The Abdus Salam
International Centre for Theoretical Physics

United Nations
Educational, Scientific and
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IAEA
International Atomic Energy Agency

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

11 - 15 May 2009

Selection of Instrumentation

Costas Hourdakis
Greek Atomic Energy Agency
Athens
Greece

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Miramare, Trieste, Italy

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Instrumentation : categorization

General categories :

Dosimeters :
equipment for the measurement of air kerma, air kerma length, air kerma area and/or air kerma rate.

kVp-meters :
equipment for the measurement of tube high voltage invasively or non-invasively.

Timers, mAs-meters, etc : Are not included in the CoP
equipment for the measurement other parameters of exposure parameters, like exposure time (ms), tube current time exposure product (mAs), etc

Instrumentation : categorization

Depending on the application there are various instrument categories and modes of operation

- Conventional diagnostic radiology (50-150 kV)
- Mammography

- ➢ Radiographic mode (accumulated – integrating - “dose”)
- ➢ Fluoroscopic mode (“dose” rate)
- ➢ Cine mode (pulsed “dose”)

- ❑ air kerma length product (CT, dental panoramic)
- ❑ air kerma area product (Angiography, fluoroscopy)

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Contents

What are we going to discuss in this topic…

- Instrumentation
  - Ionization chambers, CT chamber, KAP meter, TLDs, solid state detectors
- Dosimeter characteristics
  - response, energy dependence, …
- Choice of instruments for different applications
- kVp-meters

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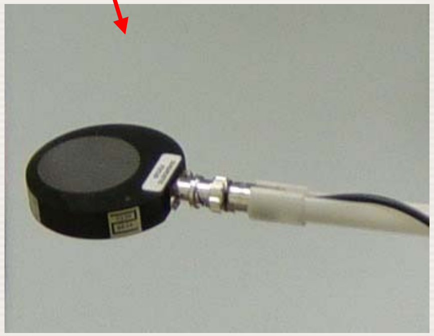
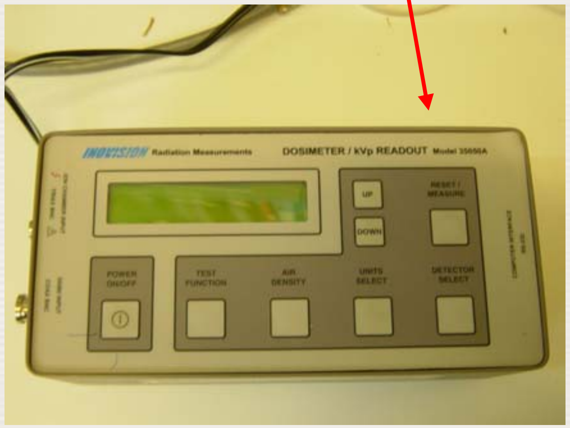
Many types of dosimeters are commercially available

Dosimeter

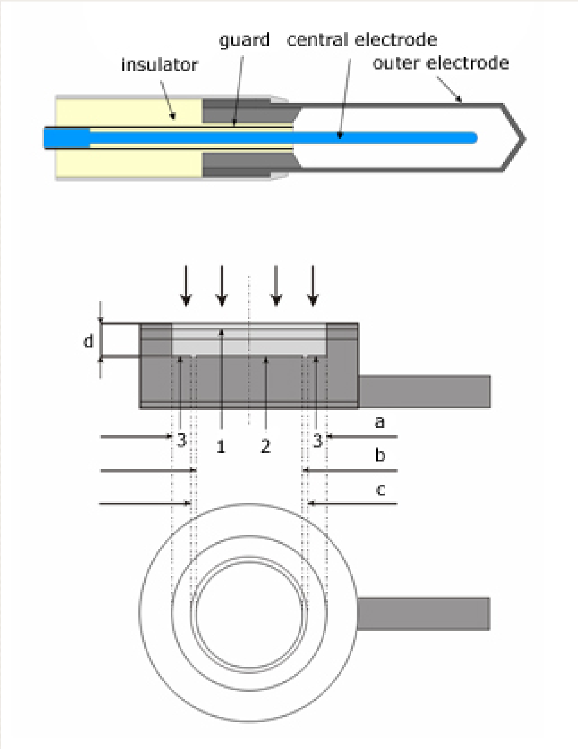
- Measuring assembly (electrometer, main unit, etc)
- Detector
  - Ionization chamber
  - Solid state detector

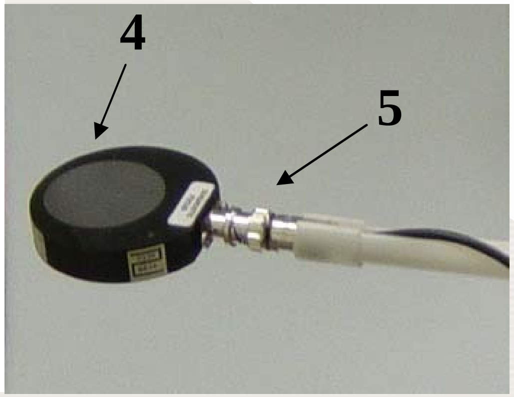


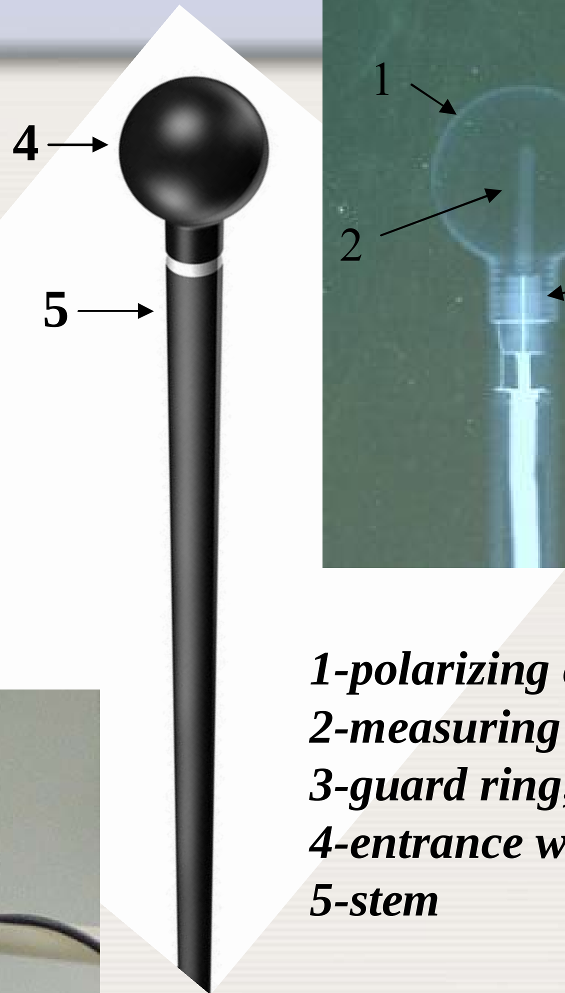


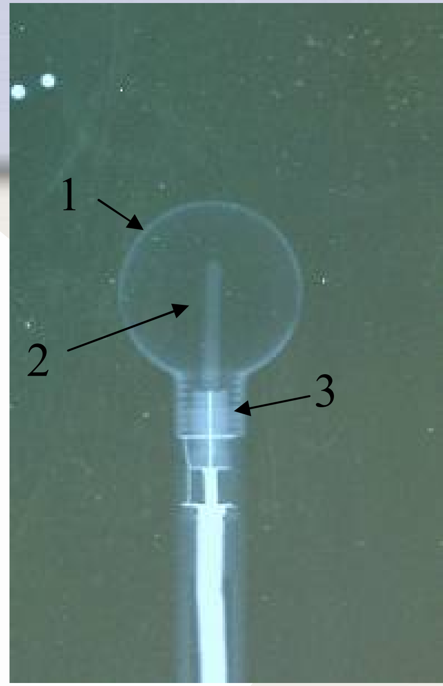
Instrumentation : Ionization chambers

Cylindrical (e.g. Radcal)
Parallel Plate (e.g. PTW)
Spherical (e.g. A3 Exradin)





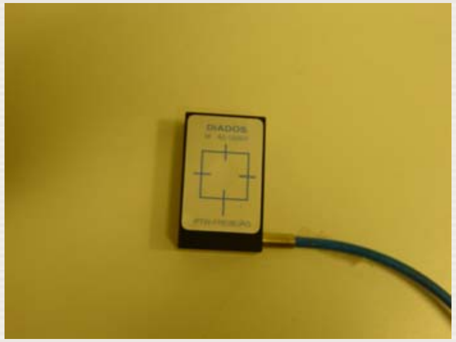




1-polarizing electrode;
2-measuring electrode;
3-guard ring;
4-entrance window;
5-stem

Advantages

- produce large signals from modest amounts of radiation
- rigid and robust
- do not require pressure correction
- convenience to use



Disadvantages

- energy dependant
- directional, positioning & angular dependency
- ageing effects (?)

