
- Beam qualities according IEC 61267
- “Shutter” mechanism
- Filters and attenuators
- Tube voltage meter (ppv, ±1.5%)

Reference class dosemeter

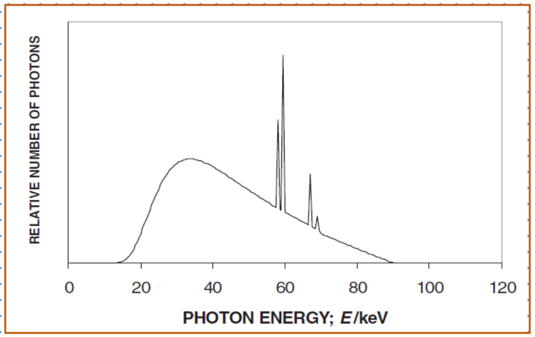
Application	Type of chamber	Range tube voltage (kV)	Intrinsic uncertainty (k=2)	Maximum variation of response (%)	Range of air kerma rate	
					Unattenuated beam	Attenuated beam
General radiography	cylindrical or plane parallel	60-150	3.2	±2.6	1 mGy/s-500 mGy/s	10 µGy/s-5 mGy/s
Fluoroscopy	cylindrical or plane parallel	50-100	3.2	±2.6		0.1 µGy/s-100 µGy/s
Mammography	plane parallel	22-40	3.2	±2.6	10 µGy/s-10 mGy/s	
CT	cylindrical	100-150	3.2	±2.6	0.1 mGy/s-50 mGy/s	
Dental radiography	cylindrical or plane parallel	50-90	3.2	±2.6	1 µGy/s-10 mGy/s	

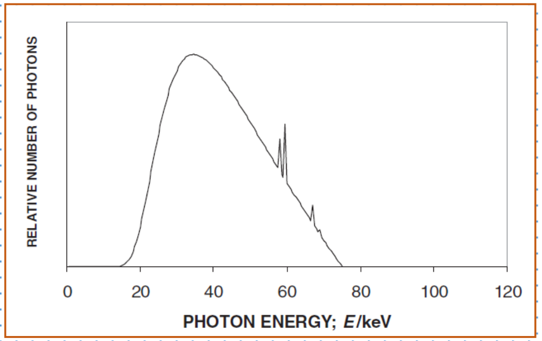
Specification of the x-ray beam

- Spectrum
- X-ray beam quality:
  - First half-value layer (HVL_1)
  - Second half-value layer (HVL_2)
  - Homogeneity coefficient:

