Patient doses in paediatric radiology

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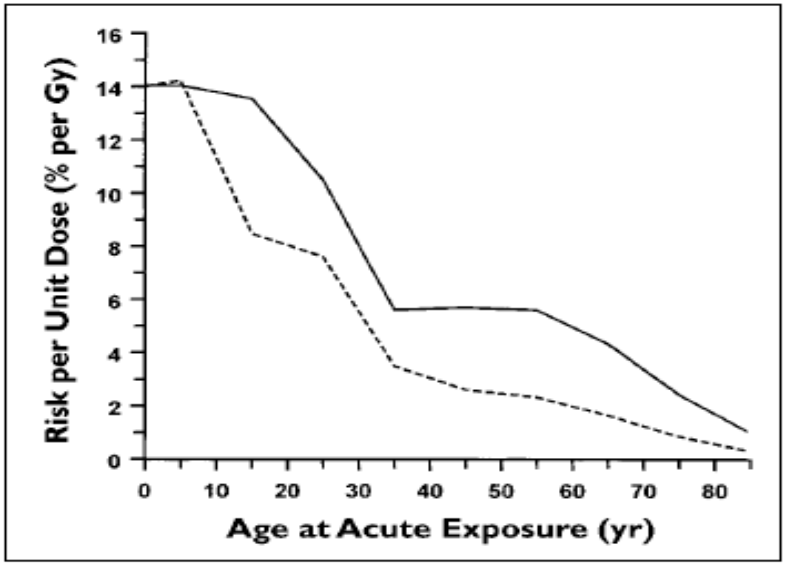
ALARA in the medical world

http://www.sck.be

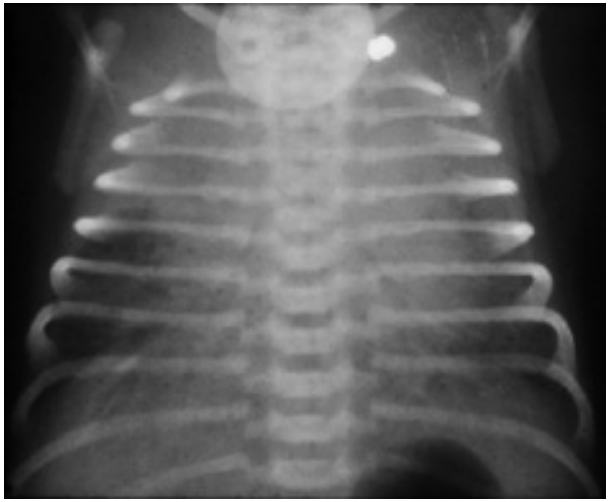
Patient dose in paediatric radiology

- Why is it important?
  - Significant radiation detriment
    - 2-3 times higher than average population
    - 6-9 times higher than a 60-year old person
  - Medical Exposure Directive (97/43/Euratom)



Patient dose in paediatric radiology

- Why is it important?
  - Long life expectancy
  - Exposed to a large number of X-ray examinations
    - Neonatal Intensive Care Unit (NICU)

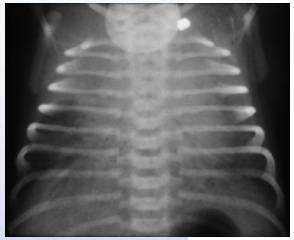


Paediatric Radiology

Dynamic examinations

< 1 year

> 1 year



Simple examinations

Paediatric Radiology

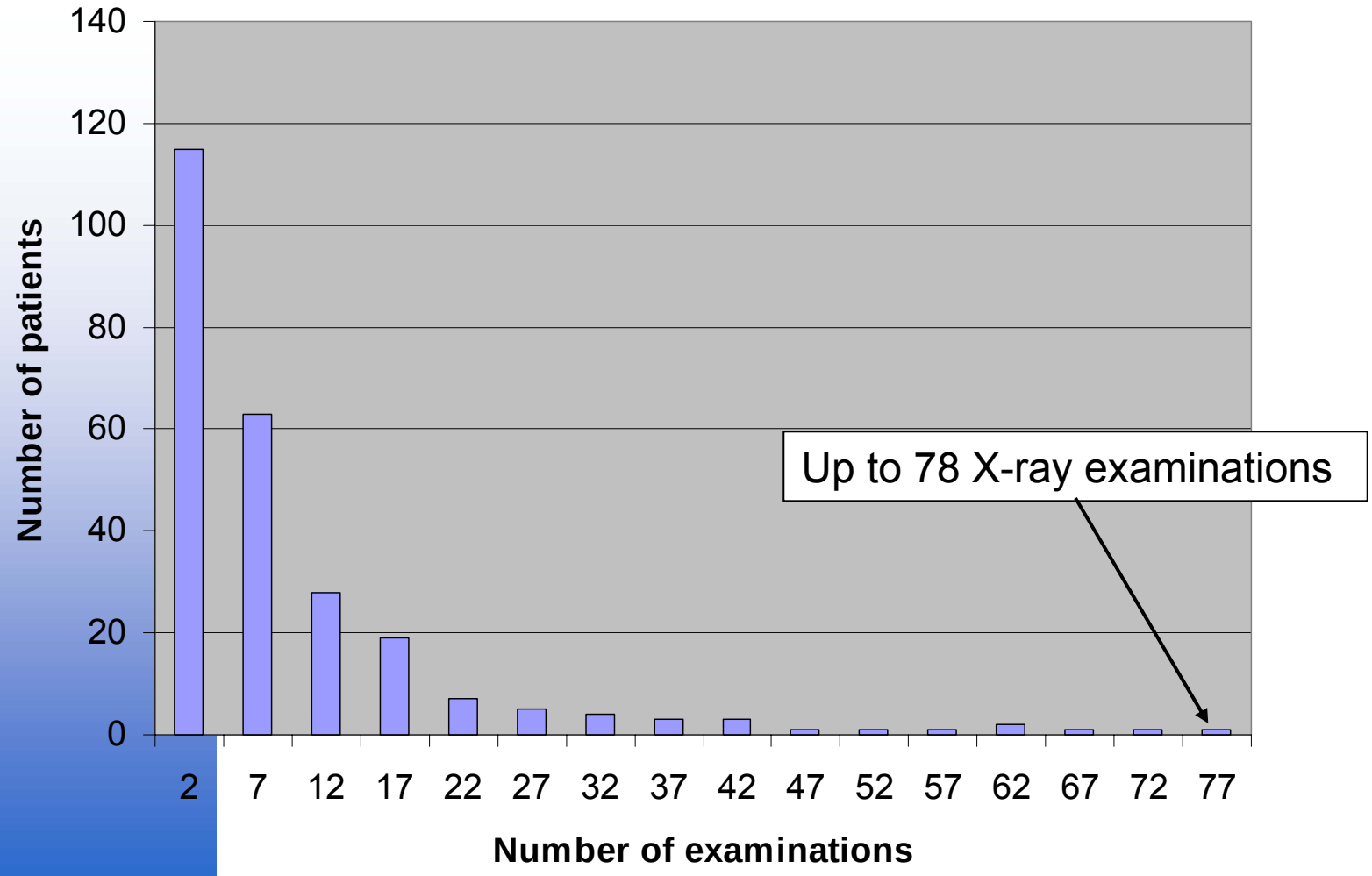
Low dose

High dose (CT)

