22NRM01 TraMeXI

Traceability in Medical X-ray Imaging Dosimetry

Setting Up Reference Fields
X-Ray Units
Establishing RQR, RQT, RQR-M

Workshop for radiation metrologists on calibration of dosimeters used for X-ray imaging
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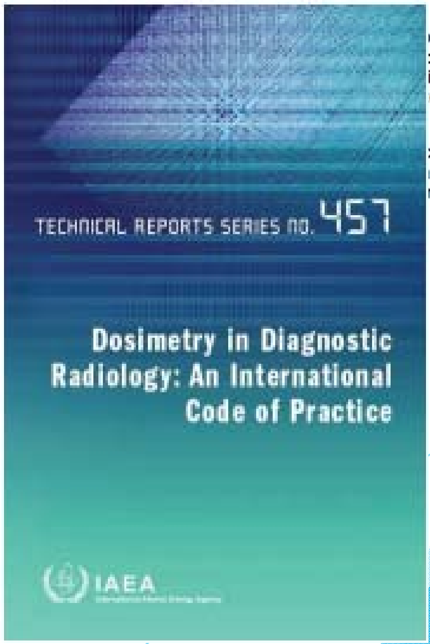
Erinç REYHANİOĞLU
TENMAK - NÜKEN

- Two reference documents
  - IEC 61267
    - Gives the definition of reference radiation qualities RQR, RQT……
    - Explians in detail the methods to generate X-ray beams used for calibration
  - TRS 457
    - Gives the same information with a practical approach
  - ISO 4037
    - Although it is protection level, has information about X-Ray fields



Setting Up Standard Radiation Qualities

IEC 61267

- A standard radiation condition is described by;
  - Anode material — Tungsten
  - Tube Voltage — 70 kV
  - Total Filtration
    - Inherent + Additional — 3,02 mm Al
  - 1st HVL — 2,58 mm Al
  - Homogeneity coefficient — 0,71

RQR 5

Radiation Qualities For Calibrations Of Diagnostic Dosimeters (TRS 457)

TABLE 6.1. RADIATION QUALITIES FOR CALIBRATIONS OF DIAGNOSTIC DOSIMETERS

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

X Ray equipment

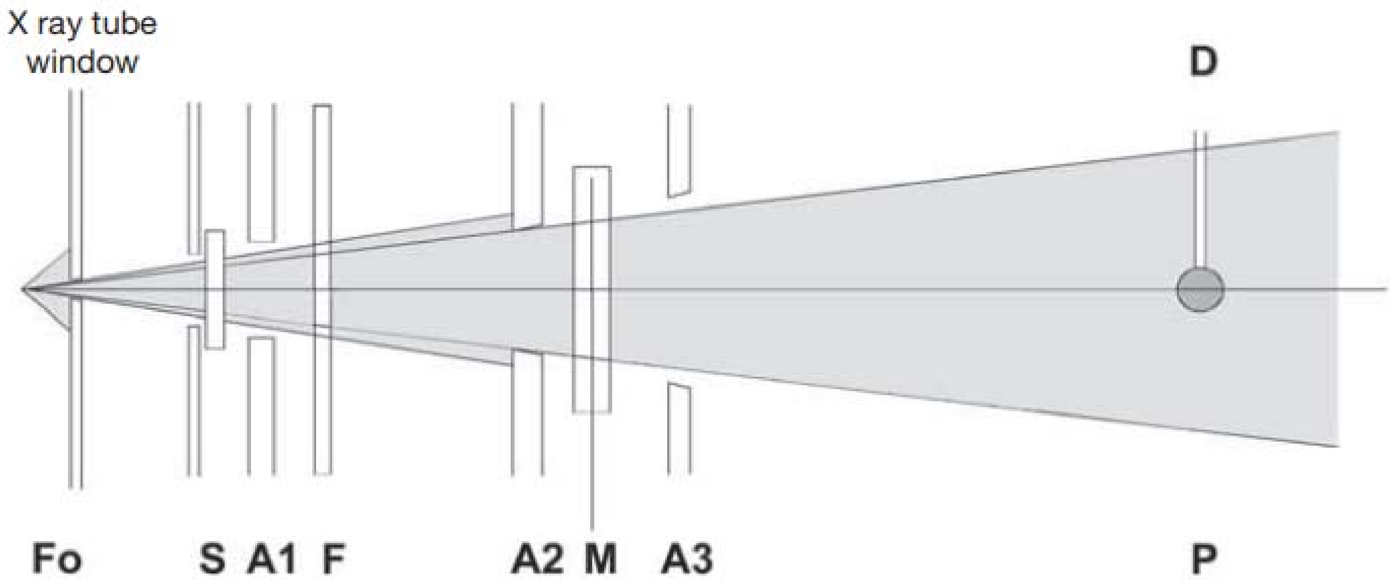


FIG. 6.5. Schematic drawing of the calibration set-up. Fo: focal spot; S: shutter; A1, A2, A3: apertures; F: added filtration; M: monitor chamber; D: detector; P: point of test.