$$h = \frac{HVL_1}{HVL_2}$$

  - Tube voltage
  - Total filtration

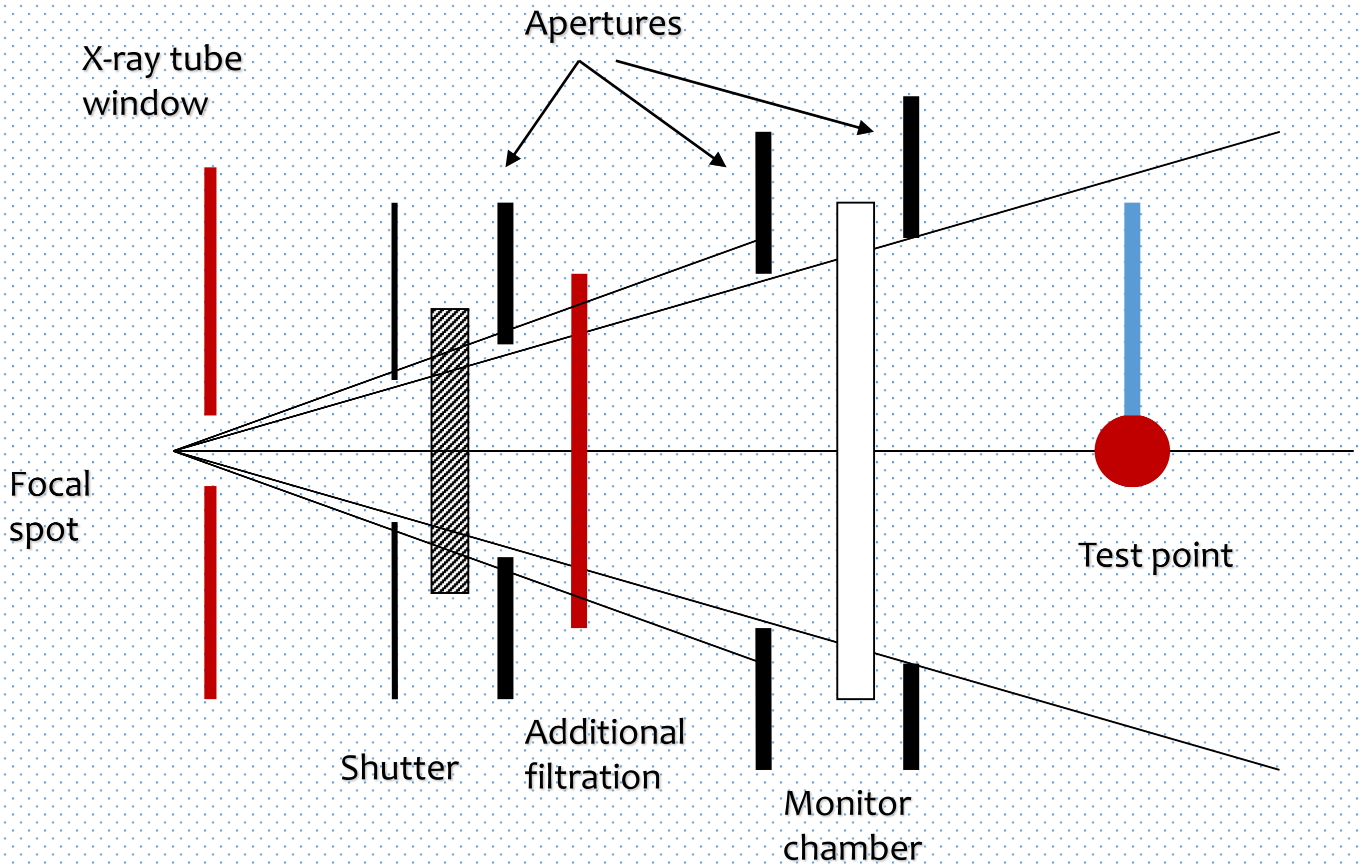




Radiation beam qualities (IEC 61267)

Radiation quality	Radiation origin	Phantom material	Application
RQR	Unfiltered beam emerging from x-ray assembly	No phantom	General radiography, fluoroscopy, dental radiology
RQA	Radiation beam from an added filter	Aluminium	Measurements behind the patient (on the image intensifier)
RQT	Radiation beam from an added filter	Copper	CT applications (free in air)
RQR-M	Unfiltered beam emerging from x-ray assembly	No phantom	Mammography (free in air)
RQA-M	Radiation beam from an added filter	Aluminium	Measurements behind the patient

Typical calibration set up



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Dosimetry formalism

- Calibration coefficients

$$N_{K,Q_0}^{\text{user}} = N_{K,Q_0}^{\text{ref}} \left(\frac{(Mk_{\text{TP}})^{\text{ref}}}{(mk_{\text{TP}})^{\text{ref}}} \right) \left(\frac{(mk_{\text{TP}})^{\text{user}}}{(Mk_{\text{TP}})^{\text{user}}} \right)$$

- Air kerma:

$$\boxed{K = (M_Q - M_0) N_{K,Q_0}}$$

- Air density correction:

$$\boxed{k_{TP} = \frac{P_0}{P} \frac{273.15 + T}{273.15 + T_0}}$$

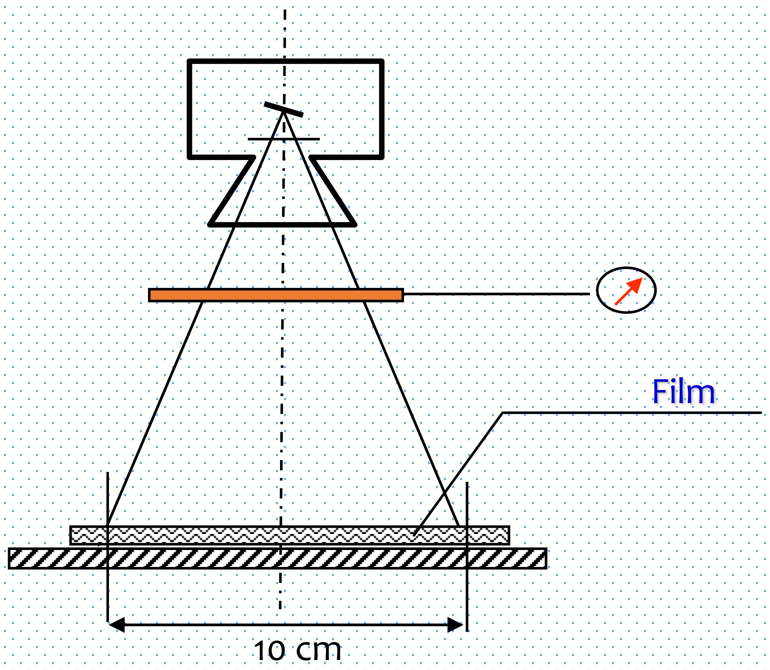
- Beam quality correction:

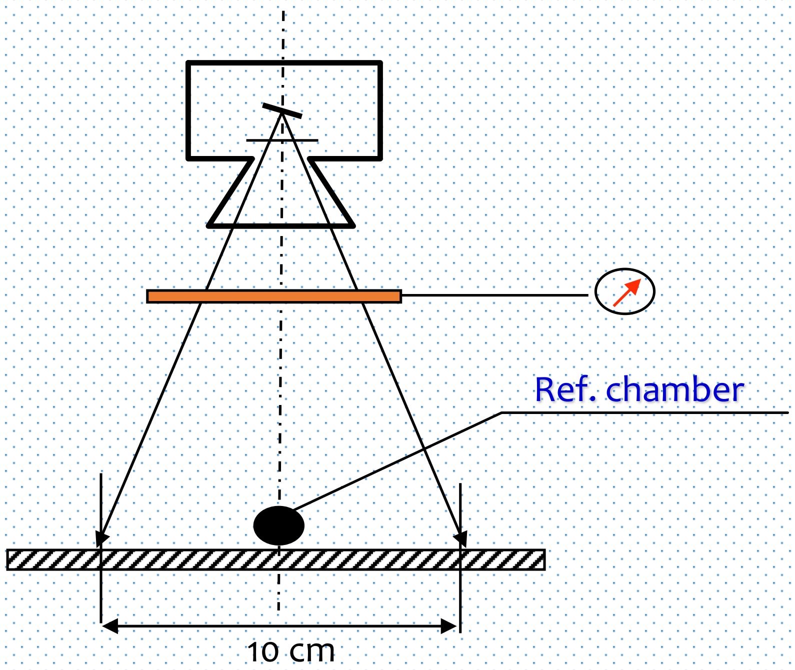
$$\boxed{K_Q = M_Q \cdot N_{K,Q_0} \cdot k_{Q,Qo}}$$

Calibration for fluoroscopy: air kerma area product

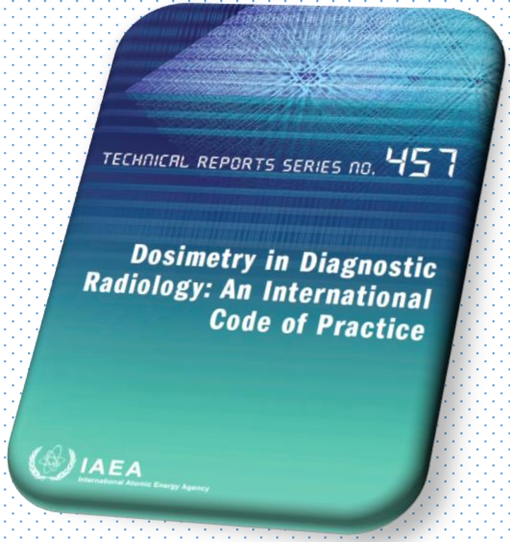
- In laboratory (SSDL)
- Field calibration

$$N_{P_{KA},Q} = \frac{M^{ref} N^{ref}_{K,Qo} k_Q A_{nom}}{M^{KAP}}$$





Calibration of KAP meters



Using a diagnostic dosimeter

$$N_{P_{KA},Q} = \frac{M_Q^{\mathrm{ref}}}{M_Q^{\mathrm{KAP}}} N_{K,Q_0}^{\mathrm{ref}} k_Q^{\mathrm{ref}} A_{\mathrm{nom}}$$

Using a reference KAP meter

$$N_{P_{KA},Q} = \frac{M_Q^{\mathrm{KAP_{ref}}}}{M_Q^{\mathrm{KAP}}} N_{P_{KA},Q_0}^{\mathrm{ref}} k_Q^{\mathrm{ref}}$$