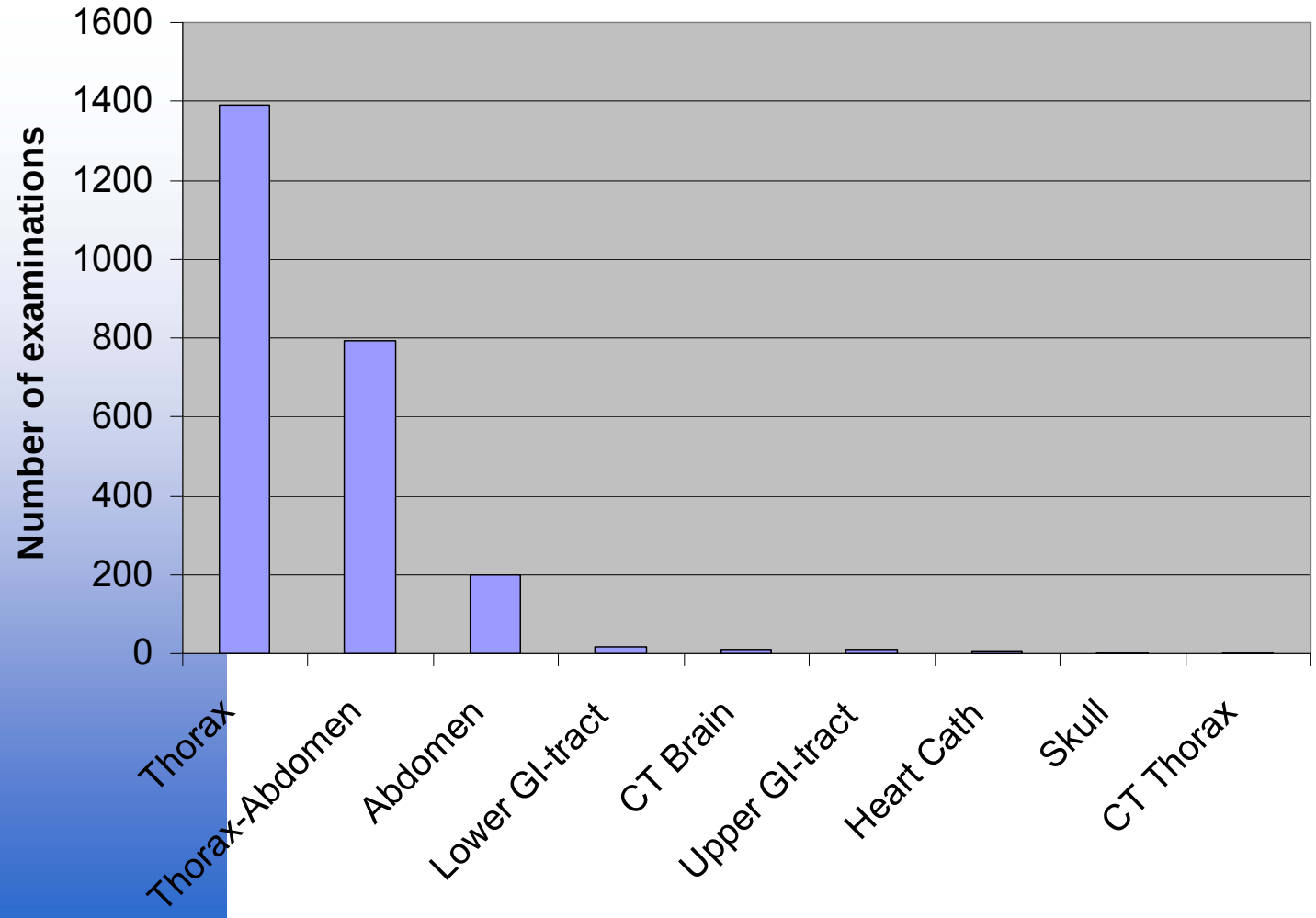
Examinations at the neonatal unit

- < 1 year
- Neonatal Intensive Care Unit
  - Newborn infants with pathology/disease
  - Premature newborn infants
- Chest radiograph and abdominal radiograph

Examinations at the neonatal unit



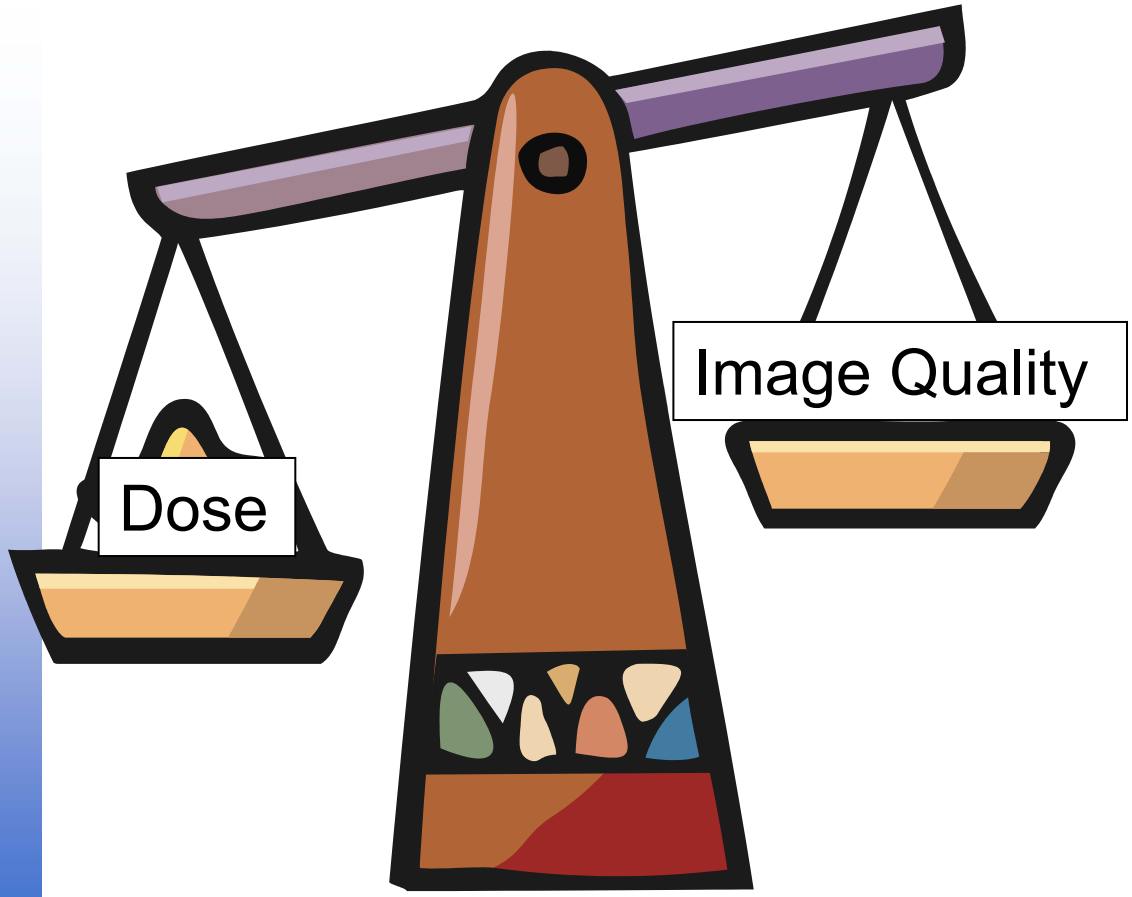
Examinations at the neonatal unit



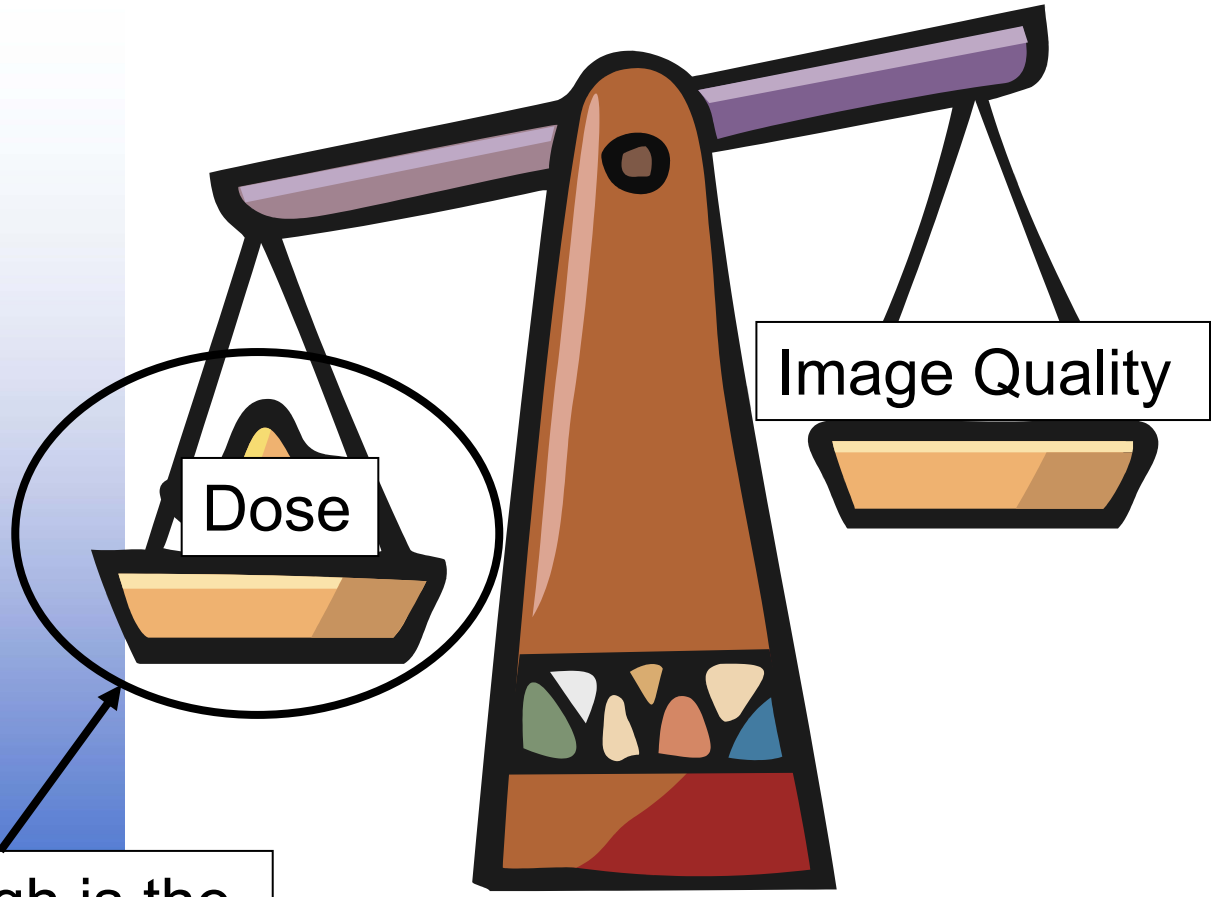
Paediatric radiology department

- > 1 year
- Simple examinations
  - Chest, abdomen, pelvis
- Dynamic examinations
  - Lower GI-tract, Upper GI-tract, Voiding Cystourethrogram

Radiation exposure



Radiation exposure



How high is the dose?