From TRS 457

X Ray equipment

- Shutter
  - must be thick enough to reduce the transmitted air kerma rate to 0.1% for the radiation quality with the highest mean energy (~2 mm at 150 kV)
- Apertures
  - Opening angle of aperture
    - no radiation emitted by the X ray tube should hit the inner cone of the aperture

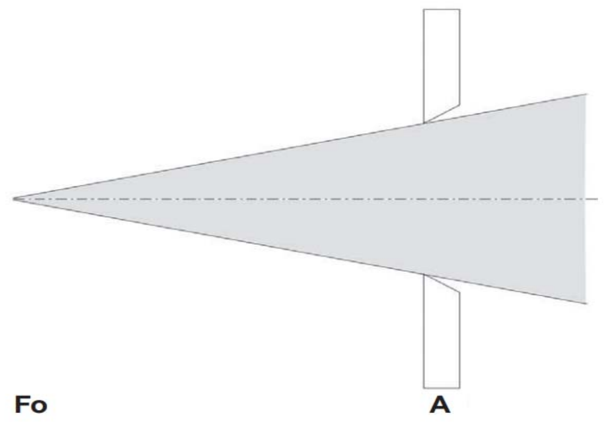


FIG. 6.6. Schematic drawing of apertures designed for low scatter contributions. Fo: focal spot, A: aperture.

X Ray equipment

- Apertures
  - A2 – close to additional filtration
  - Should enable a beam area enough to completely irradiate dosimeters
    - 1.5 times larger than linear size of secondary stadard
  - The partition at the center corresponding to 80 % of the field, air kerma rate should be within 2 %

X Ray equipment

- Anode
  - Material
    - Tungsten
    - Molybdenum
    - Rhodium
  - Angle
    - The anode angle should not be larger than 27° (TRS 457)

- Inherent filtration always should be less than 2,5 mm Al

X Ray equipment

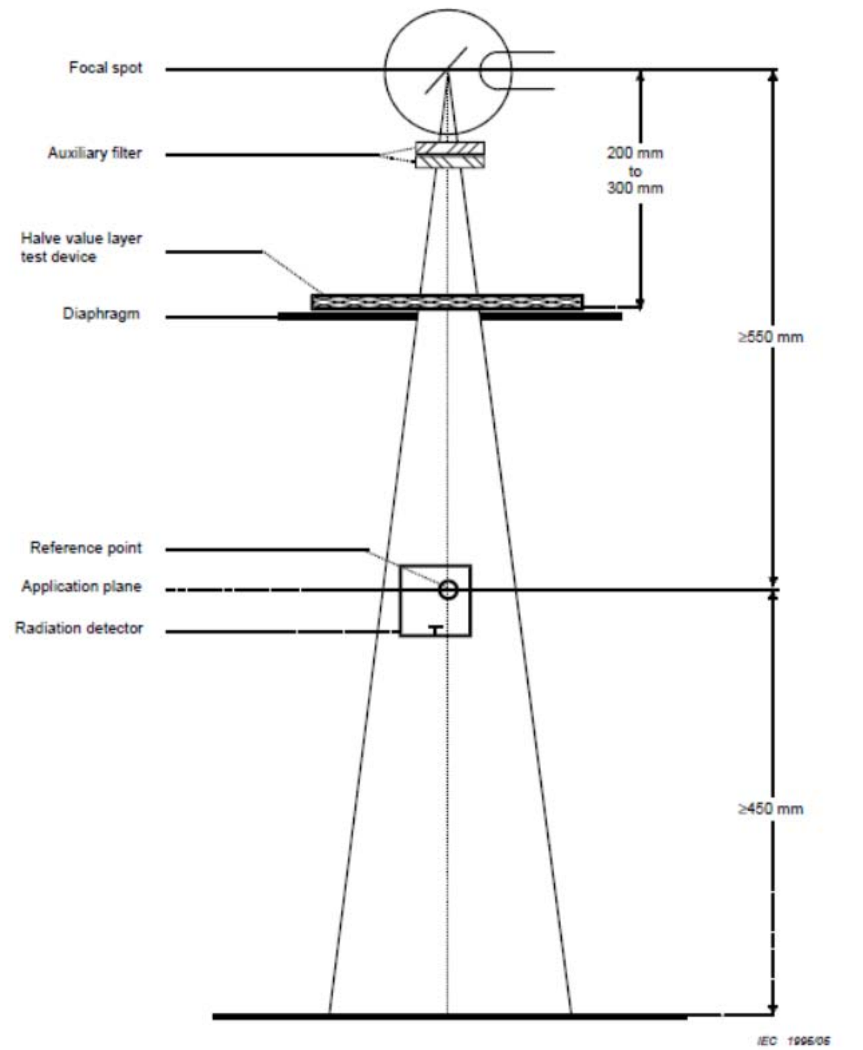
- Monitor chamber
  - Transmission chamber
  - Between A2 and A3 which should be very close
  - Leakage should be less than 2 %
- Filters
  - Used to suppress low energy region
  - 99,9 % purity required
  - Thickness to be known within 10 µm
  - Should be homogeneous over the cross-sectional area