Compensation

- use of multi element ST
- use of movable filters
- compensation and processing of signals

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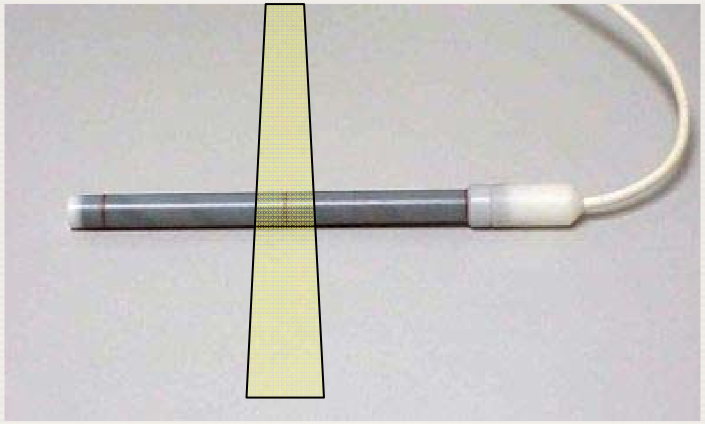
Instrumentation : CT chambers

CT chamber is often called a **pencil chamber** because its active volume is a thin cylinder 100 mm in length or sometimes longer



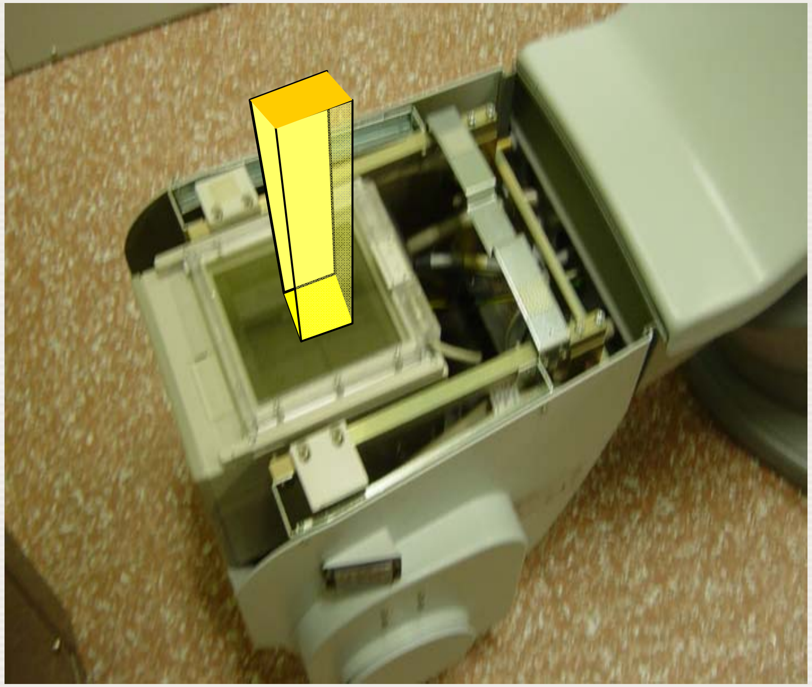
Partially irradiated (10% of its active volume)

Air kerma-length product, P_{KL}

!!!

- The response of the active volume must be uniform along its entire axial length
- Calibration procedures

the detector mounted on the tube housing is "transparent" to X rays

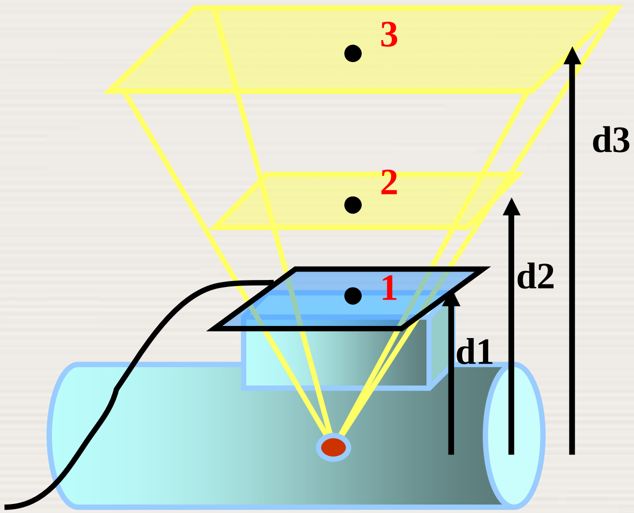


Partially irradiated

Air kerma-area product, P_{KA}

$$P_{KA} = K \cdot A = K \cdot (a \cdot b)$$

P_{KA} is the same at any distance from focus



P_{KA} is the same at any distance from focus

$$P_{KA1} = P_{KA2} = P_{KA3} = \ldots$$

$$P_{KA1} = K_1 \bullet A_1 = K_1 \bullet (a_1 \bullet b_1)$$

$$P_{KA2} = K_2 \bullet A_2 = K_2 \bullet (a_2 \bullet b_2) =$$

$$K_1(d_1/d_2)^2 \bullet (a_1 \bullet d_2/d_1) \bullet (b_1 \bullet d_2/d_1) =$$

$$K_1 \bullet (a_1 \bullet b_1) = P_{KA1}$$

So, the P_{KA} recorded by the KAP meter is the same to P_{KA} on patient therefore, the energy imparted to patient in "known".

Instrumentation : Transmission chambers - KAP meters

KAP meters use :
- fluoroscopy,
- general radiography
- dental radiography equipment

Provide useful information for

- patient doses

- comparative studies between procedures and personnel

Instrumentation : TLDs

TLDs are available in various forms (e.g. powder, chips, rods, ribbons, etc.) and made of various materials.

Most commonly used in medical applications are based on lithium fluoride doped with magnesium and titanium (LiF:Mg,Ti)

but other materials like LiF:Mg,Cu,P, Li2B4O7:Mn, CaSO4:Dy and CaF2:Mn

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Instrumentation : TLDs

application, energy dependence or response, etc

TL material	Form	Glow peak °C	Emmission maximum nm	Z_{eff}	Relative sensitivity	Linear range Gy	Fading	Annealing
LiF:Mg,Ti	Powder, chips, rods, discs	210	425	8.14	1	5×10^{-5} to 1	<5% per year	400°C, 1 h + 80°C, 24 h
LiF:Mg,Ti,Na	Powder, discs	220	400	8.14	0.5		NA	500°C, 0.5 h
LiF:Mg,Cu,P	Powder, discs	232	310(410)	8.14	15-30	10^{-6} to 10	<5% per year	240°C, 10 min
$Li_2B_4O_7$:Mn	Powder	210	600	7.4	0.15-0.4	10^{-4} to 3	5% in 2 months	300°C, 15 min
Al_2O_3:C	Powder, discs	250	425	10.2	30	10^{-4} to 1	3% per year	300°C, 30 min
$CaSO_4$:Dy	Powder, discs	220	480(570)	15.3	30-40	10^{-6} to 30	7-30% in 6 months	400°C, 1 h
CaF_2:Dy	Powder	200(240)	480(575)	16.3	16	10^{-5} to 10	25% in 4 weeks	600°C, 2 h
BeO	Discs	180 to 220	330	7.13	0.7-3	10^{-4} to 0.5	7% in 2 months	600°C, 15 min

!!!

