## Detectors and measurement tools for IR

- Measurement of DAP including DAP meter calibration
- Measurement techniques for ESD

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## Why to measure doses?

- Interventional radiology (IR) and interventional cardiology (IC) produce the greatest radiation doses to patients from diagnostic X-ray systems - stochastic effects are of importance, especially for young patients
- In complex IR or IC procedures, patient skin doses can exceed the threshold for deterministic effects

## Recommendations (ICRP 85, 2000)

- ....
- All departments performing IR procedures should know the output parameters of their IR equipment and typical doses to patients and staff
- All IR procedures should include measurement and recording of equipment technical factors used
- All IR equipment manufacturers should provide.... appropriate indicators of delivered doses...
- .....

## Legal requirements

Council directive 97/43/EURATOM (MED)

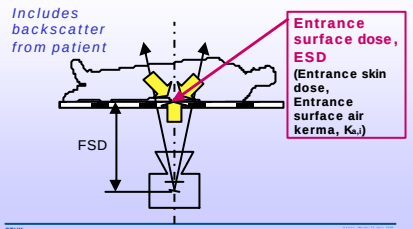
- The optimization process shall include...the assesment and evaluation of patient doses... (Article 4)
- If new radiodiagnostical equipment is used, it shall have, where practicable, a device informing the practitioner of the quantity of radiation produced by the equipment during the radiological procedure (Article 8)

## Quantities needed

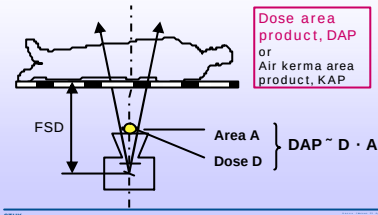
| | |
|---|---|
| Entrance surface dose (ESD)<br>• Entrance skin dose<br>• Maximum surface dose (MSD) | To determine whether exposures to the skin have exceeded deterministic levels, and if so, whether to proceed |
| Dose area product (DAP) | For information on stochastic effects, risk evaluation (may be converted to effective dose, E) |

*Neither is sufficient on its own!*

## Entrance surface dose (ESD)



## Dose area product (DAP)

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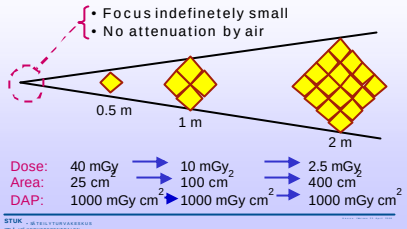



| | | | |
|---|---|---|---|
| Dose: | 40 mGy | 10 mGy | 2.5 mGy |
| Area: | 25 cm$^2$ | 100 cm$^2$ | 400 cm$^2$ |
| DAP: | 1000 mGy cm$^2$ | 1000 mGy cm$^2$ | 1000 mGy cm$^2$ |

## Difficulties of patient dosimetry in IR and IC

- Irradiation of different anatomical areas
- X-ray beam changing to different projections
- diverse field sizes
- diverse radiation qualities
- can be beam hardening by extra filters
- diverse focus-to-skin distances
- diverse focus-to-image intensifier distances
- for skin dose, the location of maximum dose is not known in advance

## Determination of ESD

- By TLD dosimeters or other solid state detectors
  - point measurements or large area arrays
- By slow radiografic films or radiocromic film

Prospective
Can be laborious for routine practice

- Computational methods
  - By calculation from tube output
  - By calculation from DAP
  - Retrospective calculation from DICOM header data (when trigger level exceeded)
- Electronic point detectors
  - portal monitoring, special DAP

Enables real time (on-line) measurement
Requires knowledge on procedure and parameters
Limited applicability (especially in cardiology)

## Measurement of ESD

## Measurement of ESD

By TLD dosimeters

- The most accurate in-vivo estimate of skin dose
- Placed at the centre and around the irradiated area on the entrance surface, at the points of expected maximum exposure
- Requires knowledge of the IR procedure and exposure pattern

## Measurement of ESD

By radiografic slow films (also RC films)