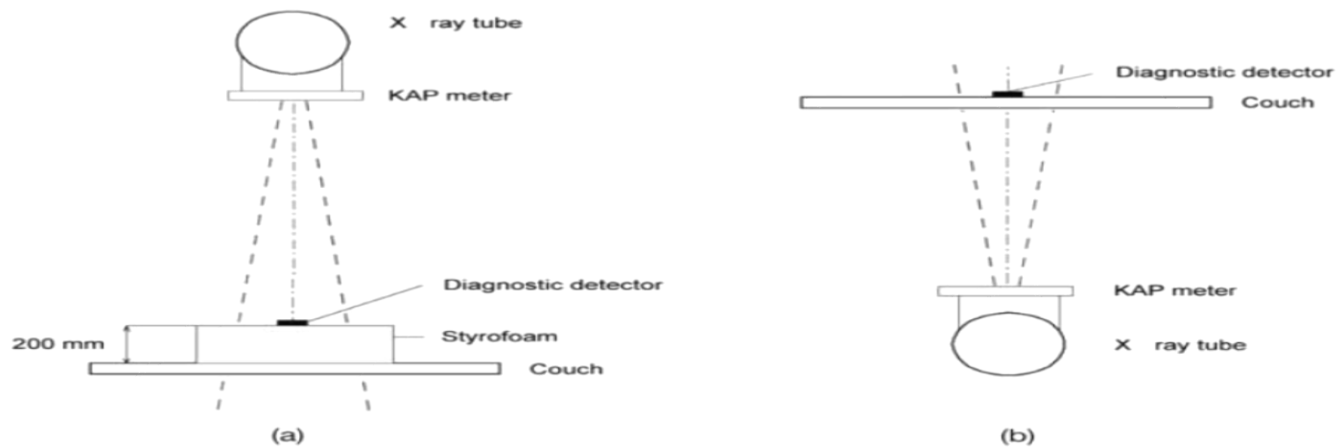


FIG. IX.1. Set-up for KAP meter calibrations: (a) is an over couch installation, Styrofoam being used to support the detector at a distance sufficient to avoid the effect of backscattered radiation, (b) is an under couch installation.

Uncertainty budget ate SSDL

- Uncertainty of the reference standard
- Uncertainty of user's instrument
- Uncertainty due to calibration set up
- Uncertainty of the evaluation procedure

Uncertainty budget

- Calibration coefficient
- Repeatability
- Resolution of reading
- Long term stability
- Radiation quality
- Air kerma rate
- Incidence of radiation
- Field size
- …

Uncertainty budget at SSDL

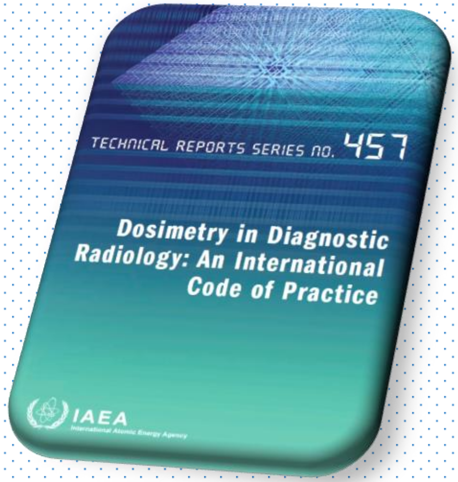
- Air kerma: ± 2.7 %
- Air kerma length product: ± 3.0 %
- Air kerma area product: ± 15 %
- Non-invasive tube voltage measuring devices: 2.5 %

Uncertainty budget of clinical dosimetry

- A Clinically Qualified Medical Physicist (CQMP) has to be aware of **the level of confidence** with which results are reported.
- **Appropriate calibration** is necessary to ensure acceptable level of accuracy.

Uncertainty budget of clinical dosimetry

- **Examples of the overall uncertainty** of **measurement** with **calibrated field dosimeter**, applying air density correction
  - $\mathbf{K_i}$ (radiography) : 12.6%
  - $\mathbf{K_e}$ (fluoroscopy) : 14.2%
  - $\mathbf{D_G}$ (mammography) : 13.8%
  - $\mathbf{P_{KL,CT}}$ (CT) : 14.6%



Quality assurance of dosemeters

- General properties of an instrument type are characterized during type testing
- Response to different radiation energies, angles of incidence, doses, dose rates, and other influencing parameters are measured
- Before use, a given instrument **must be calibrated**
- The complexity of the calibration procedure depends on the particular type of instrument and its intended use (single point vs entire range)
- Constancy checks are desirable (uncertainty type A)

VERIDIC

Validation and Estimation of Radiation skIn Dose in Interventional Cardiology

Testing of the filed dosemeters in standard and non-standard beam qualities

Diagnostic dosemeters

- Ion chambers: standard instruments used for diagnostic radiology dosimetry and quality assurance for many years
- **Semiconductor detectors:** widely available and more convenient to use
- Both should be in ***compliance with IEC 61674 standard***
- Traditionally, the main disadvantage of semiconductors has been their energy dependence of response which differs considerably from that of ionization chambers

Semiconductor dosemeters: basic properties

- Different from that of ionisation chambers
- Multiple semiconductor elements incorporated into the semiconductor detector used for x-ray dosimetry
- Assessment of radiation quality that is used to derive a dose and **compensation which is then applied automatically**
- The commercial semiconducting detectors are mounted on lead backing plates, to attenuate radiation incident from the rear (for corrected automatic energy compensation)
- Capable to determine: **air kerma, tube voltage, half value layer (HVL), and exposure time, output waveform** from a single irradiation

