The Abdus Salam
International Centre for Theoretical Physics

United Nations
Educational, Scientific and
Cultural Organization

IAEA
International Atomic Energy Agency

2033-4

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

11 - 15 May 2009

Dosimetry for General Radiology and Clinical Uncertainty

Peter Homolka
EFOMP

Strada Costiera 11, 34014 Trieste, Italy - Tel. +39 040 2240 111; Fax +39 040 224 163 - sci_info@ictp.it, www.ictp.it

IAEA Training Course on Medical Physics in Diagnostic Radiology
May 11 – 15 2009, Trieste, Italy

Dosimetry for general radiology and clinical uncertainty

Peter Homolka

Center for Biomedical Engineering & Physics

Medical University of Vienna, Austria

IAEA
International Atomic Energy Agency

Goals

1. Determination of reliable dosimetric values
2. Optimally, dosimetric values corresponding to a standard patient undergoing standardized x-ray examinations
3. Determination of individual patient doses (that's easier than 2)

Approaches

- Dosimetry on phantoms – 1, ? 2 ?
- Dosimetry on patients / dosimetry using patient exposure data – 1,2,3
  - Note: even if same methodology used for 2 and 3, this results in totally different uncertainty budget → dose audit methods & interpretation

IAEA

Dosimetric quantities

- Incident air kerma K_i
  - measured for phantoms
  - calculated for patients from measured tube output
- Entrance surface air kerma K_e
  - measured for patients using TLDs
  - calculated for patients
- Air kerma-area product P_{KA}
  - measured for patients

IAEA

Patient exposure

- Does determination of K_e, K_i or P_{KA} allow determination of energy imparted, e.g.?
- We need to know beam hardness also
- → Measurement of HVL

- **Full dosimetric measurement must include also HVL determination**

- Or, determination of kV and total filtration. If done properly with suitable and suitably maintained equipment this is equal. This necessitates a kVp meter capable of measuring also total filtration. These instruments will usually also measure HVL.