- Radiotherapy verification films: e.g. Kodak X-Omat V film (33 cm x 41 cm)
- Placed underneath the patient, centered as closely as possible to the expected most irradiated areas, and exposed throughout the normal IR protocol
- Dose often confirmed by TLDs placed in contact with the film
- Total ESD, maximum ESD or total DAP



## Measurement of ESD

By radiografic slow films (also RC films)

- Films calibrated by standard sensitometry and read by densitometry
- Accuracy within 5 to 20 %
- Dosimetry can be supplied and analysed far from a given installation (by mailed films and TLD chips)

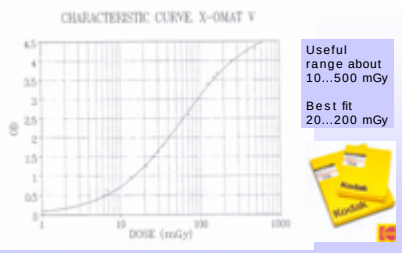


## Measurement of ESD

By radiografic slow films (also RC films)

- Provides additional valuable information for retrospective optimization of the procedures
  - distribution of the irradiated areas together with dose levels
  - number and types of projections
  - check of appropriate use of beam limiting devices, wedge filters etc






Useful range about 10...500 mGy

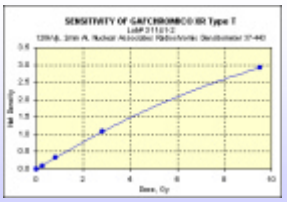
Best fit 20...200 mGy



Radiochromic film

Useful range about 0,2 ...10 Gy (200...10000 mGy)

Max size 25 cm x 30 cm → more than one film may be needed

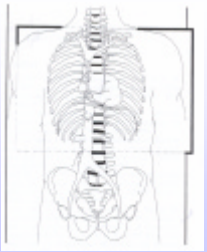


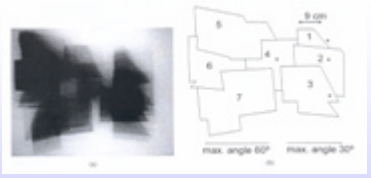



Example:
A coronary angiography procedure

Placement of the film
(Kodak X-omat V)

(Vano et al. 1997, Br.J.Radiol 70, 195-200)

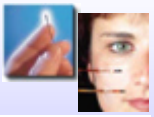




Example: A coronary angiography procedure (Vano et al.1997)
- one film 31 cm x 41 cm is enough (if correctly placed)
- all standard projections can be identified
- some fields overlap resulting in ODs above the linear region: can still be used to judge "MSD is higher than a certain value"

## Measurement of ESD

By other dosimeters
- Diode
- Mosfet
- Scintillation detectors
- Ionization chamber (on a phantom)



Mosfet dosimeters

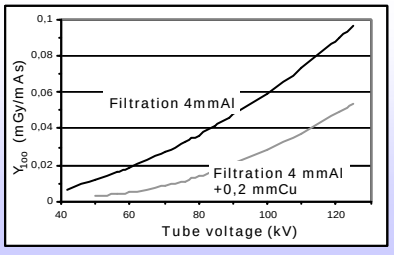
*General problem: The point(s) of maximum ESD difficult to know, laborous, inconvenient for patient*

## Computational methods for the determination of ESD

## Computational methods:
### Calculation of ESD from tube output

$$ESD = Y_{100}(U,F)(100\,cm/FSD)^2 Q\ BSF$$

$Y_{100}(U,F)$ tube output (mGy /mAs)
at a distance of 100 cm from the focus,
*with high voltage of U kV and total filtration F*
$FSD$ focus-to-skin distance (cm)
$Q$ tube current-time product used (mAs)
$BSF$ back scatter factor

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## Calculation of ESD from DAP

$$ESD = \frac{DAP}{A} \bullet BSF$$

*A* Field size at the entrance surface to the patient (=*A(FSD)*)