Radiation exposure

- Radiation risks
  - Based on doses in various organs and tissues in the body
  - ~~Effective dose~~

$$E = \sum w_T . \sum w_R . D_T$$

W_T: Developed for reference populations of equal number of both sexes and a wide range of ages

Radiation exposure

- Radiation risks
  - Based on doses in various organs and tissues in the body
    - Direct measurements of organ doses are not possible
  - What can we measure? What do we know?
    - Protocols
    - Entrance Surface Dose (ESD)
    - Dose Area Product (DAP)

Radiation exposure

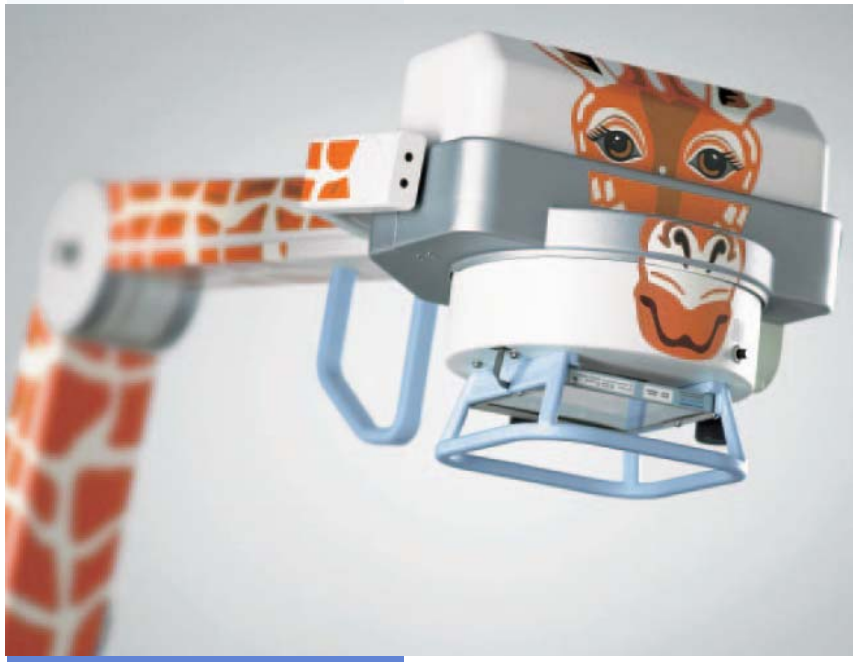
- Leuven
  - University Hospitals Leuven
- Europe
  - Sentinel project
    - European survey on patient doses in paediatric radiology
    - 13 Countries
    - http://www.dimond3.org/
  - European Guidelines
    - European Commission. European Guidelines on Quality Criteria for Diagnostic Radiographic Images in Paediatrics. EUR 16261, (1996)

I. Measurements

Radiation exposure

- What can we measure? What do we know?
  - Protocols
  - Entrance Surface Dose (ESD)
  - Dose Area Product (DAP)

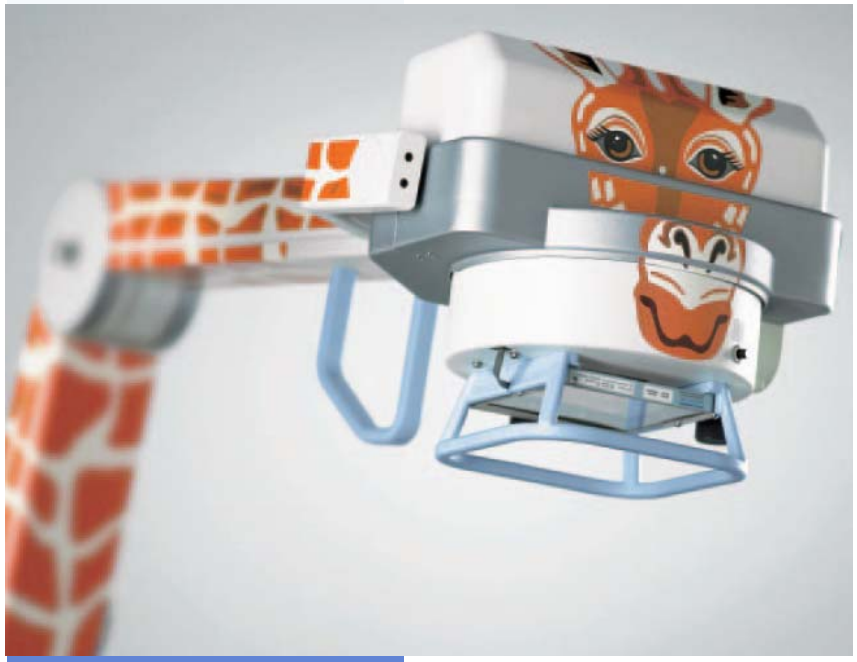
Protocols and equipment (NICU)

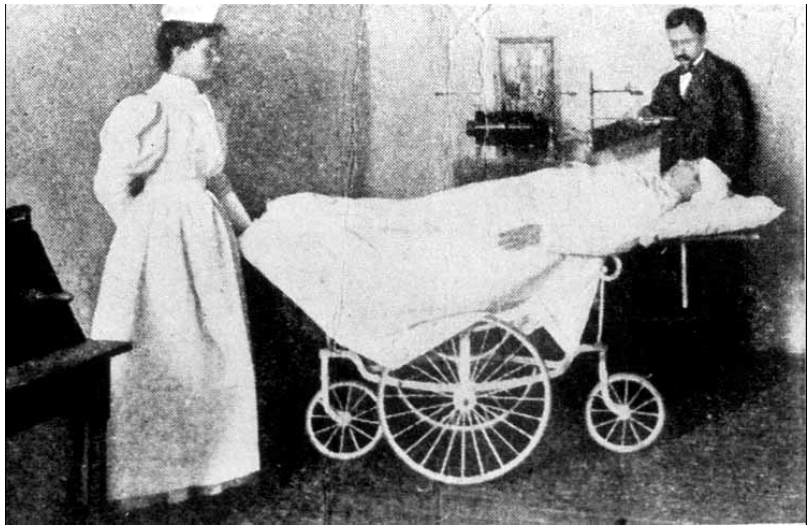


- Equipment
  - Mobile X-ray unit
  - Computed Radiography plates

Protocols and equipment (NICU)

- Equipment
  - Mobile X-ray unit
  - Computed Radiography plates
  - Old, secondhand





Protocols and equipment (NICU)

Procedure map

- Protocols
  - Where are they coming from?
  - Are they optimized for Computed Radiology?

Protocols in Leuven (NICU)

- Procedure map is available:
  - No Automatic Exposure Control
  - Exposure parameters have to be selected based on patient weight.

Gewicht (g)	kV	mAs
500	60	0,56
800	60	0,63
1100	60	0,63
1300	61,5	0,8
1700	64,5	0,8
2000	66	0,8
2500	68	0,8
2800	68	0,8
3000	70	0,8
4000	70	1

Protocols in Europe (NICU)

	Distance [cm]	kVp	mAs
Centre 1	100	60-70	0.56-1.0
Centre 2	80-100	50-70	1.0-2.0
Centre 3	50-70	60-65	2.0-2.5
Centre 4		55	
European Guidelines	80-100	60-65	

K. Smans et al., “Results of a European Survey on Patient Doses in Paediactric Radiology,” accepted for publication in Rad. Prot. Dos.

Protocols in Europe (NICU)

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Centre 1	100	60-70	0.56-1.0
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European Guidelines	80-100	60-65	

Proportional with the length of the radiographer!

K. Smans et al., "Results of a European Survey on Patient Doses in Paediactric Radiology," accepted for publication in Rad. Prot. Dos.

Equipment (Paediatric department)

- Equipment
  - Fixed X-ray unit
  - CR (computed radiography) or DR (digital radiography)

Protocols in Europe (Paediatric department)

	Distance [cm]	kVp	mAs
Centre 1	110-150	70-110	1.6-4
Centre 2	78-146	37-54	5-13
Centre 11	100-200	38-73	4-42
European Guidelines	100-150	60-80	

K. Smans et al., “Results of a European Survey on Patient Doses in Paediactric Radiology,” accepted for publication in Rad. Prot. Dos.