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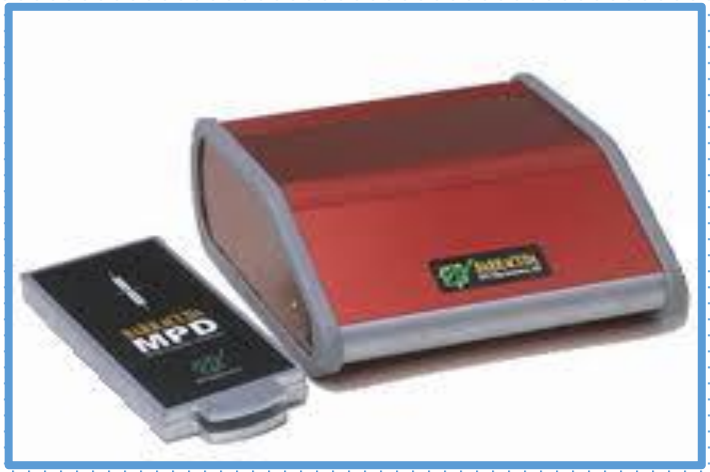
Calibration

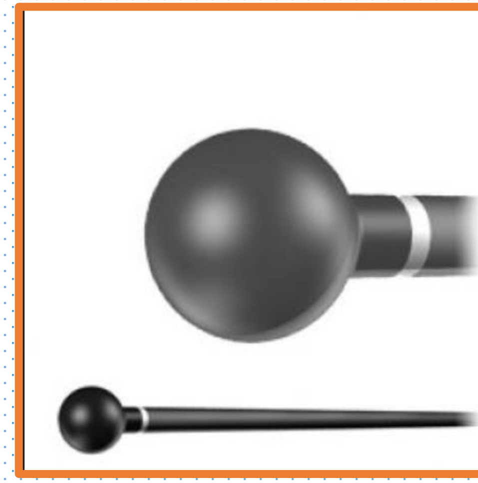
- Routinely calibrated (reference beam qualities according to IEC 61267): RQR 3 (50 kV) - **RQR 5 (70 kV)** - RQR 6 (80 kV) - RQR 8 (100 kV) - RQR 9 (120 kV)
  - Not necessarily representative of the beams used clinically
  - Combination of different energy and angular responses will influence detector performances in different x-ray fields
  - Could lead to significant differences in air kerma measurements

Protocol: dosemeters

No	Manufacturer	Model	X-ray tube voltage or energy	Dose range	Dose rate range	Remark
1	**RTI. Moldaln. Sweden**	MPD. Barrcuda	35 – 155 kV	15 nGy – 1000 Gy	15 nGy/s – 450 mGy/s	Multidetector elements. reference point at center of marked area
2	**RTI. Moldaln. Sweden**	R100. Barrcuda	Not specified	2 nGy – 10 kGy	0.04 µGy/s – 160 mGy/s	Single detector. reference point at center of marked area
3	**RTI. Moldaln. Sweden**	Black Piranha	50–150 kVp. 1–90 mm Al or 2 mm Cu	0.1 nGy–1500 Gy	1 nGy/s–320 mGy/s	Multidetector elements. reference point at center of marked area
4	**RaySafe. RTI. Moldaln. Sweden**	Xi R/F Classic	35 – 160 kV/kVp (for up to 0.5 mm Cu or equivalent)	10 nGy – 9999 Gy	10 nGy/s – 1000 mGy/s	Multidetector elements. reference point at center of marked area
5	**Exradin A3 .Standard Imaging. PTW**	A3. Unidos. 3.6 cc	-	-	-	Dosimetry standard


MPD


Piranha




TUBE SIDE
R100
Code: 8
RTI Electronics


RaySafe
Xi

Protocol: Beam qualities

- STANDARD BEAM QUALITIES

Beam quality	X-ray tube voltage (kV)	First HVL (mm Al)
RQR 5	70	2.58
RQR 6	80	3.01
RQR 8	100	3.97
RQR 9	120	5.00