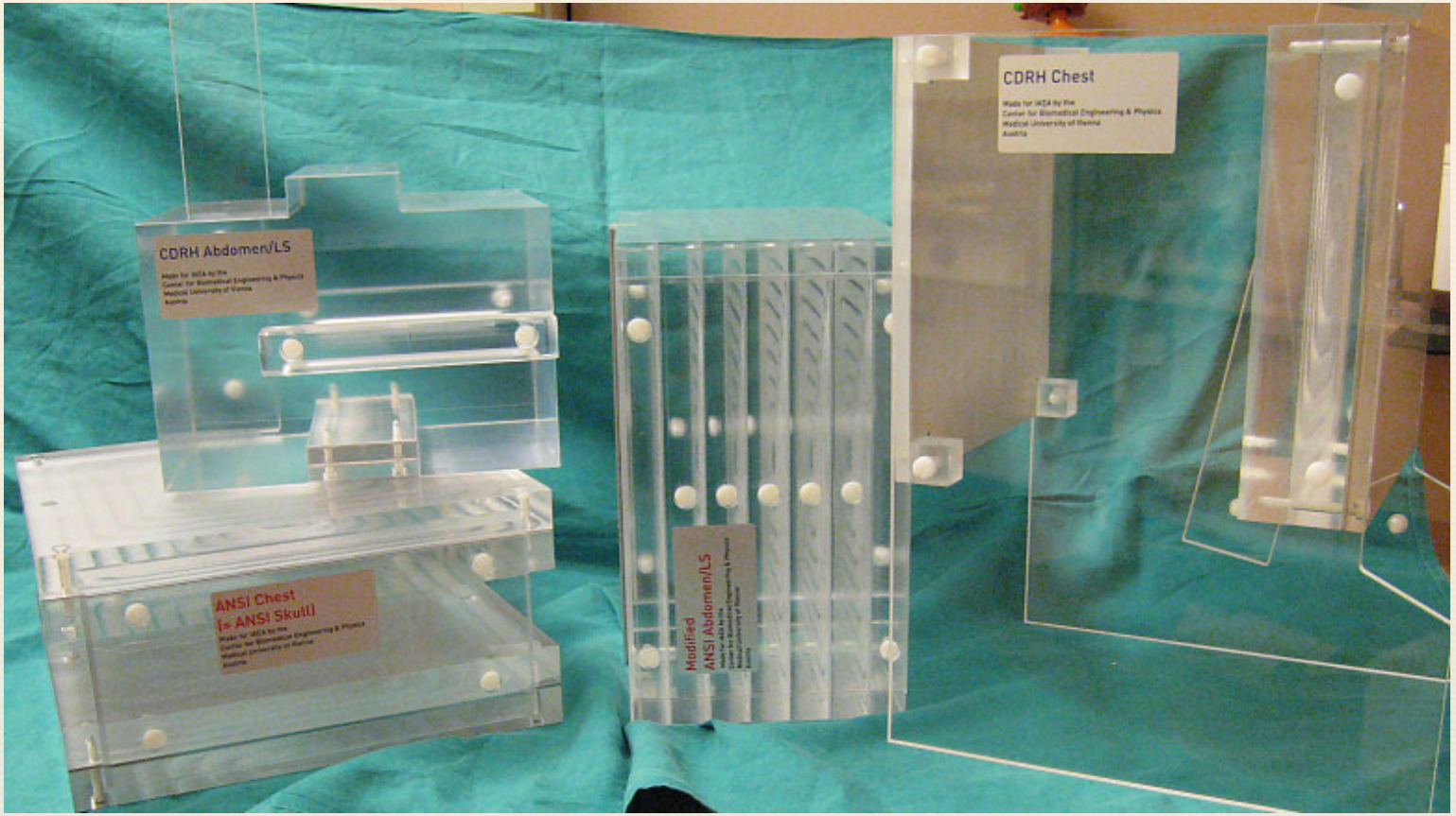
IAEA

P_{KA} or K_i/K_e

- Kerma Area Product accounts for collimation, K_i and K_e do not
- Whether P_{KA} results in a better suited dosimetric quantity depends on examination and collimation practice
- Many flat panel (DR) systems calculate P_{KA} and can include it in the DICOM header → simple to use for dose auditing

IAEA

Dosimetry using Phantoms



IAEA
International Atomic Energy Agency

Phantoms

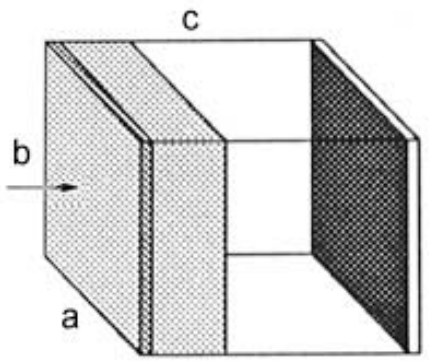
- Dosimetry with phantoms only makes sense if AEC is used
- With manual setting of mAs phantom is not needed (will only be used as holding device for dosimeter) – K_i measurement can be made free in air without phantom
  - Measurement with fixed settings corresponds to a patients' K_i if mAs and other technique parameters are manually set to the values used with a "standard sized" patient → would not be regarded as dosimetry with phantom

IAEA

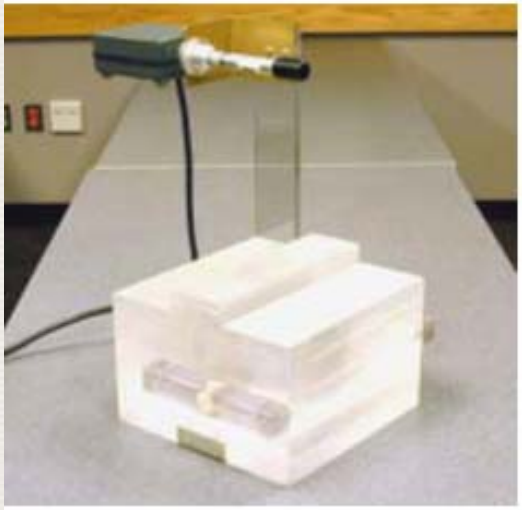
Phantoms for general radiography measurements

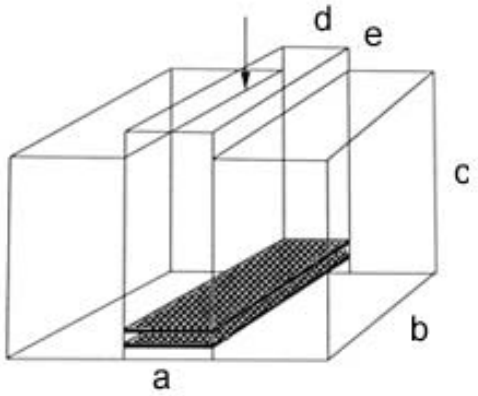
- CDRH Chest & Abdomen/L Spine phantoms
- Correspond to average US citizen in PA/AP projection (?)
- Incorporate holders for ionization chambers (avoiding back scatter)
- Constructed from PMMA & Al (with air gap for chest phantom)
- Obtainable commercially or can be manufactured