Radiation exposure

- What can we measure? What do we know?
  - Protocols
  - Entrance Surface Dose (ESD)
  - Dose Area Product (DAP)

Entrance surface dose

- Entrance Surface Dose (ESD)
  - Measurement: TLD (ThermoLuminescent Dosimeter)
  - TLDs wrapped in plastic bag
  - Attached to patients skin
  - Time consuming

Entrance surface dose

- Entrance Surface Dose (ESD)
  - Measurement: TLD (ThermoLuminescent Dosimeter)
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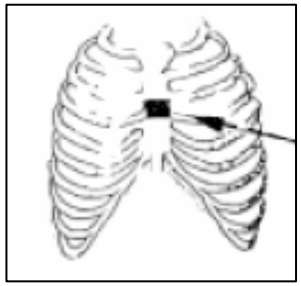
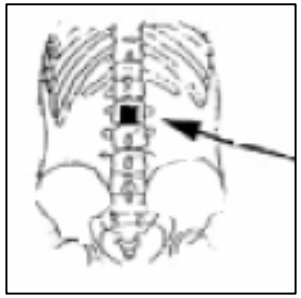
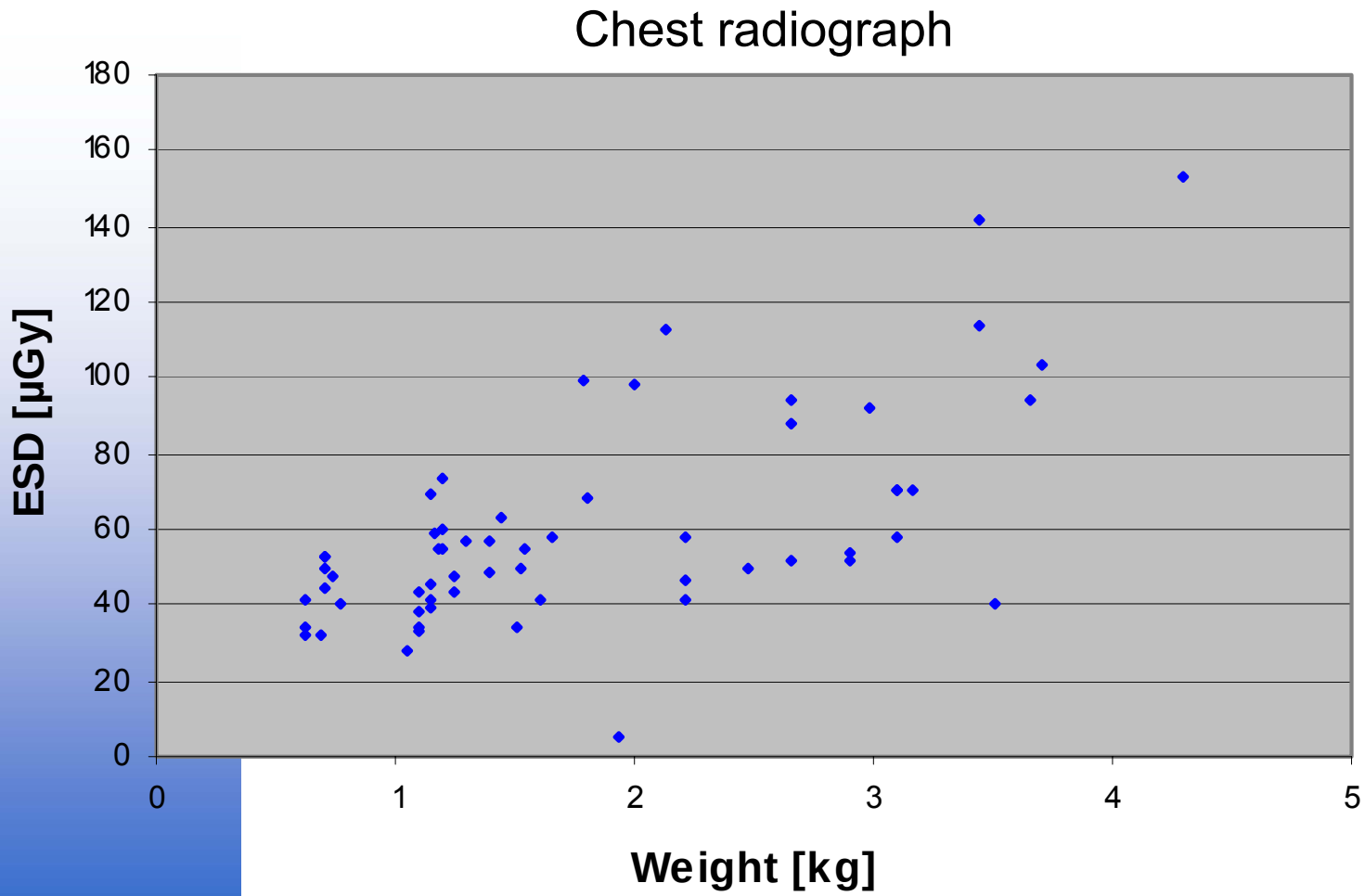




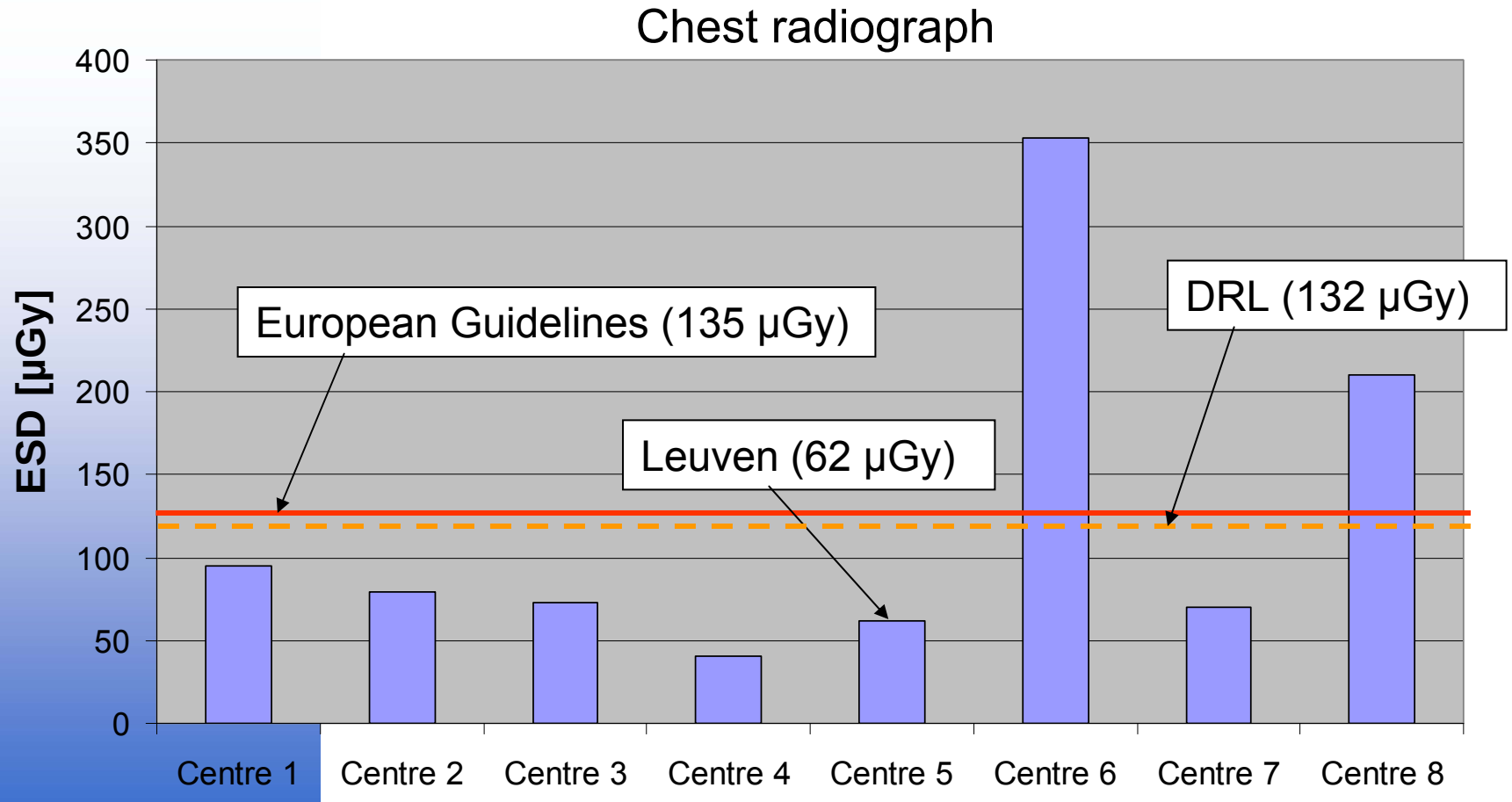
Entrance Surface Dose Study in Leuven (< 1y)



Entrance Surface Dose Study in Leuven (< 1y)

Median ESD (µGy)	
Chest Radiograph	62 [5-142]
Abdomen Radiograph	89 [67-102]
Combined Radiograph	81 [30-151]

Entrance surface dose European study (<1y)