Protocol: Beam qualities

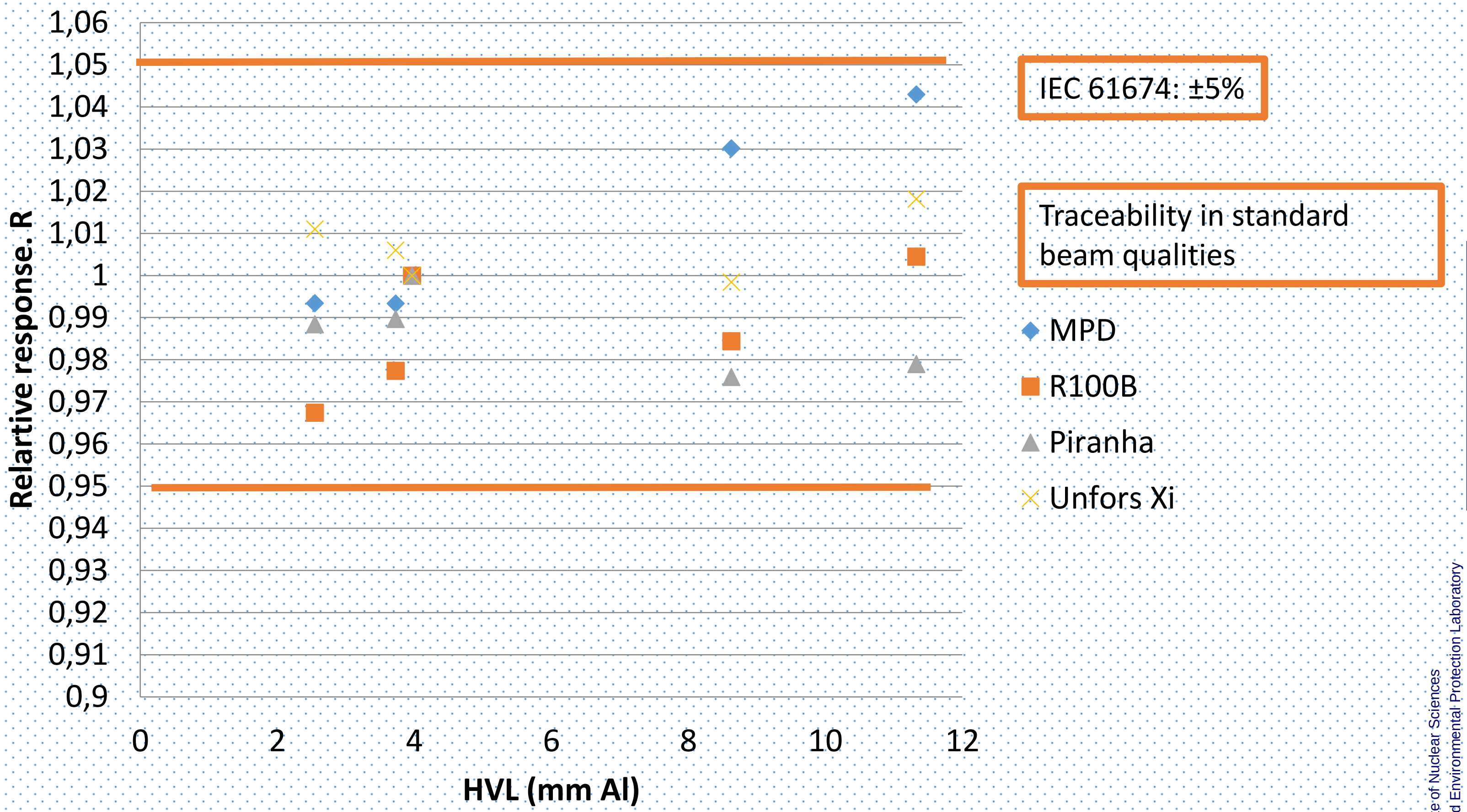
- NON-STANDARD BEAM QUALITIES

Beam quality	X-ray tube voltage (kV)	Inherent filtration (mm Al)	Added filtration (mm Cu)	First HVL (mm Al)
R80_0	80	2.5	0	2.55
R80_01	80	2.5	0.1	
R80_03	80	2.5	0.3	
R80_09	80	2.5	0.9	8.63
R120_0	80	2.5	0	3.73
R120_01	80	2.5	0.1	
R120_03	80	2.5	0.3	
R120_09	80	2.5	0.9	11.33

Protocol: Parameters

No	Parameter	Method	Details
1	**In air comparison**	Substitution	FDD = 100 cm
2	**Angular response**	Clockwise rotation of detector (positive) and opposite (negative) using protractor	RQR8 and frequently used non-standard R80_09. D = 100 cm. angles: 0, ±15, ±30, ±45, ±60, ±90, all measurements normalized to zero angulation
3	**In air comparison for energy response**	Substitution, all standard and non-standard beam qualities	FDD = 100 cm, all measurements normalized RQR8
4	**Response linearity**	Substitution	RQR8 and frequently used non-standard R80_09, FDD = 100 cm, dose rates generated using tube current in the range (3-25) mA, 5 (7) dose rate points