IAEA



a = 254 mm
b = 254 mm
c = 267 mm





a = 254 mm
b = 254 mm
c = 169 mm

d = 70 mm
e = 24 mm

IAEA

Alternative phantoms

- ICRU phantoms
  - PMMA walls filled with water
- ANSI phantoms
  - PMMA + Al

IAEA

Equipment for phantom measurements

- Diagnostic dosimeter calibrated for general radiography beam qualities
- CDRH chest phantom
- CDRH abdomen/lumbar spine phantom
- Set of Al attenuators and lead diaphragm for HVL measurements
- Loaded cassette (for screen-film and computed radiographic systems)
- Tape measure or ruler
- Thermometer and barometer (for measurements with an ionization chamber)
    - beware of cheap electronic thermometers (display tenths of a centigrade but may be off several degrees)

IAEA

Methodology for phantom measurements I

- Position phantom
  - directly against table top or vertical bucky
  - centred transversely
  - positioned vertically to cover AEC detectors
  - beam size adjusted to phantom edges

IAEA

Methodology for phantom measurements II

- Set up equipment for chosen exam of normal adult patient
  - AEC
  - tube voltage (kV)
  - grid / air gap
  - Focus detector distance (focus table top distance in CoP): use what is applicable
  - collimation

IAEA

Methodology for phantom measurements III

- Position dosimeter in holder, avoiding covering AEC detectors
  - 240 mm recommended between phantom and dosimeter to minimize backscatter to acceptable values
- Measure distances between table top & tube focus d_{FTD} and table top & dosimeter d_m
- Insert cassette (loaded? why? Why now?)
- Expose 3 times under AEC and record readings
- Record temperature & pressure (ion chamber)

IAEA

Calculation of incident air kerma I

$$K(d) = \overline{M} N_{K,Q_0} k_Q k_{TP}$$

K(d): incident air kerma at measurement point

$\overline{M}$: mean value of dosimeter readings

k_{TP} : correction factor for temperature and pressure

$N_{K,Qo}$: dosimeter calibration coefficient

k_Q : factor which corrects for differences in the response of the dosimeter at the calibration quality Q_0, and at the quality Q of the clinical X-ray beam

IAEA

Calculation of incident air kerma II

$$K_i = K(d)\left(\frac{d_{\mathrm{FTD}} - d_{\mathrm{m}}}{d_{\mathrm{FTD}} - t_{\mathrm{P}}}\right)^2$$

Distance correction from chamber to patient surface:

d_{FTD} : measured tube focus-to-patient support distance in mm

d_m : distance from the table top
(or a wall Bucky) to the reference point of the chamber at the measurement position

t_P : thickness of a standard chest (or abdomen/lumbar spine) patient

recommended values for standard patient thickness: NEXT (USA): 225 mm chest / 230 Abdomen and LS. Use other values as appropriate

IAEA

Uncertainty budget estimations for K_i from phantoms

- Discussion on patient equivalence of phantoms will follow later
- Measurements are understood as phantom measurements → dose to phantom → there is a systematic difference to dose to patients
- This difference does not account for the uncertainty budget, since uncertainty means here “how accurate is the measured dose to the phantom” rather than “how well will the dose determined reproduce the typical patient dose”
  - Note: different if no AEC is used and technique parameters from a typical patient are manually set

IAEA

Dosimetry with patients and patient exposure data

IAEA
International Atomic Energy Agency

Possible scope

- Determine dose for a single patient
- Determine average dose for a patient collective

- Remember: will be associated with different uncertainty budgets

- Note: CoP does not differentiate here and provides methodologies for both with implicit focus on the latter

IAEA

Patient dosimetry

1. K_i calculated from measured tube output
2. K_e calculated from measured tube output
3. K_e measured using TLD
4. P_{KA} measured using KAP meter

IAEA

K_i versus K_e

- The CoP specifies both quantities as *principal quantities for patient dosimetry in General Radiography*
- Calculating K_i from tube output is more straight forward and does not necessitate a backscatter factor, that may be cumbersome and associated with considerable uncertainties in some examinations, as chest e.g.
- In GR skin injuries are not our focus because of small entrance doses, so it is not necessary to consider K_e. The reason to consider K_e is to allow comparison with values measured with TL dosimeters.