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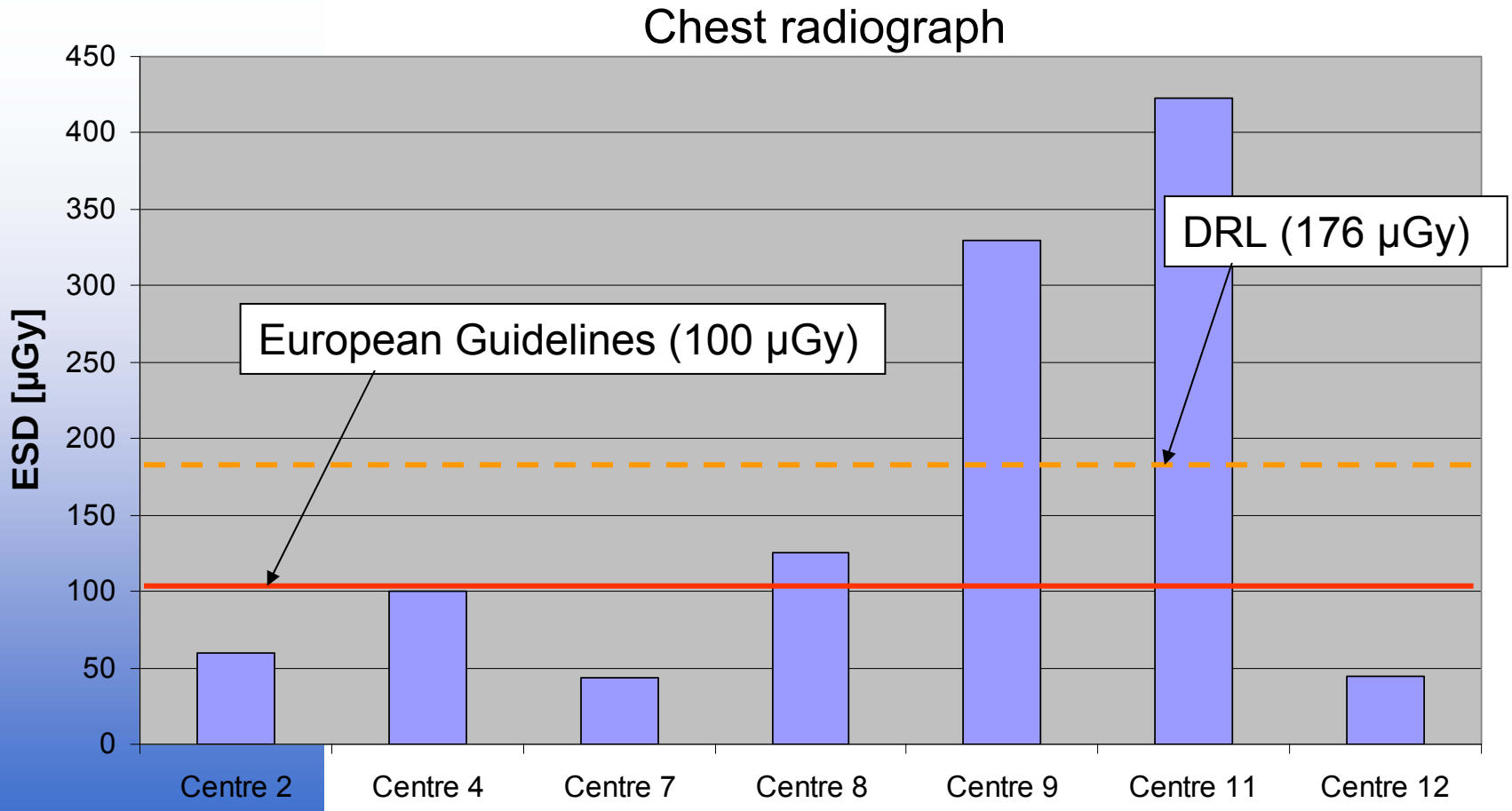
Entrance surface dose European study (3y-8y)

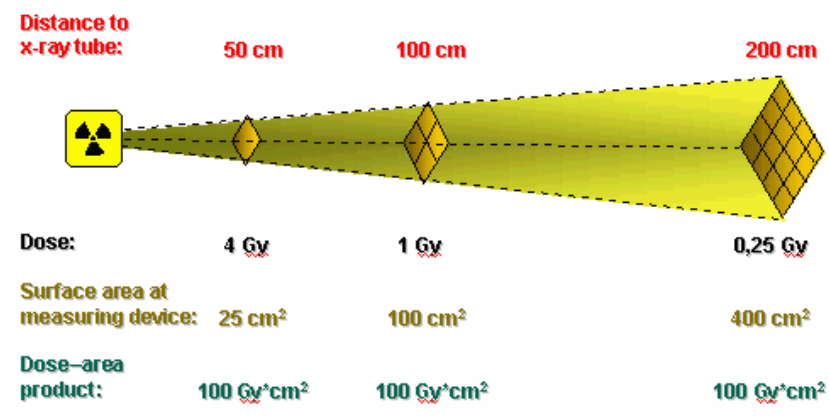


Radiation exposure

- What can we measure? What do we know?
  - Protocols
  - Entrance Surface Dose (ESD)
  - Dose Area Product (DAP)

Dose area product

- Dose Area Product (DAP)
  - DAP-meter = plan parallel ionization chamber
  - DAP = Dose x irradiated area
  - Attached to diaphragm RX-tube
  - ‘easy’ measurement

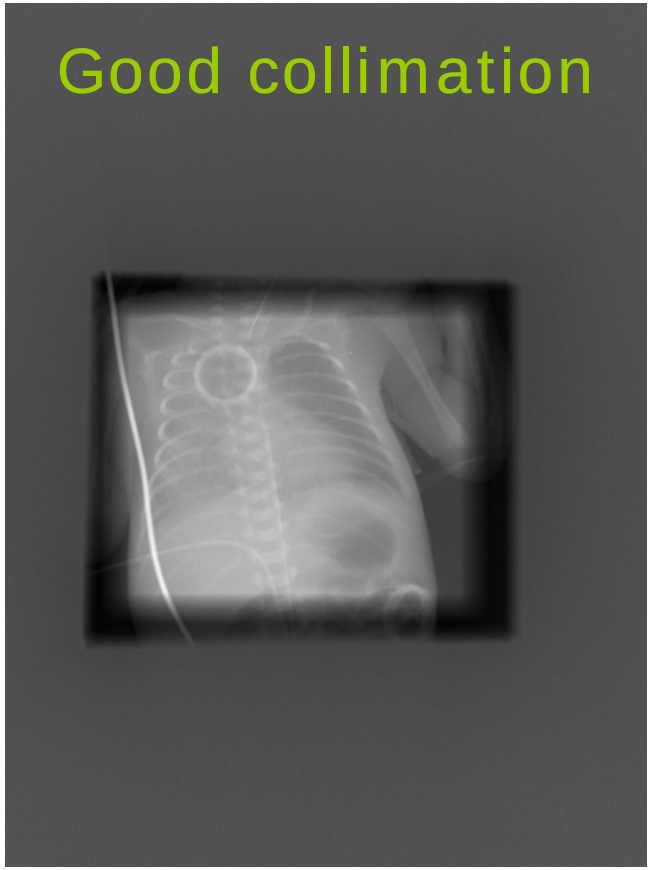


Dose area product

- DAP-measurements
  - DAP = Dose Area Product
- “Dose”
  - Depends on exposure parameters
- “Area”
  - Depends on collimation

Fieldsize	Patient 1	Patient 2	Patient 3	Patient 4
Day 1	56 cm²	90 cm²	190 cm²	90 cm²
Day 2	91 cm²	140 cm²	112 cm²	108 cm²
Day 3	84 cm²	122 cm²	109 cm²	-