X Ray equipment

- Ionization chamber
  - Leakage current should be less than 10^{-14} A
  - wall thickness sufficient for completion of buildup
- Power suppy
  - The voltage output should be known to within 1% and be stable to within 0.05% (k = 2). Short term stability should be within 1 mV/s
- Electrometer
  - sufficient quality to meet the laboratory's accuracy goals for the calibration at all kerma rates

Calibration Set up

- Scattering conditions, environmental conditions should be considered.
- Detector positioning, to restrict detector positioning error to a level consistent with uncertainty goals



X Ray equipment

- High voltage generator
  - Should deliver constant tube voltage over the required range
    - 50 – 120 kV for diagnostic radiology
    - 20 – 40 kV for Mammography
  - Ripple : [(Vmax – Vmin) / Vmax] x 100
    - Less than 10 % diagnostic radiology
    - Less than 4 % for mammography
  - Should be calibrated and tracable

Reference Fields

The full characterization of an X ray beam can be obtained by fluence spectrum. A more practical characterization can be done by measurement of 1st and 2nd HVL

- To begin with, Tube voltage must be determined
  - Practical Peak Voltage

The PRACTICAL PEAK VOLTAGE is based on the concept that the radiation generated by a high voltage of any waveform produces the same AIR KERMA contrast behind a specified PHANTOM as a radiation generated by an equivalent constant potential. The constant potential producing the same contrast as the waveform under test is defined as PRACTICAL PEAK VOLTAGE.

- Defines a reproducable physical method, including ripple, easy to measure
- Clinically relevant (image contrast), relevant to technical aspects of X-Ray unit and its performance

Tube Voltage (Practical Peak Voltage)

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

When U_i is in kilovolts, the weighting function $w(U_i)$ is given by the following formulas:

in the voltage region of $U_i < 20$ kV by:

$$w(U_i) = 0 \tag{IV.2}$$

in the voltage region of $20 \text{ kV} \leq U_i < 36$ kV by:

$$w(U_i) = \exp\left(aU_i^2 + bU_i + c\right) \tag{IV.3}$$

and in the voltage region of $36 \text{ kV} \leq U_i \leq 150$ kV by:

$$w\left(U_i\right) = dU_i^4 + eU_i^3 + fU_i^2 + gU_i + h \tag{IV.4}$$

with constants:

$a = -8.646855 \times 10^{-3}$	$b = +8.170361 \times 10^{-1}$	$c = -2.327793 \times 10^{+1}$
$d = +4.310644 \times 10^{-10}$	$e = -1.662009 \times 10^{-7}$	$f = +2.308190 \times 10^{-5}$
$g = +1.030820 \times 10^{-5}$	$h = -1.747153 \times 10^{-2}$	

More info :

KRAMER, H-M., SELBACH H-J., ILES, WJ. The PRACTICAL PEAK VOLTAGE of diagnostic X-RAY generators. *British Journal of Radiology*, 1998, 77, p.200-209

Tube Voltage (Practical Peak Voltage)

- Measurements must be done with a calibrated voltage divider IEC 61267.
  - TRS 457 suggest non invasive measurement as an alternative

- IEC 61267 states : : PPV must be known with an uncertainty of 1,5% or 1,5 kV (coverage factor k = 2) whatever is larger.