- annealing process
- fading
- energy response
- accuracy - calibration

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Instrumentation : Characteristics for selection

Response - Sensitivity (nC/mGy) : Charge (signal) collected per radiation unit

In general, the larger the active volume the more sensitive (higher response)
Response is the reciprocal of calibration coefficient.

Example : for image intensifier entrance $K_{i,R}$
Radcal 20x5-30 flat chamber (30cm^3 p-p) more appropriate than A3 Exradin (spherical 3.6cm^3)

Leakage : Any signal appeared in the absence of radiation

Leakage (noise) : < 1% of signal (NSR<1%)

Example : to measure K_i=100 µGy (instantaneous accumulative dose)
PTW 77337 : Sensitivity=0.04 pC/µGy; Leakage=0.02pC/s ; measuring time 10s;
Signal=4pC, noise (leakage)=0.2pC; NSR=5%

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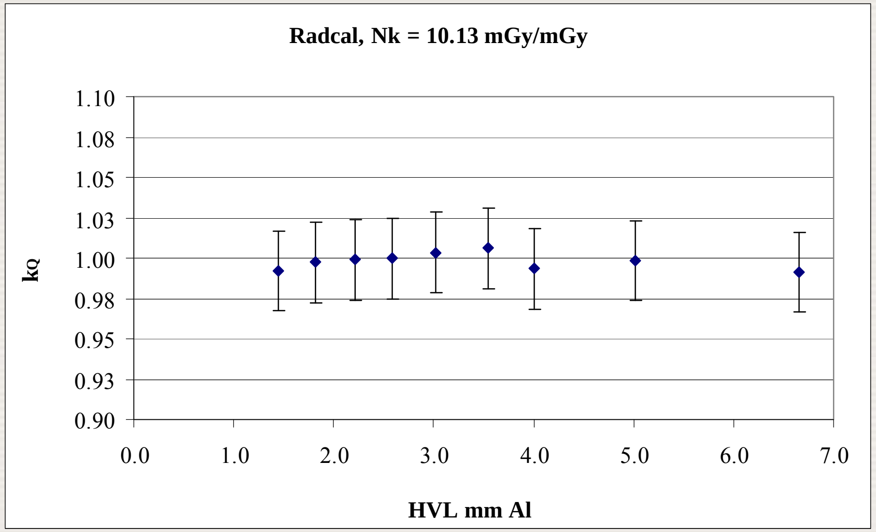
Instrumentation : Characteristics for selection

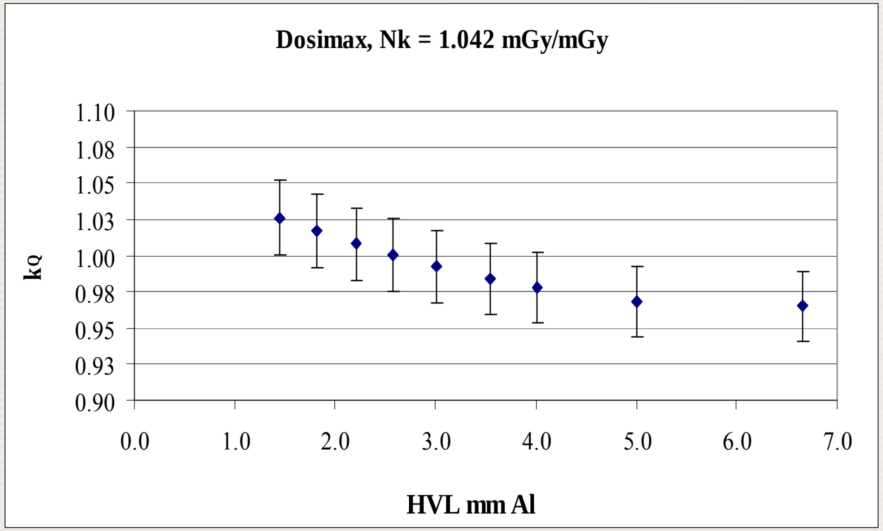
Energy response : Difference response in beam qualities

It is determined by N_K or/and k_Q by calibration at PSDL or SSDL
It should be less than 5% at all X-ray energy range (20-40kV or 50-150kV)

Examples :



ionization chamber



solid state

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conventional radiology

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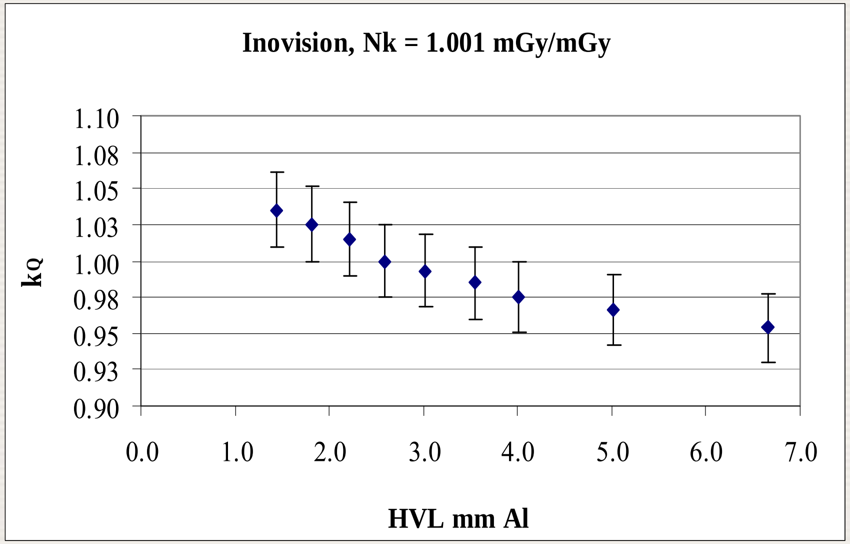
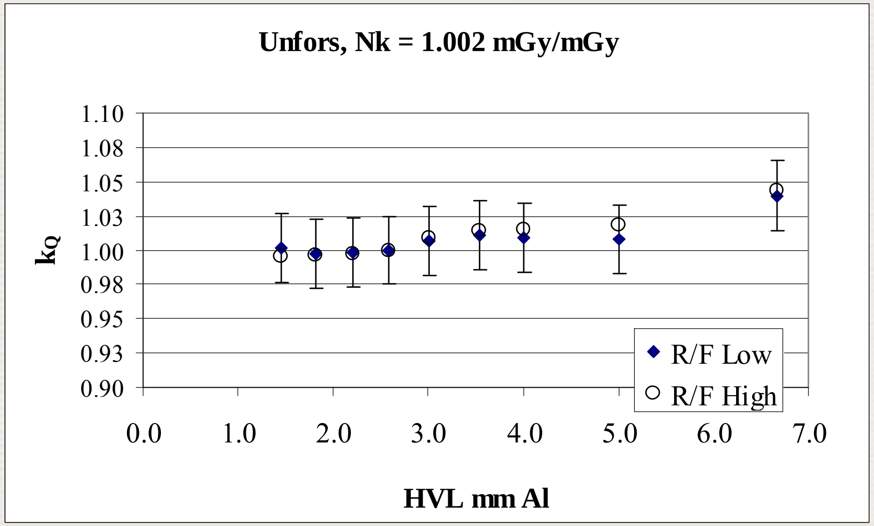