*BSF* Back-scatter factor for the given U (kV), field size and HVL-value

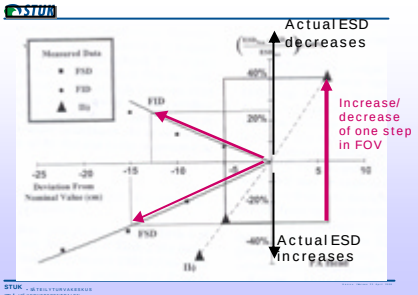
## Calculation of ESD from DAP - Backscatterfactors (ICRP 85)

| Peak applied voltage, kV | Field size, cm x cm | | |
|---|---|---|---|
| | 10x10 | 20x20 | 30x30 |
| 60 | 1,26 | 1,29 | 1,30 |
| 80 | 1,29 | 1,34 | 1,36 |
| 100 | 1,32 | 1,39 | 1,41 |

## Calculation of ESD from DAP

Assumptions (for a given IR procedure)

- Uniform dose distribution accross the field size
- Image intensifier FOV is reasonably constant throughout the procedure and consistent between procedures
- Beam orientations and their relative weighting are consistent between each procedure of this type
- FSD for each orientation is nearly constant




## Calculation of ESD from DAP

Problems

- In cardiology procedures, DAP, and other approximations based on X-ray tube output rate are not sufficient to estimate MSD (Vano et al 2001, Br.J.Radiol. 74, 48-55)
- On-line dosimetry systems require the connectivity between the DAP meter or DAP indication, the radiological equipment and the radiological information systems
- Need for standardization and development of interventional equipment and DAP meters

## Retrospective calculation of ESD

- A threshold (or trigger) of fluoroscopy time and/or simple measurable quantities (DAP) selected for each procedure type to alert the operator and to initiate a more detailed investigation of the skin exposure when the trigger value is exceeded
  - the trigger level must be conservative
  - DAP values of 200-300 Gy · $cm^2$ are proposed
- Retrospective calculation from DICOM header data once the trigger level is exceeded
  - DICOM header data not yet always sufficient

## Direct on-line determination of ESD

Most DAP-systems and software packages currently do not provide sufficient information to allow estimation of ESD on line

New solutions are available or coming to the market e.g. PTW Diamentor M4-KDK "chamber-in-chamber": can measure both DAP and beam area --> estimate of ESD


## Measurement of DAP

## Measurement of DAP

General

- Either DAP-meter or computational display for DAP (based on beam parameters)
- DAP-meter can be removable or fixed
- Fluoroscopic and radiographic DAP can be obtained separately but many units only indicate total DAP

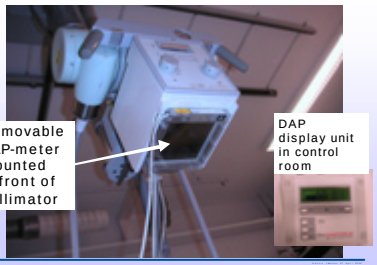
## Measurement of DAP

- *DAP* is a quantity used in patient dosimetry (unit Gy·m2).

$$DAP = \iint_{dx\,dy} D_{air} \,.\, dx \,.\, dy$$

- The main part of DAP meter is a **ionization chamber** which measures the *DAP* quantity according to its definition.

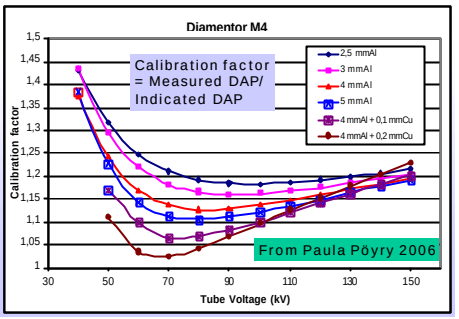
From Paula Pöyry 2006

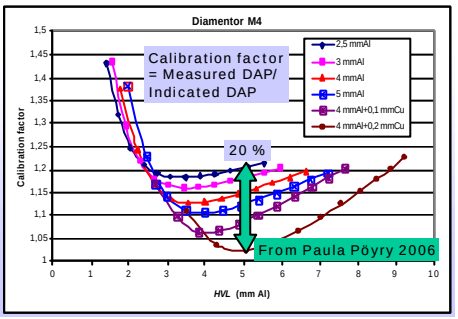



Fixed DAP-meter inside the housing

## Why DAP meters should be calibrated?

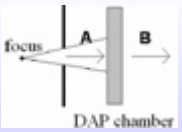
- The response of the DAP chamber is dependent on radiation spectrum; chambers are usually adjusted to show average value with total **uncertainty of 20 – 30 %** for the operational area.
- The calibration improves the **accuracy** in the measurement **(to less than 10 %)**.
- To get **comparable** and **reliable** results, the calibration should be **traceable** to international measuring system.