Establishing RQR

- Once you have PPV adjusted, obtain an attenuation curve
  - Shall cover at least an attenuation of a factor 6

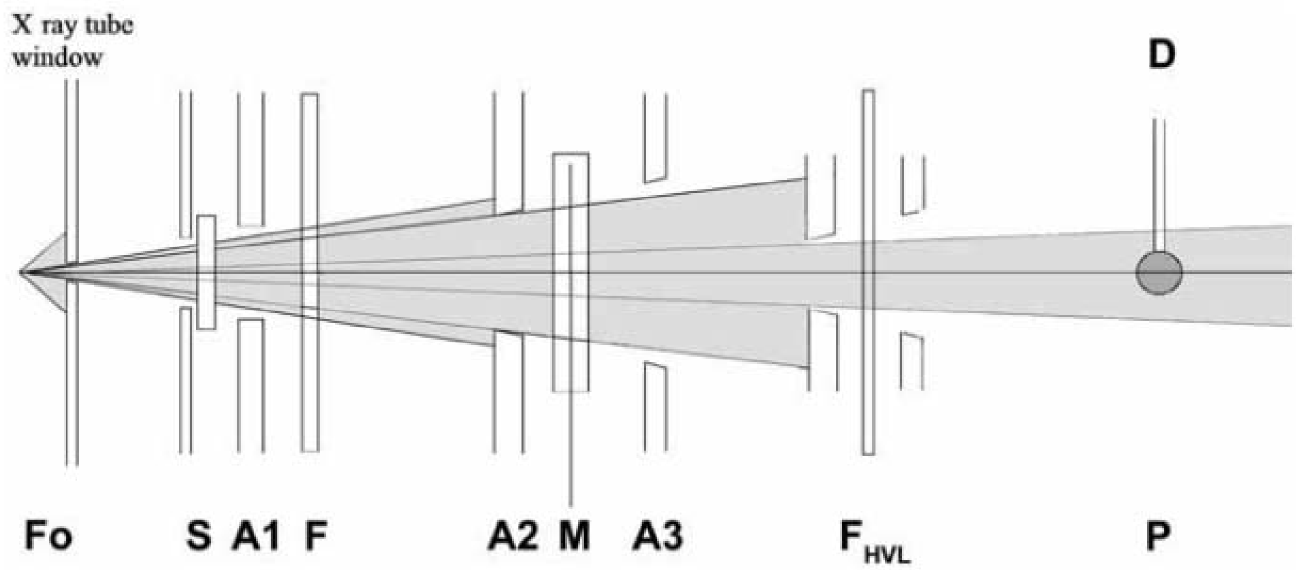
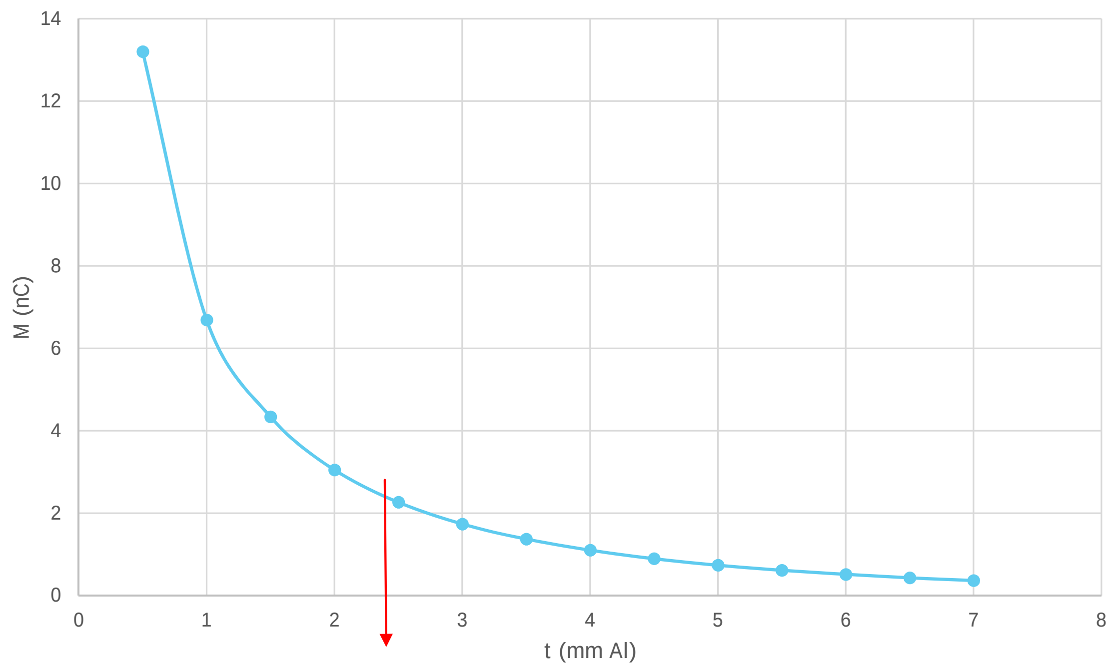