ionization chamber



solid state

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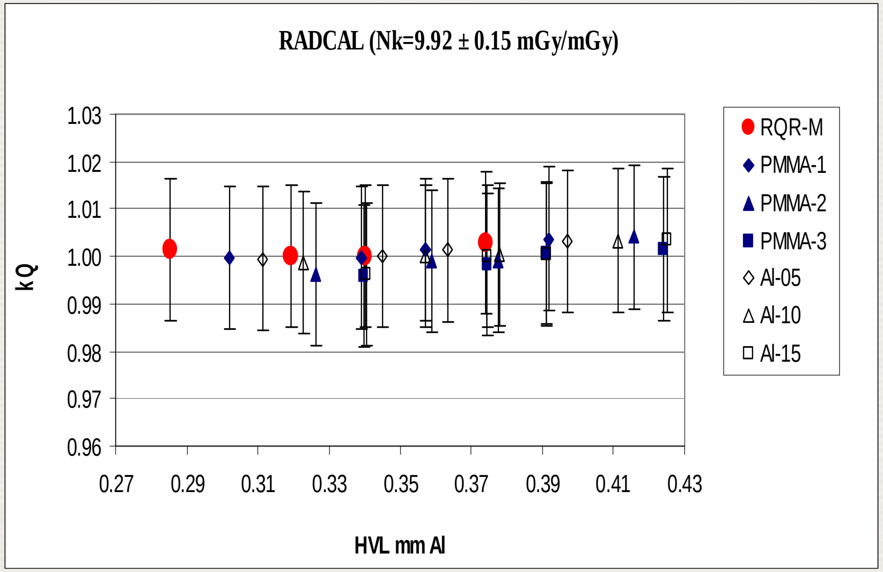
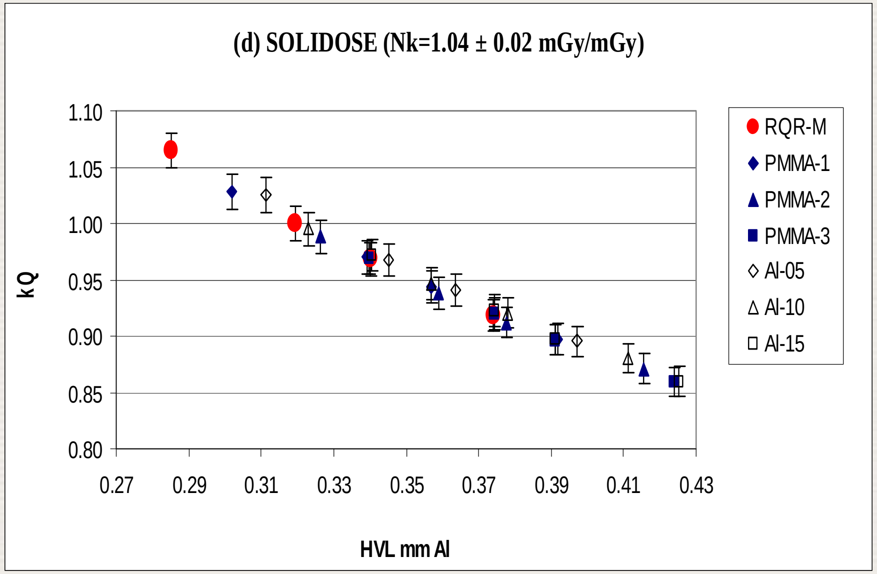


ionization chamber



solid state

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mammography

Instrumentation : Characteristics for selection

Energy response : Difference response in beam qualities

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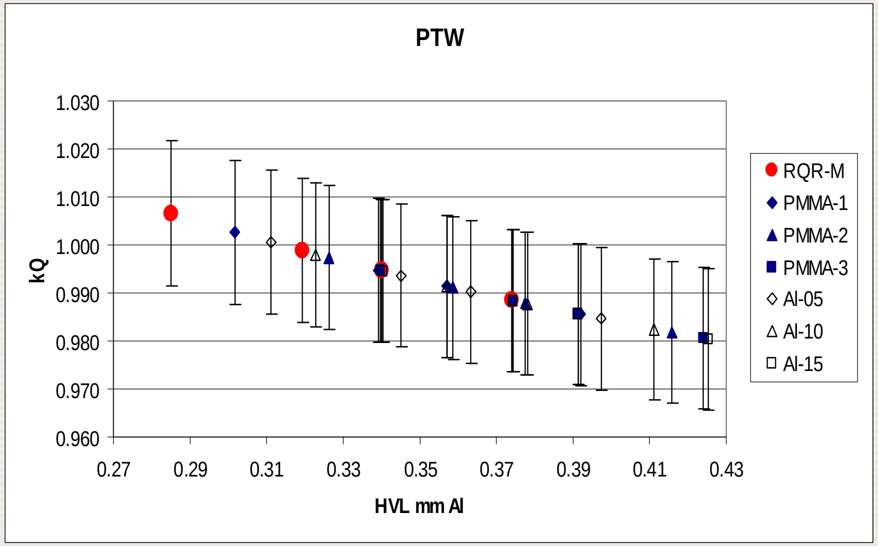