IAEA

Patient selection → Audit

- Select examination of interest
- Define weight range (typically 60-80 kg)
- Make measurements / collect data for at least 10 patients – 20 preferable

IAEA

Determination of patient doses from tube output measurement

= determination of does using patient exposure data

IAEA
International Atomic Energy Agency

Equipment for measuring tube output

- Calibrated diagnostic dosimeter
- Tape measure or ruler
- if ion chamber used, also:
  - Chamber support stand
  - Thermometer & barometer

IAEA

Measurement of output

Determination of dose yield at a given distance (best choice: 100 cm): Y(d) – Y(100), sometimes Y_{100}

- Recommend: Use of 100 cm (Y(100)) is standard and recommended to avoid mistakes if you have many different x-ray systems and use a different distance for tube output tables for every installation

- Position dosimeter in stand, away from patient support (in case of ion chamber)
- Measure distance between tube focus and dosimeter
  - You may wish to adjust distance to 100 cm, see above.
- Manually select clinically relevant technique factors (tube voltage, mAs, field-size)
- Expose chamber 3 times & record results
- Measure temperature & pressure
- Repeat for range of clinical beam qualities (kV, filtration)
- Calculate Y by dividing measured and appropriately corrected (k_q, k_{tp}) by mAs set

IAEA

Calculation of patient incident air kerma

- Record technique parameters for examination
  - tube voltage
  - tube loading (P_{IT})
  - focus-skin-distance or focus-film distance (d_{FTD}) & patient thickness (t_p)

$$K_i = Y(d) P_{It} \left(\frac{d}{d_{FTD} - t_P} \right)^2$$

Where Y(d) is the X-ray tube output at distance d from tube Focus & the clinical tube voltage

IAEA

Y(100) measurements

- Recommendation: keep record of measured Y(d) values with x-ray equipment for further reference

- If you use them later, check validity first (x-ray tube may have been changed, etc. . . .)

IAEA

Calculation of patient entrance surface air kerma

Determine appropriate backscatter factor (B) for clinical beam HVL & field-size

$$K_e = K_i B$$

IAEA

Feasibility of this approach

- When is this approach not possible?
  - AEC used on a system with no post exposure mAs display
  - Still possible: TLD or P_{KA} (recommended: latter), see next chapter ☺
- In all other situations
  - This is the most commonly used approach if no automatic measurement (or calculated dose) with every patient exposure is automatically obtained
    - This would be P_{KA} determination and recording for every patient

IAEA

Determination of patient doses from measurements on patients (TLDs) or during patient exposure (P_{KA})

Direct determination of patient exposure

IAEA

International Atomic Energy Agency

Equipment for direct measurement of entrance air kerma

- Thermoluminescence reader (or access to external TLD service)
- Well calibrated TLD in sachets
- Cellophane tape
- Worksheet for recording data