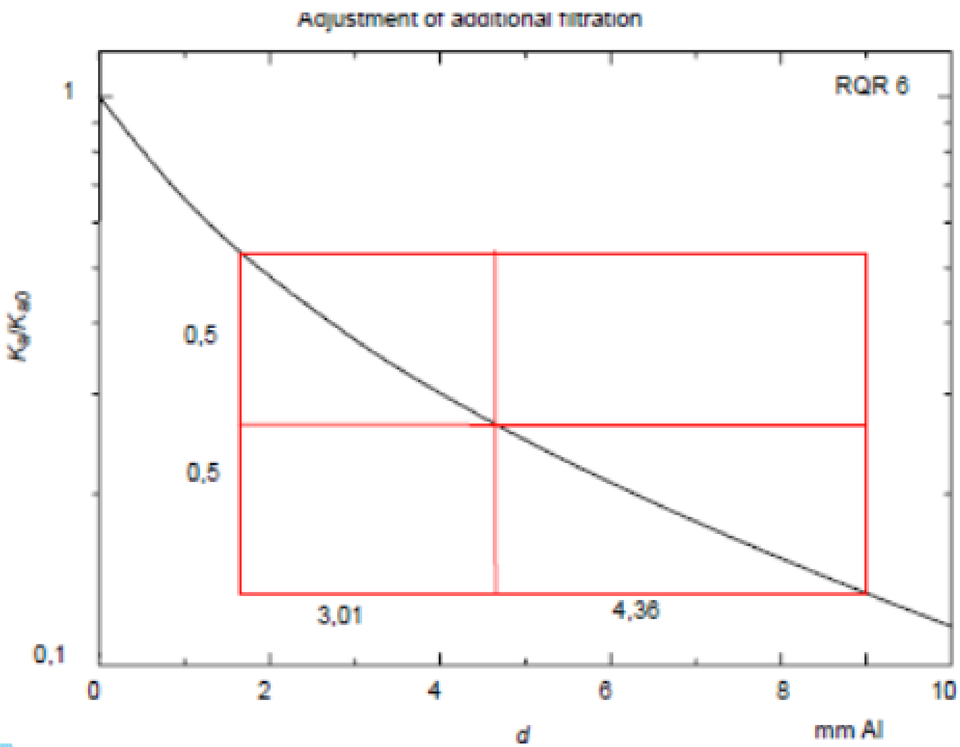
FIG. V.1. Schematic drawing of the HVL measurement set-up, where: Fo is the focal spot; S is the shutter; A1, A2, A3 are apertures; F is added filtration; F_{HVL} is the HVL absorber; M is the monitor chamber; D is the detector; P is the point of test.

Establishing RQR



- Find the additional filter to obtain the HVL given in IEC 61267
  - 2,49 mm Al in our case for RQR 2 HVL : 1,42

Establishing RQR



- Using log scale for measured attenuation ratios, plot attenuation curve
- Form the rectangular template described
  - 2nd HVL = 1st HVL x (1+1/h)
  - Horizontal line to split in two equal parts
  - Vertical line to 1st HVL value
- Place the template on the attenuation curve
  - 3 points to fit
  - Left side gives you the additional filter

Establishing RQR

- The additional filter obtained is inserted
- To verify, attenuation ratio for HVL test device is measured.
- The attenuation must be in between 0,485 – 0,515

- From TRS 457 :
  - The actual value of the homogeneity coefficient associated with the appropriate radiation quality RQR should lie within 0.03 of the value given in column 4 of Table 6.2.

RQT

- Once RQR is established, the filter given in IEC 61267 is added.

Standard RADIATION QUALITY Characterization	X-RAY TUBE VOLTAGE kV	Nominal ADDED FILTER for RQT thickness in copper mm	First HALF-VALUE LAYER in thickness of aluminium mm
RQT 8	100	0,2	6,9
RQT 9	120	0,25	8,4
RQT 10	150	0,3	10,1

- The attenuation ratio for HVL test device shall be between 0,485 – 0,515

RQR-M

- RQR-M is described as;
  - Molybdenum target
  - Tube voltage ripple < 4 %
  - Total filtration of 0,032 mm ± 0,002 mm Molybdenum

Standard RADIATION QUALITY Characterization	X-RAY TUBE VOLTAGE (nominal value) kV	Nominal first HALF-VALUE LAYER in mm of aluminium
RQR-M 1	25	0,28
RQR-M 2	28	0,31
RQR-M 3	30	0,33
RQR-M 4	35	0,36

- The value determined experimentally should be within ± 0,02 of Nominal 1st HVL

Thank you for your attention!

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