## Calibration of DAP meter (used in hospitals)

- DAP meter should be calibrated using the same X-ray equipment and beam geometry as in actual measurements.
- DAP meters should measure the amount of radiation incident to patients.




$$A \neq B$$

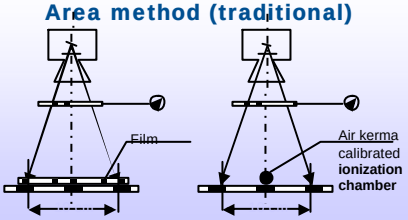
From Paula Pöyry 2006

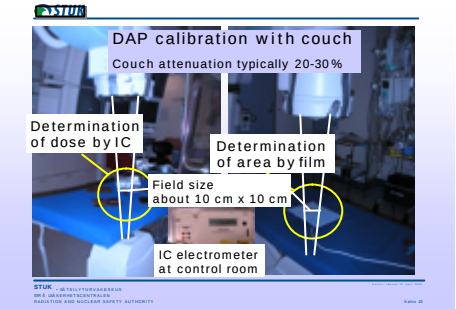
## Calibration of DAP meters (used at hospitals)

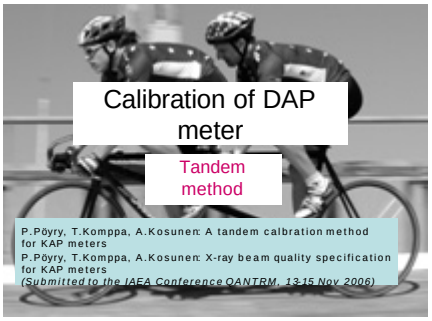
Two optional methods

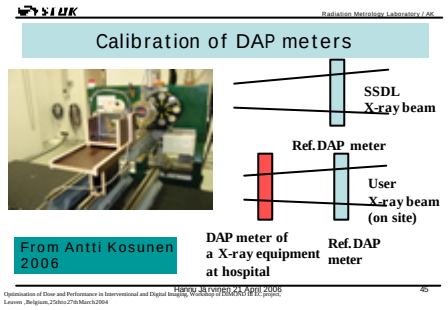
- "Area method" - Traditional
  - separate determination of dose and area, DAP by multiplication
- "Tandem method" - New proposal
  - Calibration by comparison with a calibrated reference DAP-meter

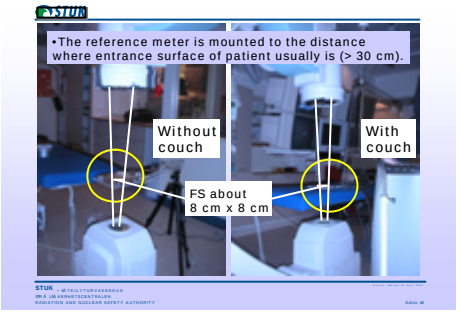
## Calibration of DAP meters: Area method (traditional)

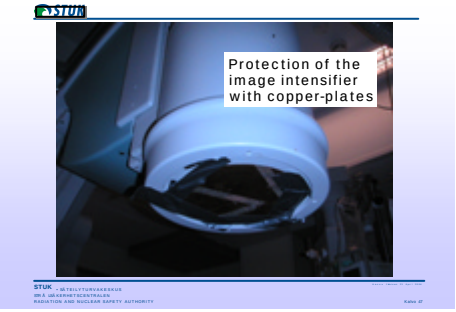





Comparison of the methods for DAP calibration

| | Area method | Tandem method |
|---|---|---|
| Main advantages | Small energy dependence of the response of dose meter | No need to determine field size --> no uncertainty for field size. No need for positioning of reference meter at exact distance. |
| Main dis-advantages | Excactly same distance needed for dose meter and film. Uncertainty of field size. | High energy dependence of reference meter response. |

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