Energy response



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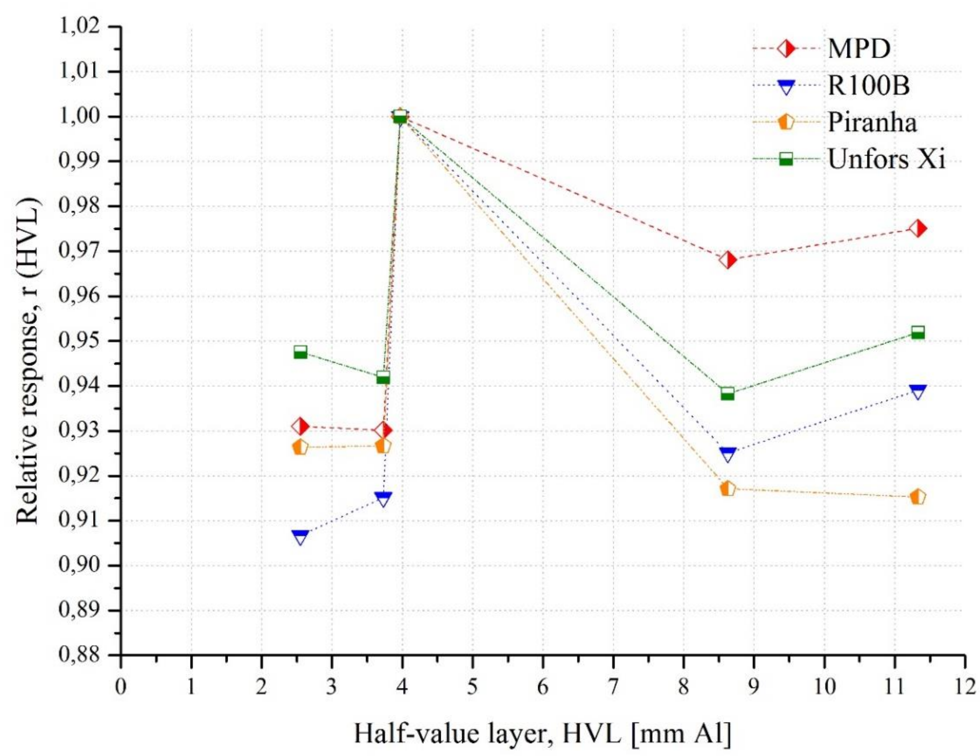
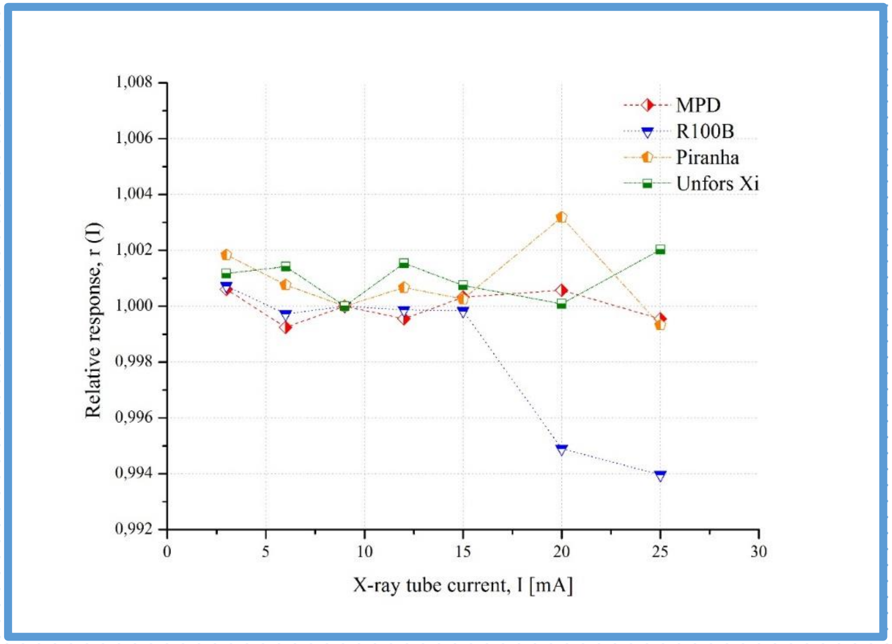
Energy response



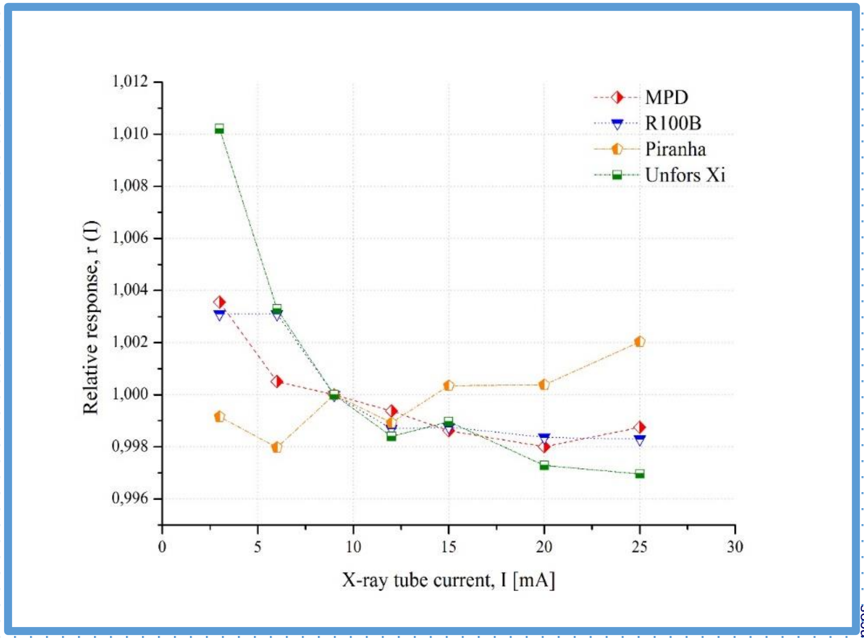
Traceability in non-standard beam qualities