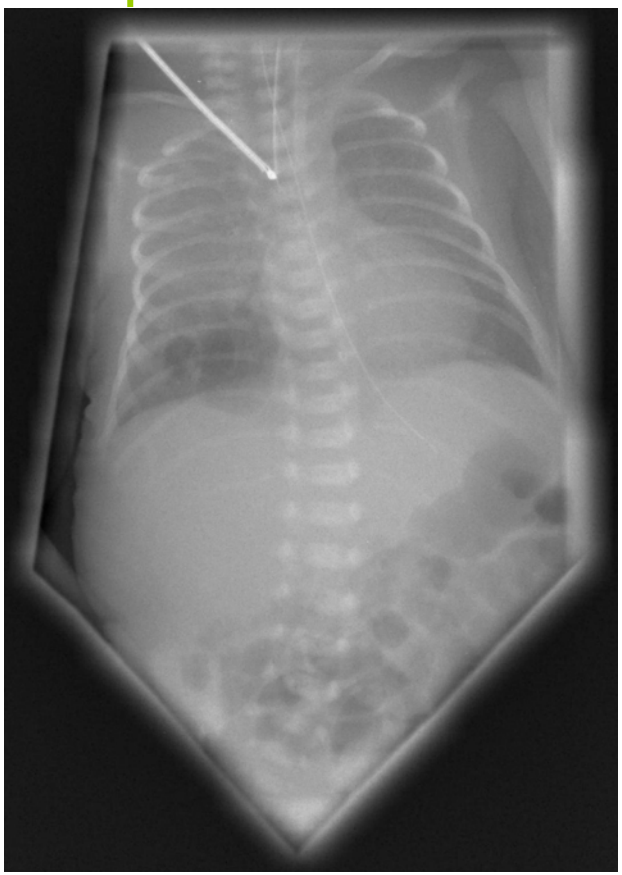
Dose Area Product



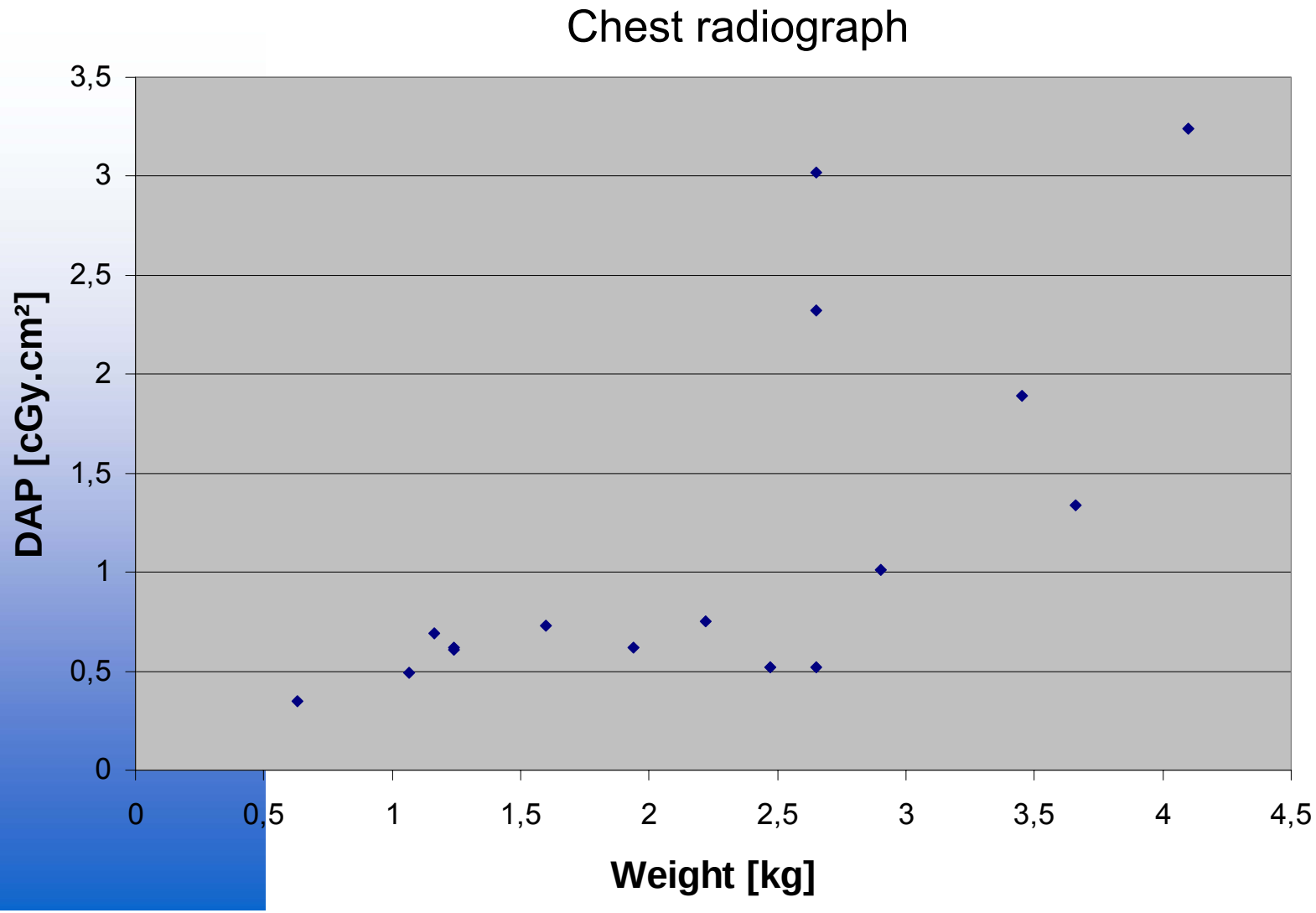
Dose Area Product

No radiation protection

Good radiation protection

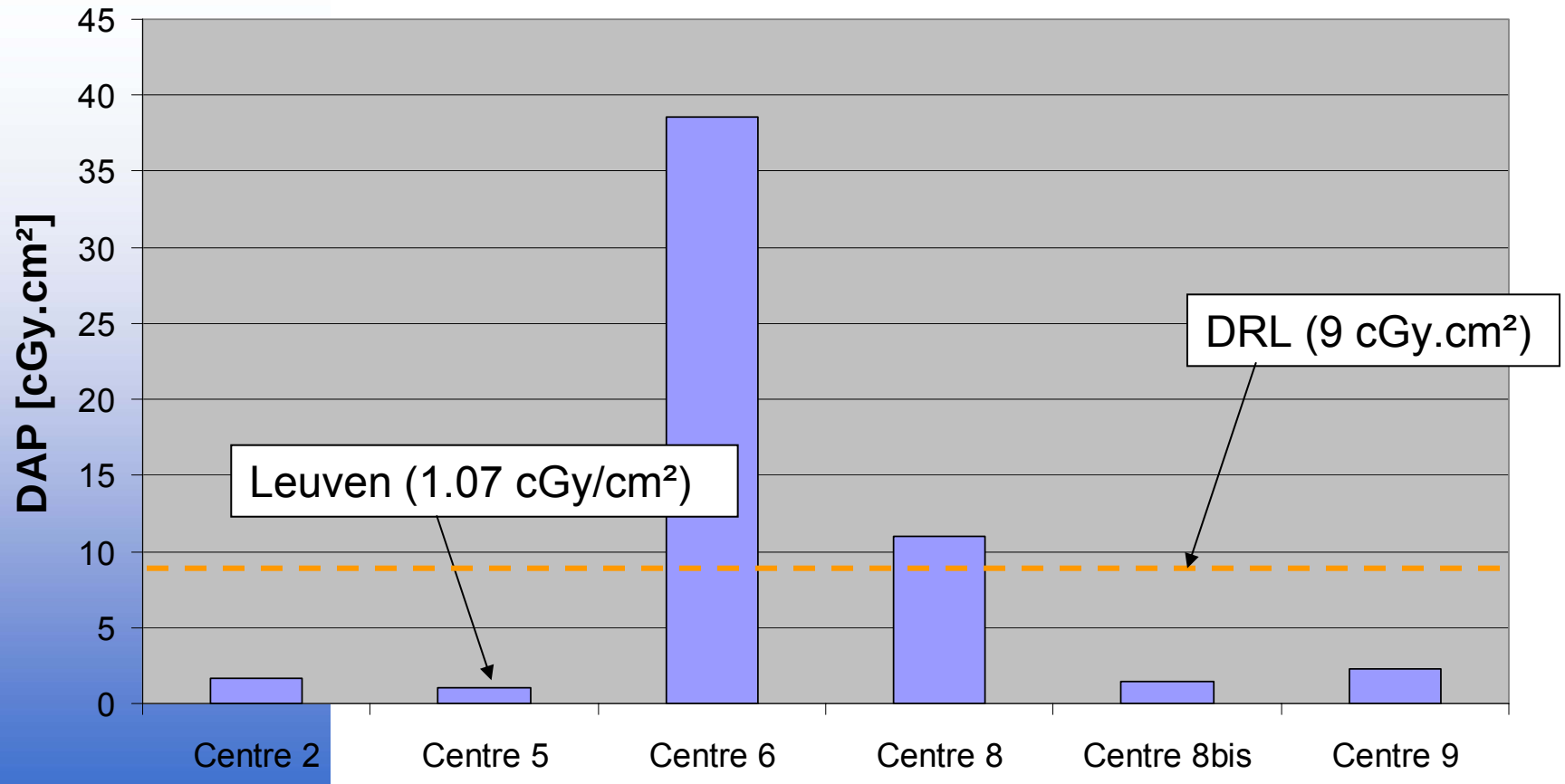


Dose area product Study in Leuven (< 1y)



Dose area product European study (1 y)