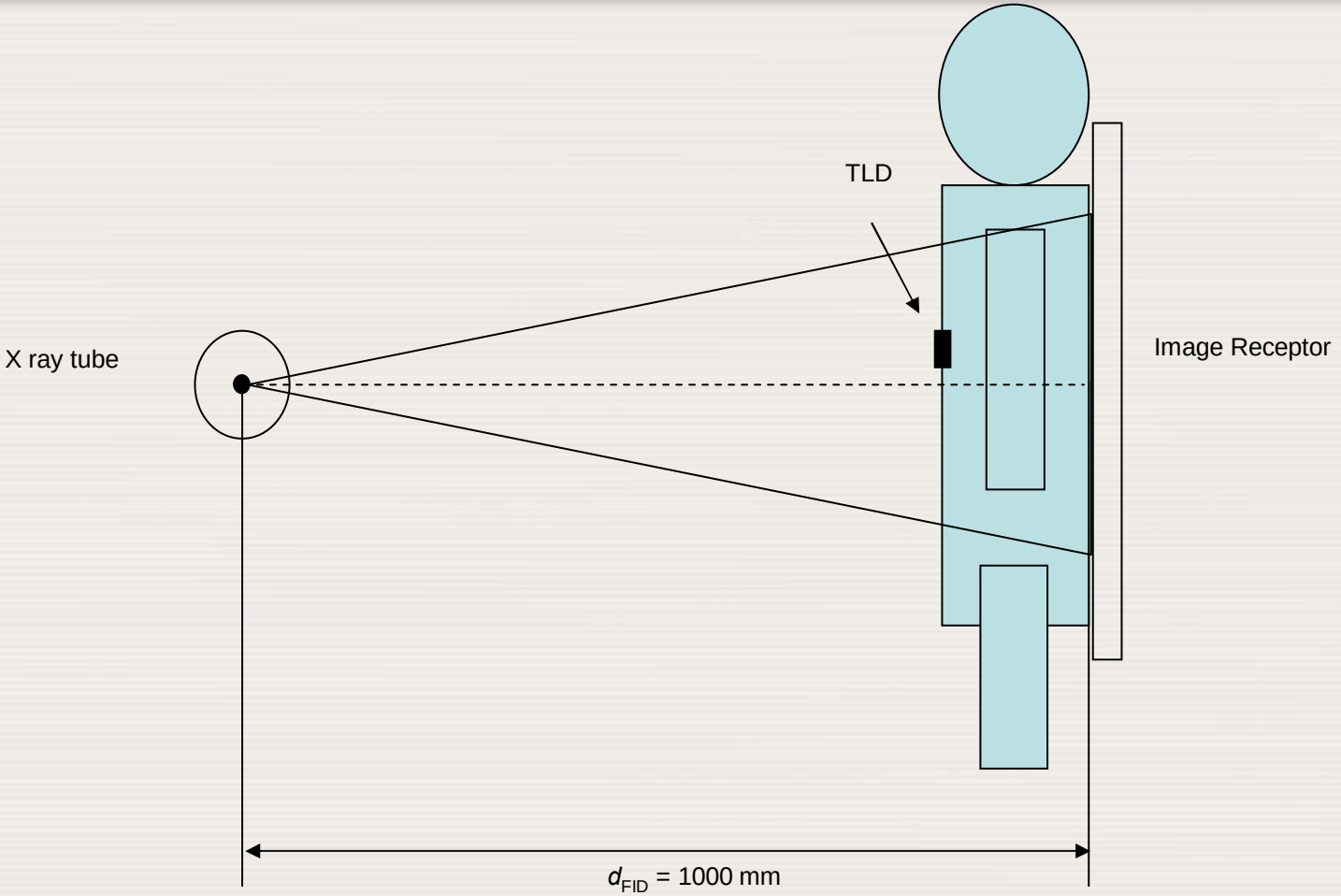
IAEA

Methodology for direct measurement of entrance air kerma

- Retain 1 TLD sachet for assessment of background correction
- When patient positioned, attach TLD sachet(s) to skin at centre of entrance beam
- Record patient & technique data with TLD identification
- Remove TLD after exposure & attach to worksheet
- Read TLDs to obtain dose readings & background correction

IAEA

Schematic arrangement for TLD measurements



Entrance air kerma from TLD measurements

$$K_e = \overline{M} N_{K,Q_0} k_Q k_f$$

$\overline{M}$: mean value of dosimeter readings with background correction

k_f : correction factor for fading of TL signal

$N_{K,Qo}$: dosimeter calibration coefficient

k_Q : factor which corrects for differences in the response of the dosimeter at the calibration quality Q_0, and at the quality Q of the clinical X-ray beam

IAEA

Uncertainties

associated with doses in general radiography

IAEA

International Atomic Energy Agency

Sources of uncertainty

For determination of dose to a phantom or single patient:

- Measurement scenario
  - . . . This is the tricky one !!
- Calibration, stability and energy dependence of dosimeter
- Precision of reading
- Uncertainty in measurement position
- Uncertainty in back scatter factors
- Uncertainty in TLD correction factors
- . . .

For the determination of average dose to a patient collective (i.e., dose to patients undergoing Thorax pa examination calculated from a sample of 10 to 20 patients)

- All above
- Plus uncertainty arising from dose variations between patients and limited number of observations (=patients)

→ There is a tutorial on this issue this and tomorrow afternoon

IAEA

Achievable and typical uncertainties

Achievable:

- Phantom measurement of K_i : 5.6 - 12.6%
- Calculation of K_i : 5.5 - 12.5%
- Calculation of K_e : 6 - 13%
- TLD measurement of K_e on patient: 12%

Note: this is a very optimistic estimation for single observations (one patient/phantom measurement).

- ***Typical*** *expanded (2σ) uncertainties for clinical measurements will be not less than 10%. In many instances application of corrections for beam quality and individual patient diameter will not be feasible; in these cases expanded uncertainties of approximately 25% should be considered*
- For determination of typical doses to patients (patient collective) this estimation is valid for a very large number of patients

IAEA

Thanks to

- This presentation was compiled by several authors. Credits belong especially to

- Claire-Louise Chapple
- Donald McLean

IAEA