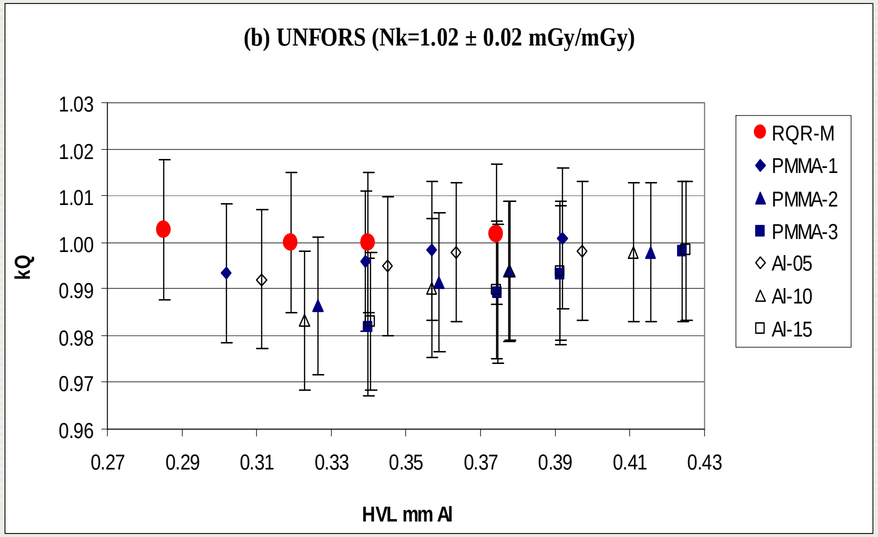

ionization chamber

solid state

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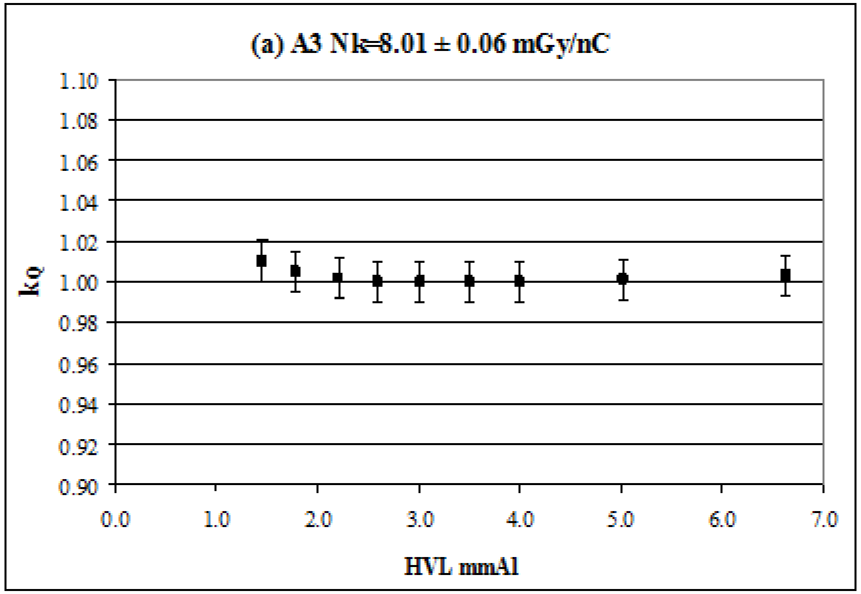
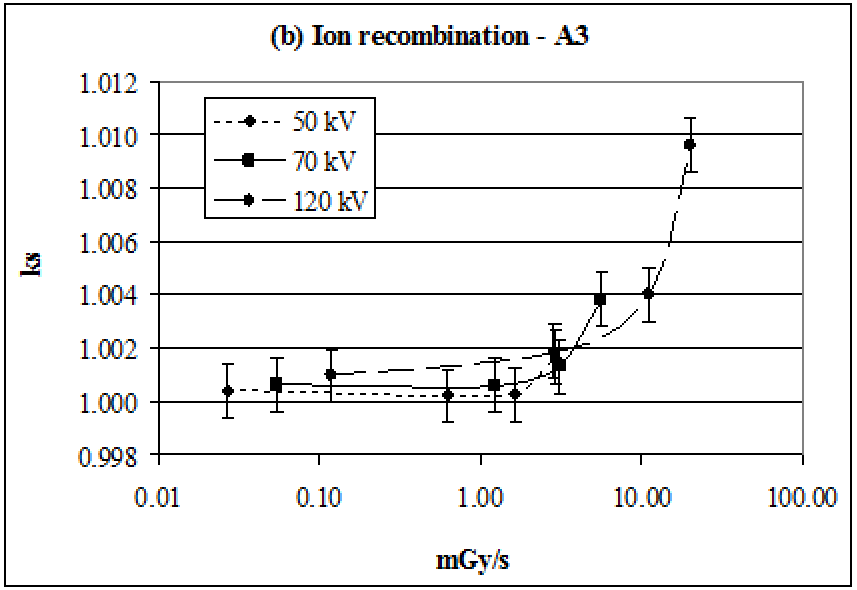
mammography