Chest radiograph



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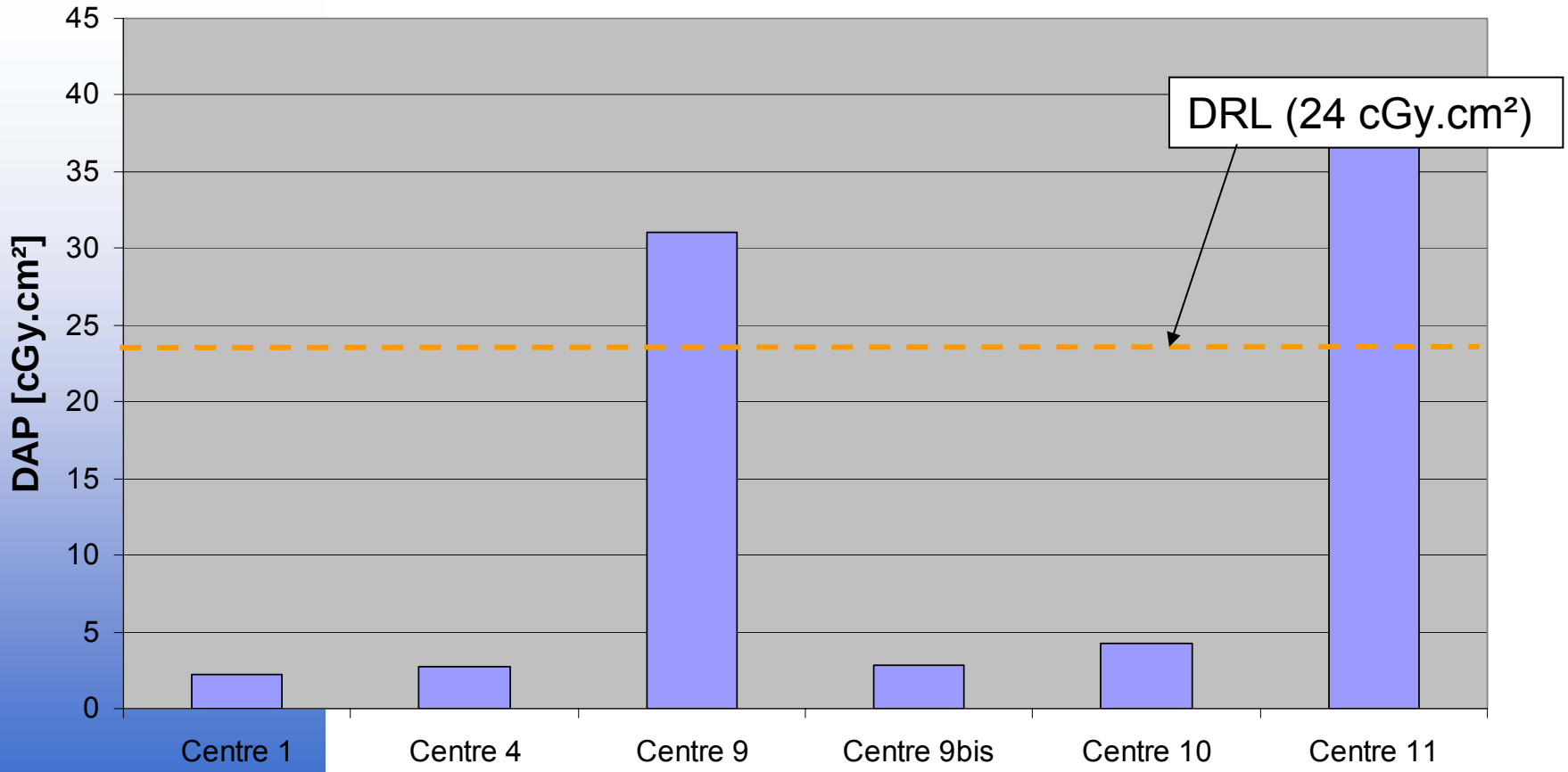
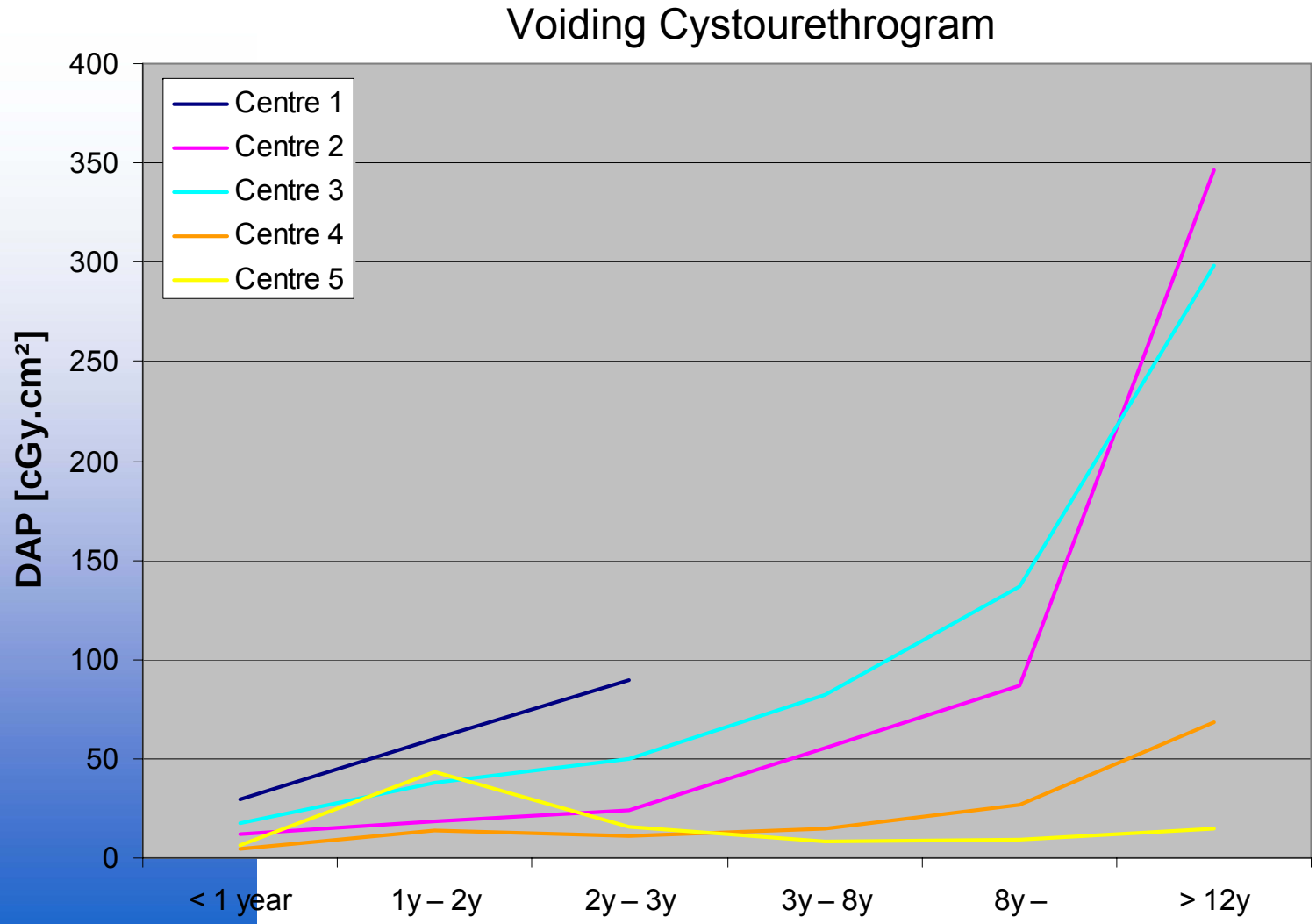
Dose area product European study (3y-8y)

Chest radiograph



Dose area product European study



Dose and risk Overview

- Protocols
- ESD
- DAP

→

- Organ dose

Step 1:
Measurements

Dose and risk Overview

- Protocols
- ESD
- DAP

→

- Organ dose

- Conversion factors
  - NRPB
  - PCXMC
  - Simulations with Monte Carlo software

Step 2:
Conversion factors

II. Conversion coefficients

Conversion coefficients

- Conversion coefficients
  - NRPB
  - PCXMC
  - Simulations with Monte Carlo

Conversion coefficients NRPB

- NRPB
  - NRPB-R279: “Coefficients for estimating effective dose from pediatric X-ray examinations”
    - $D_{organ} = CC_{ESD} * ESD$
    - $D_{organ} = CC_{DAP} * DAP$
  - Fixed radiographic views – 26 organs
  - Phantom: 0, 1, 5, 10 and 15 years old

Conversion coefficients NRPB

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  - NRPB-R279: “Coefficients for estimating effective dose from pediatric X-ray examinations”
    - $D_{organ} = CC_{ESD} * ESD$
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  - Fixed radiographic views – 26 organs
  - Phantom: 0, 1, 5, 10 and 15 years old