Laboratoire National
Henri Becquerel

Linearity



r (I) / r (Kair) - RQR8



R (I) / r (Kair) - R80_09

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Linearity

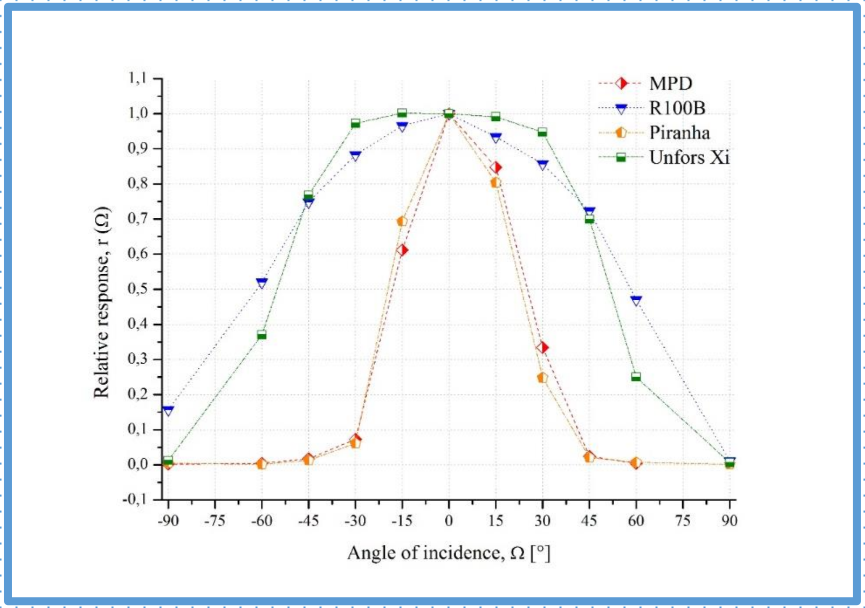
- IEC 61674:2012

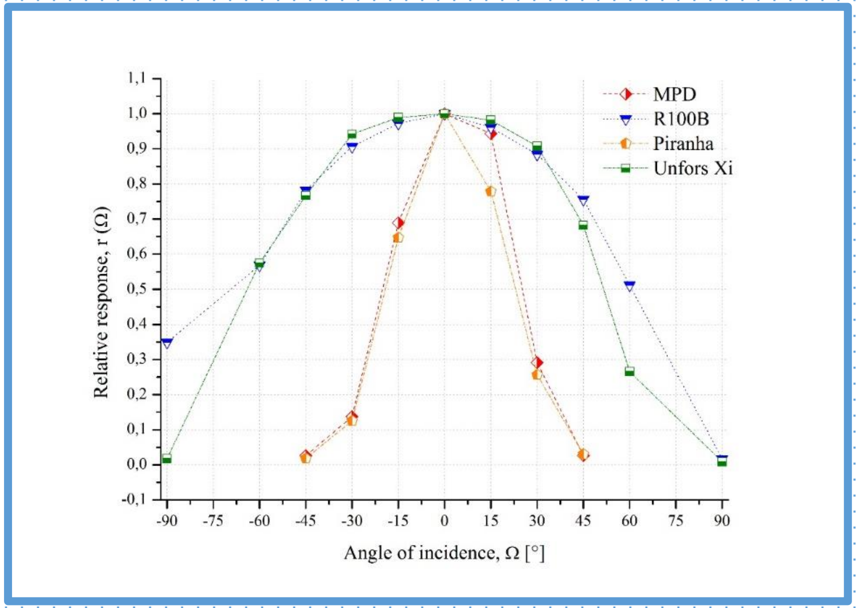
$$\frac{R_{\max} - R_{\min}}{R_{\max} + R_{\min}} \leq 0{,}02$$

RQR8	MPD	R100	Piranha	Xi
min	2,70	2,75	2,77	2,77
max	2,70	2,77	2,78	2,77
R	**0,00**	**0,00**	**0,00**	**0,00**

R80_09	MPD	R100	Piranha	Xi
min	2.67	2.57	2.56	2.62
max	2.69	2.58	2.58	2.65
R	**0.00**	**0.00**	**0.00**	**0.01**

Angular response





Re-cap

- Fundamental, application specific and risk related quantities
- Application specific dosimetry quantities
  - The measurement methodology used depends upon the type of examination
  - Patients and phantoms
- Calibration and testing ofdosemeters
- Uncertainty of dose measurement

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