Air Kerma rate dependence of response

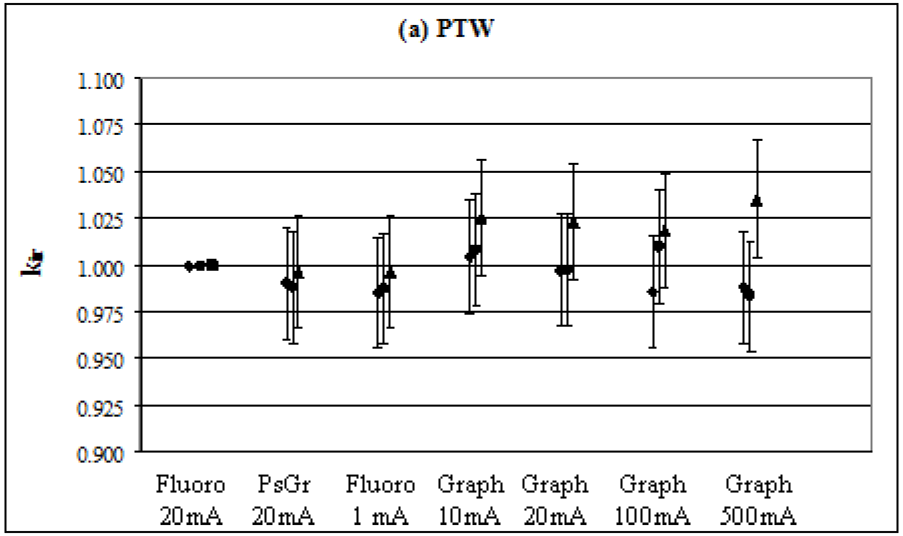


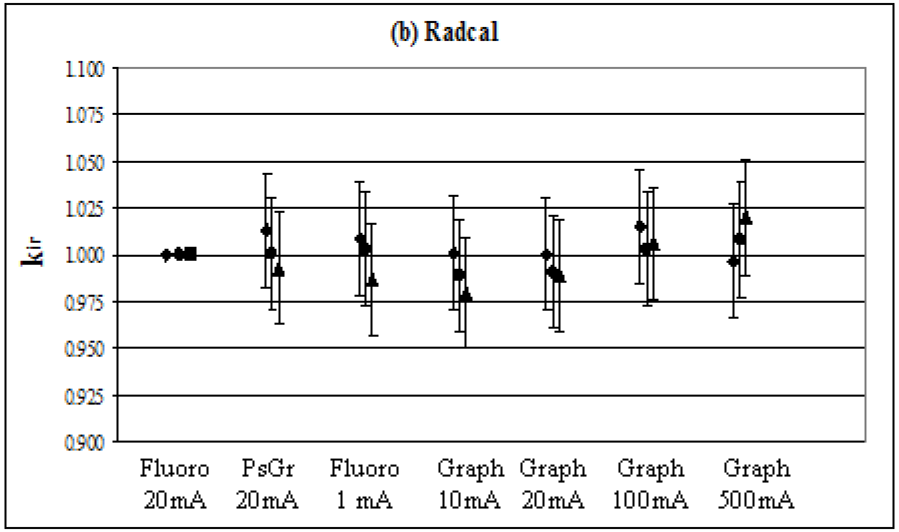


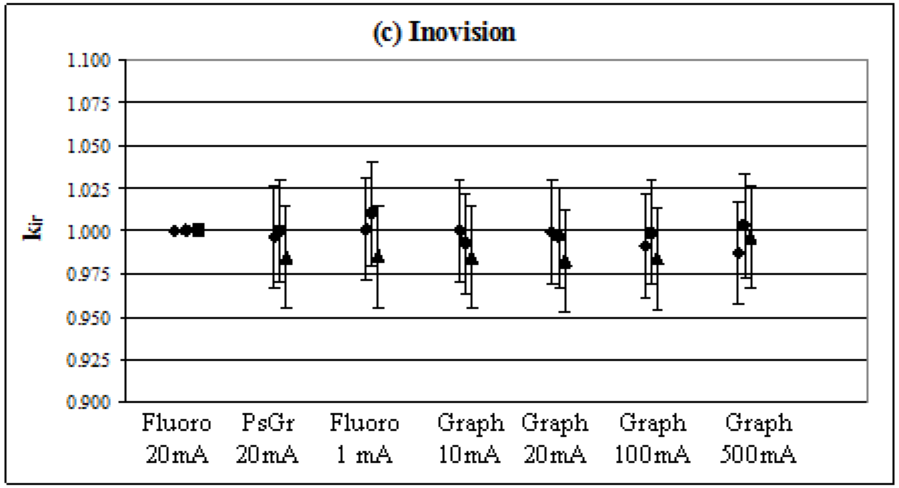
Energy dependence of response

Saturation coefficient

Instrumentation : Characteristics for selection



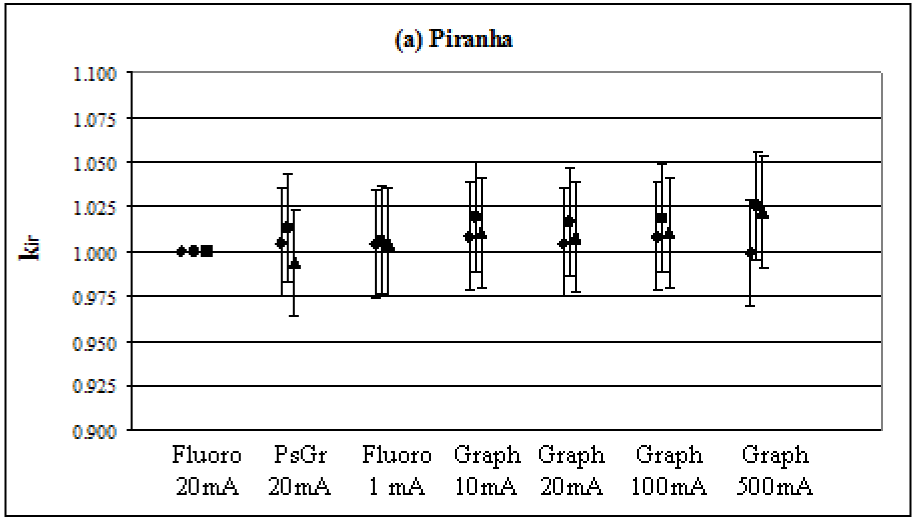


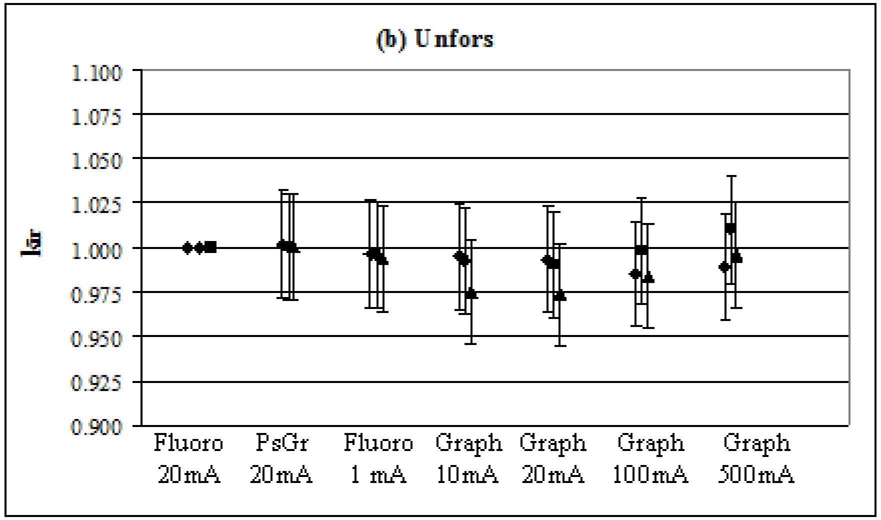


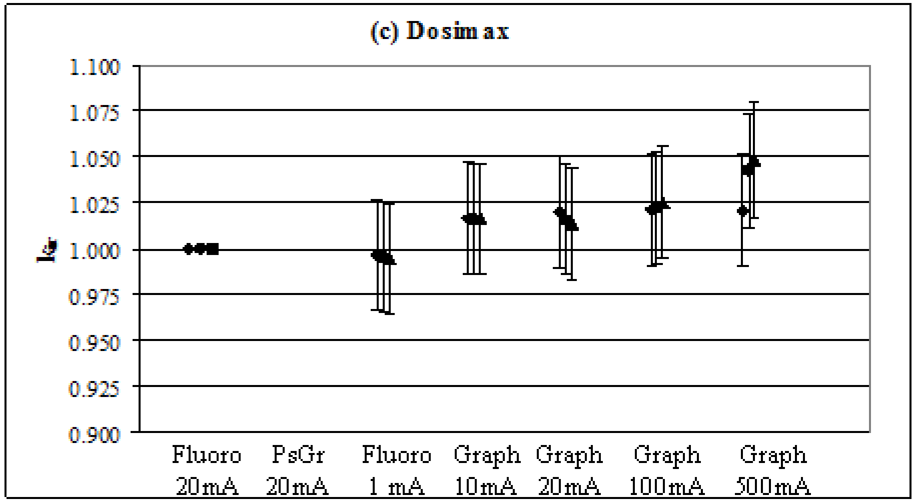
♦ 50 kV ●70 kV ■120kV

Air Kerma rate dependence of response

Instrumentation : Characteristics for selection







♦ 50 kV ●70 kV ■120kV

Air Kerma rate

dependence of response

Entrance window : Depending on the application

General radiography : thicker windows (plastic, PMMA, acrylic etc) acceptable
Mammography : thin windows required

Temperature & pressure corrections :
Ionization chambers, vented : k_{TP} ⟶ $$k_{TP} = \frac{P_0 \cdot T}{P \cdot T_0} = \frac{P_0 \cdot (273.2 + \theta)}{P \cdot (273.2 + \theta_0)}$$
Solid State detectots : $k_{TP} = 1.00$
TLDs : $K_{TP} = 1.00$

Physical characteristics : Robust, dimensions, purpose and frequency of use

IEC 61674 : 1997 standard provides the requirements for the DR dosimeters' performance

IEC 61767 dosimeter performance characteristics			
Influence quantity	**Minimum rated ranges**	**Reference conditions**	**Limits of variation**
Intrinsic error, air kerma Intrinsic error, air kerma rate	> 100 µGy > 100 µGy/s	reference	± 5% ± 5%
Radiation quality of unattenuated beam (GR)	50 – 150 kV W anode, 2,5mmAl filtration	RQR5	± 5%
Radiation quality (Mammo GR)	22 – 40 kV Mo anode, Mo filtration	RQR-M2	± 5%
Air kerma rate	as stated by the manufacturer	as at calibration	± 2% [a]
Incident radiation angle	± 5°	reference angle	± 3%
Field size	minimum : manufacturer specification max : 35 cm x 35 cm	as at calibration	± 3%
Air pressure	80 kPa – 106,0 kPa	101.3 kPa	± 2%
Temperature	15 – 35 °C	20 °C	± 3%
Operating voltage	-15% to +10%	Nominal	± 2%
Electromagnetic compatibility	IEC 61000-4	Without EM	± 5%

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Instrumentation : Characteristics for selection

TABLE 5.2. RECOMMENDED SPECIFICATIONS OF DETECTORS OF A REFERENCE CLASS DOSIMETER, BY APPLICATION.

Application	Type of detector	kV	I.E. %	Resp 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	
Computed tomography[1)]	Cylindrical (pencil type)	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	

[1)] The dosimeters must have no greater variation in their sensitivity than ±3% along the active length.

Instrumentation : Dosimeter choice

General radiography

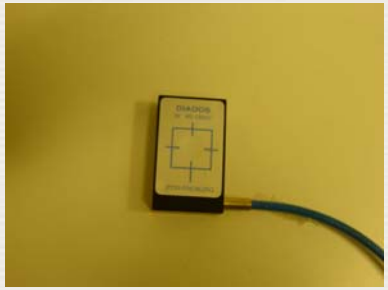
Free in air & with phantoms

IC small volume ($3cm^3$)

Solid state detectors

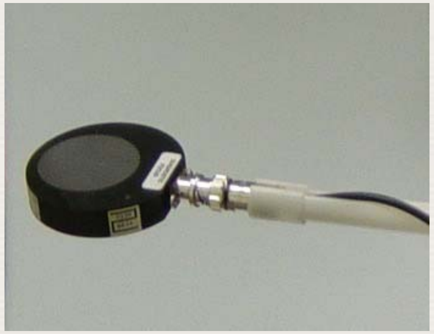
On patients :

TLDs



Instrumentation : Dosimeter choice

General radiography



Free in air & with phantoms

IC small volume ($3cm^3$)

Solid state detectors

On patients :

TLDs

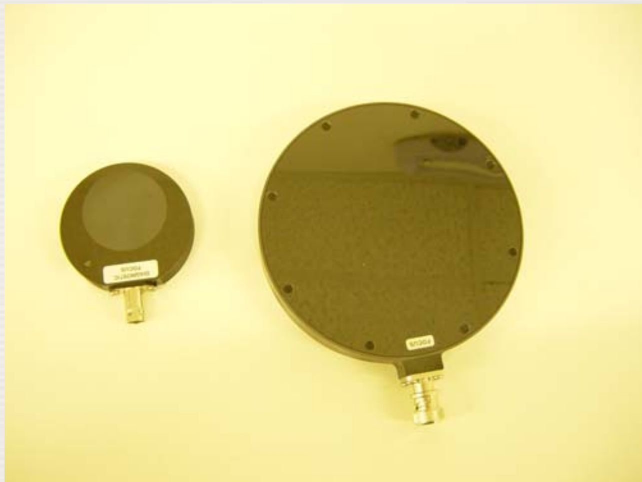
Instrumentation : Dosimeter choice

Fluoroscopy

Free in air & with phantoms

IC chambers of suitable design for positioning

Solid state detectors



On patients

KAP meters

Instrumentation : Dosimeter choice

Mammography

Free in air & with phantoms

IC chambers with thin windows

Solid state detectors appropriate for mammo measurements

On patients

Average Glandular Dose deduced computationally from K_i

CT

Free in air & with phantoms

Pencil type ionization chamber

On patients

Patient doses deduced computationally from K_{LP}

CT air kerma index ${}_{n}C_{W}$ is used in combination with the scan parameters to calculate the CT air kerma index ${}_{n}C_{VOL}$

Instrumentation : Dosimeter choice

Dental

Bitewing projections

IC small volume ($3cm^3$)

Solid state detectors

For panoramic projections :

pencil type (CT) chamber

array of TLDs

Using phantoms and On patients

TLDs

computationally from K_i

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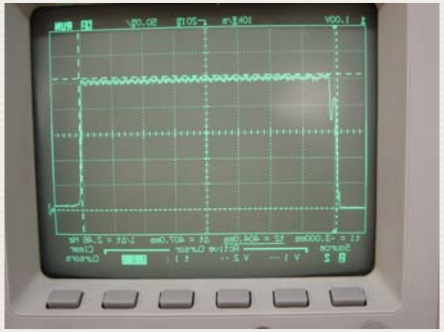
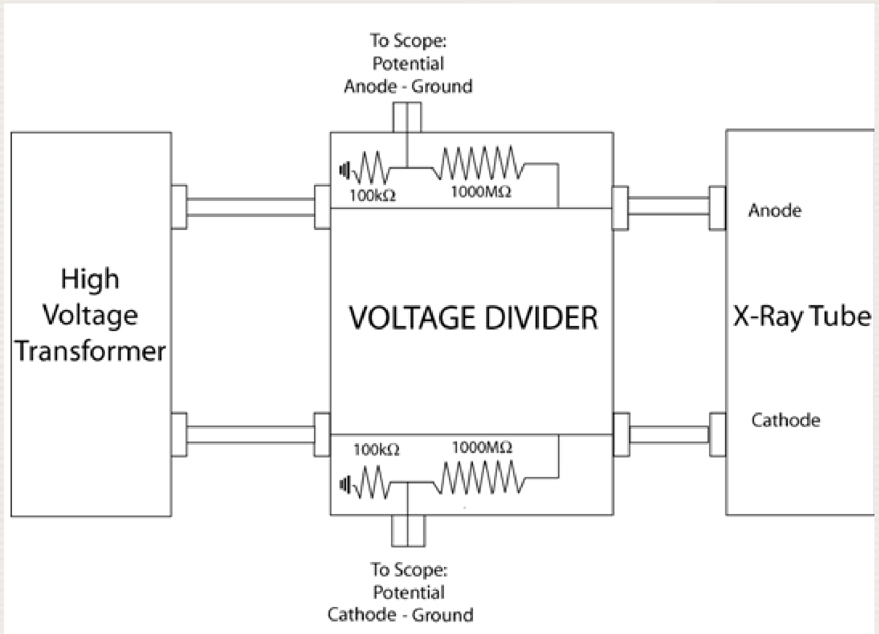
Invasive measurement of PPV using a high voltage divider





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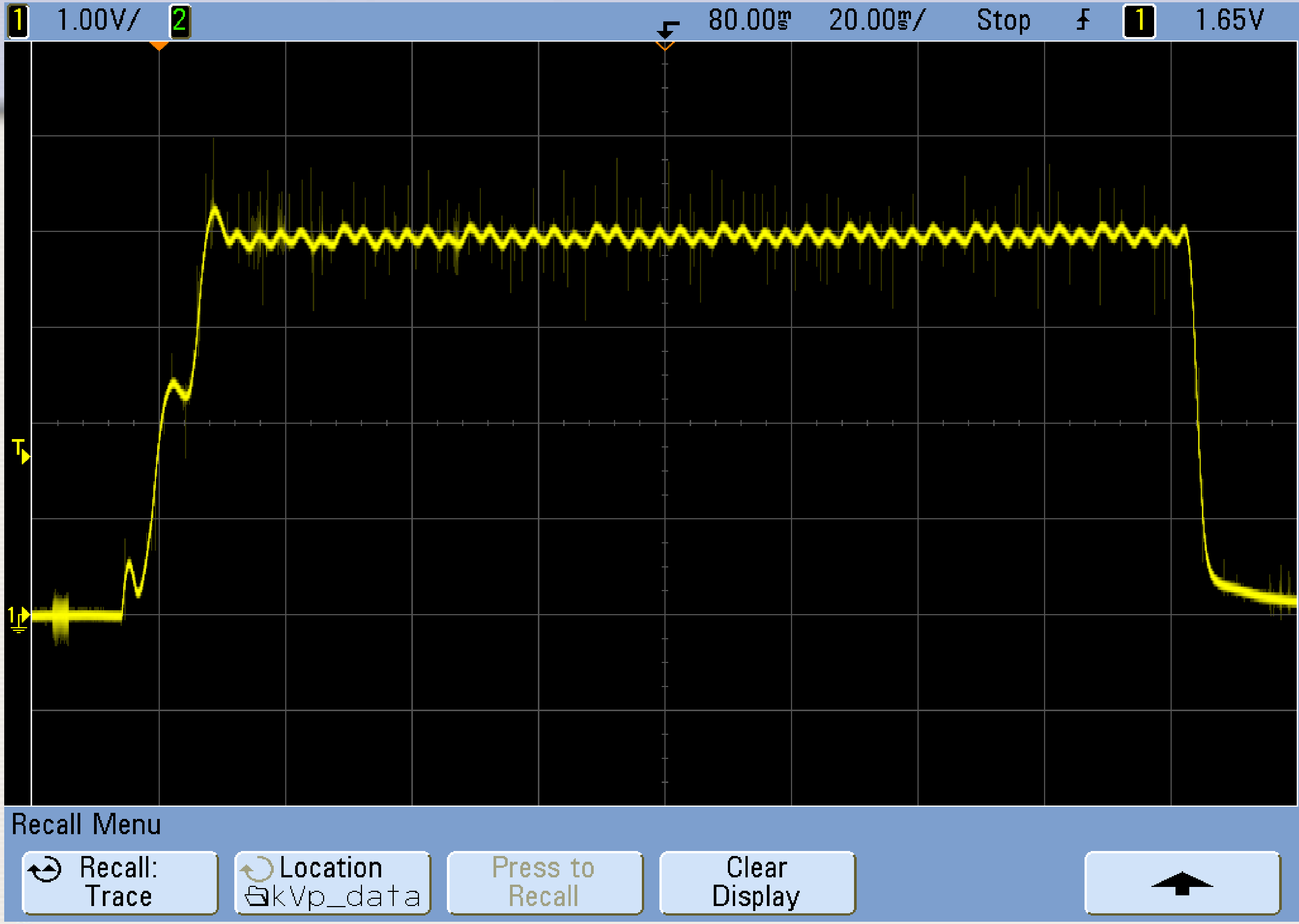
1 1.00V/ 2
80.00ms 20.00ms/ Stop 1 1.65V
Recall Menu
Recall: Trace
Location kVp_data
Press to Recall
Clear Display

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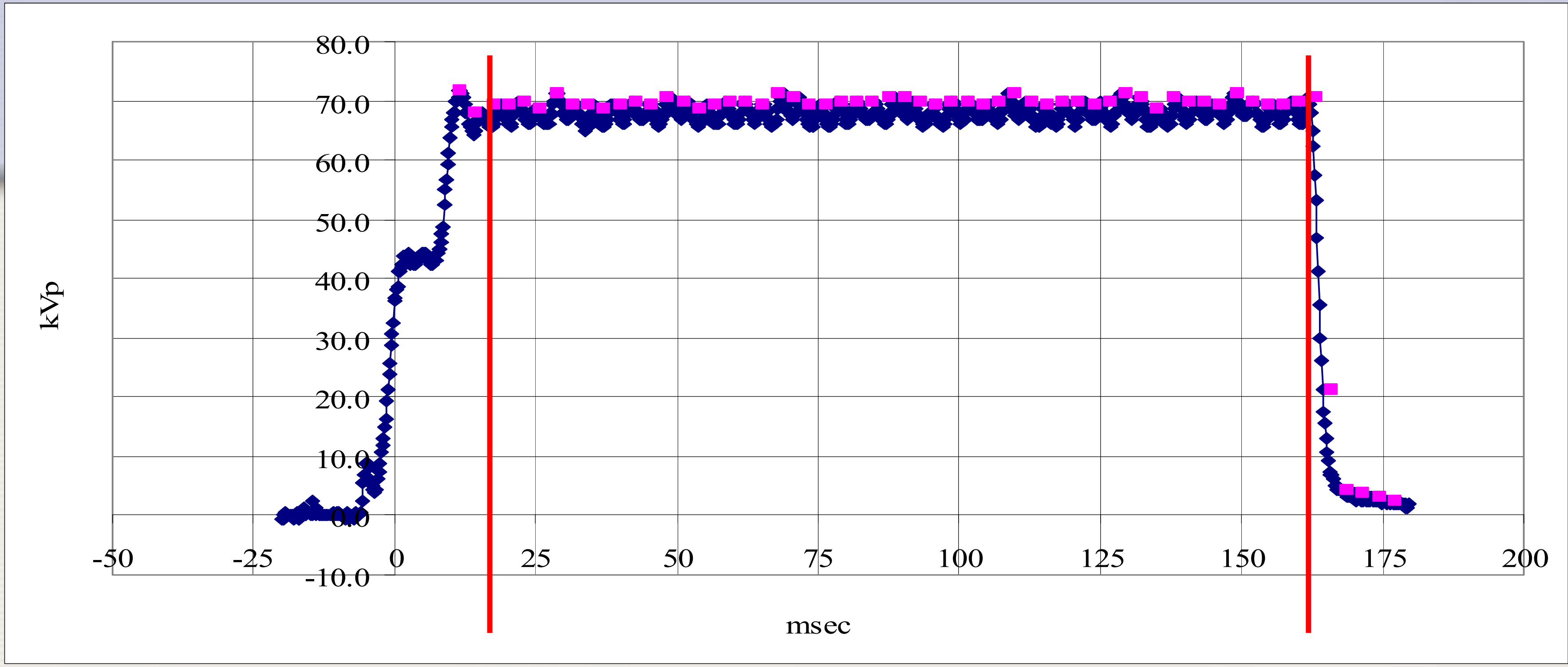

Practical Peak Voltage, PPV

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

U_{mean} : average of the continues trace within the time range

kV_{mean} within the time range

$$kV_{mean} = \frac{\sum U_{i,peak}}{n}$$

kV_{max} : max peak within the time range

$$U_{mean} = \frac{\sum_{i}^{N} U_i}{N}$$

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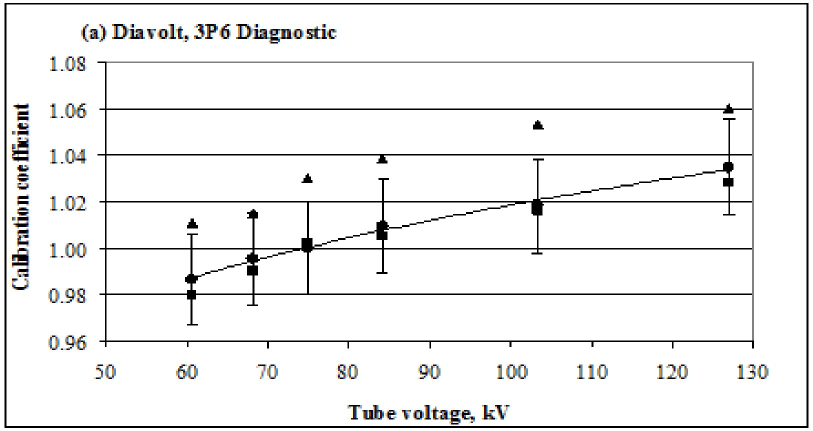
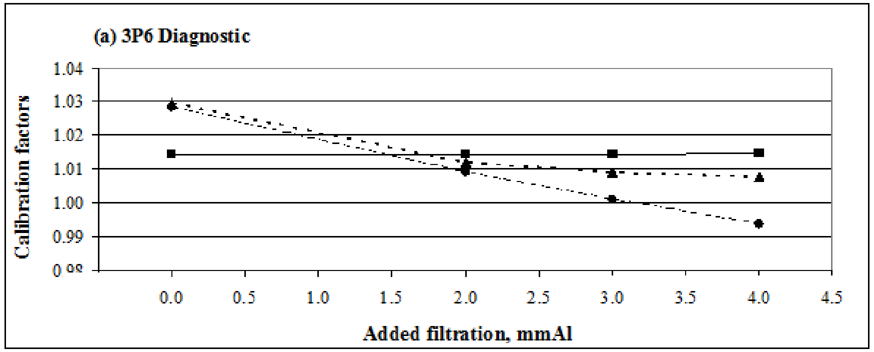
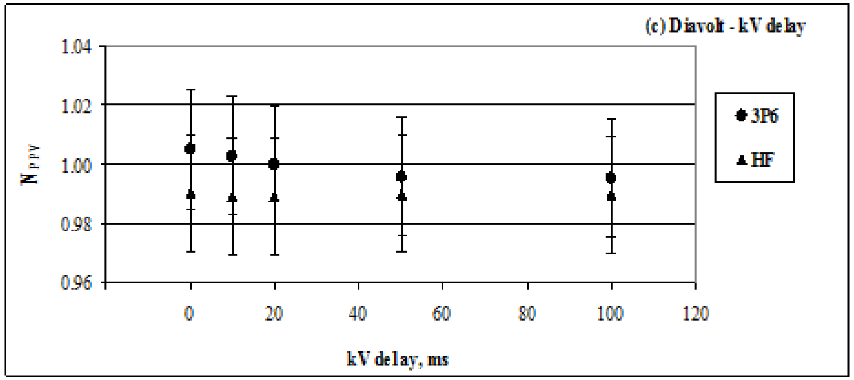
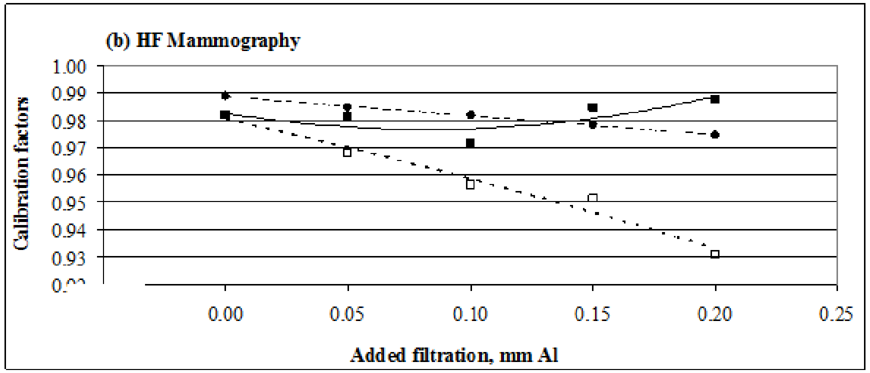
kVp-meter calibration : effect of tube voltage & added filtration









Thank you for your attention

Use a suitable instrument for optimizing “dosimetry”