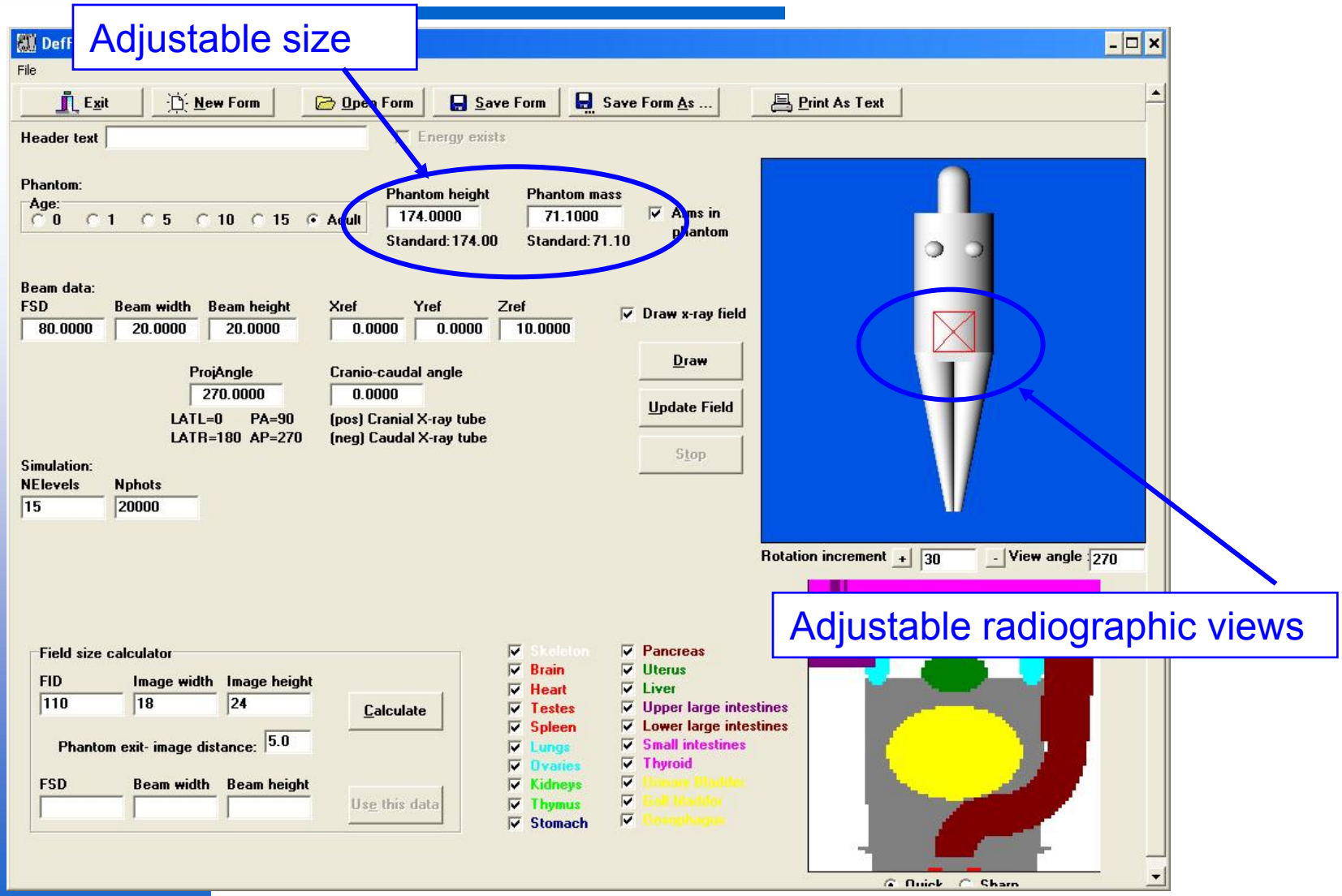
- Discrete ages?

- Appropriate to represent premature babies?

Conversion coefficients

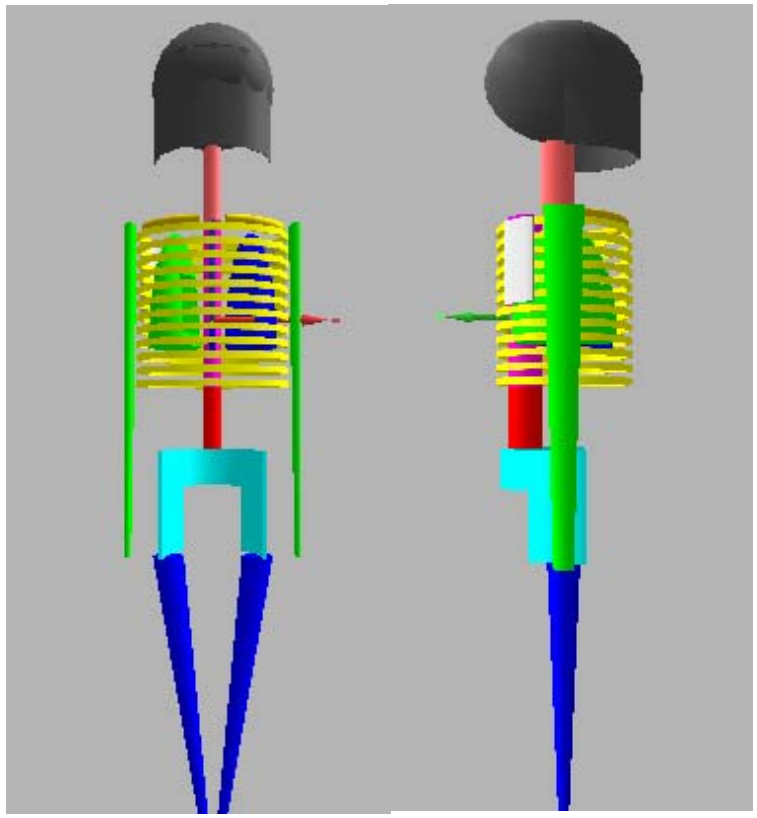
- Conversion coefficients
  - NRPB
  - PCXMC
  - Simulations with Monte Carlo

Conversion coefficients PCXMC



Conversion coefficients PCXMC

- Mathematical Phantom
  - Modify phantom based on patient weight (m) and height (h)
  - Linear scaling

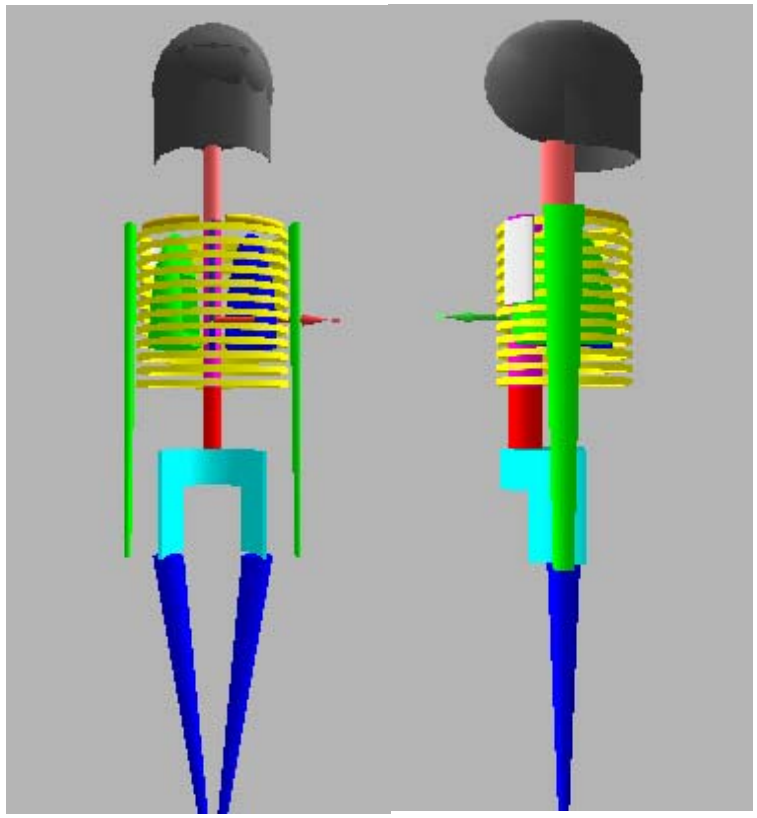


PCXMC: http://www.stuk.fi/sateilyn_kayttajille/ohjelmat/PCXMC/en_GB/pcxmc/

Conversion coefficients PCXMC

- Mathematical Phantom
  - Modify phantom based on patient weight (m) and height (h)
  - Linear scaling

Not validated



Conversion coefficients PCXMC

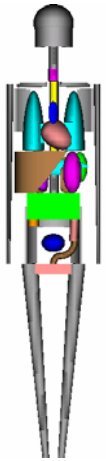
- Input Dose
  - Entrance Skin Dose (ESD), Dose Area Product (DAP), Current Time Product (mAs)
  - Spectra (kVp + filtration)
- Output Dose Calculation
  - Dose to tissues/organs

Conversion coefficients

- Conversion coefficients
  - NRPB
  - PCXMC
  - Simulations with Monte Carlo

Conversion coefficients MCNP

- Mathematical models (Adam, Eva)
  - Planes, spheres and cylinders are used to represent the model
  - Model resembles human anatomy only vaguely



- Voxel models
  - High resolution cross-sectional digital images of internal anatomy are used to create a 3D representation of the shape, volume and composition of the human organs.
  - Realistic representation of anatomical structures

Voxel models

- Currently published models
  - www.virtualphantoms.org

Model	Number
Adults	30
Children	6
Babies	7

Voxel models

- Currently published pediatric models
  - Voxel models > 1y

Model	Gender	Age	Modality	Author
ADELAIDE	F	14 years	CT	Caon et al
CHILD	F	7 years	CT	Zankl et al
UF 4-y	F	4 years	CT	Lee et al
UF 8-y	F	8 years	CT	Lee et al
UF 11-y	F	11 years	CT	Lee et al
UF 14-y	F	14 year	CT	Lee et al

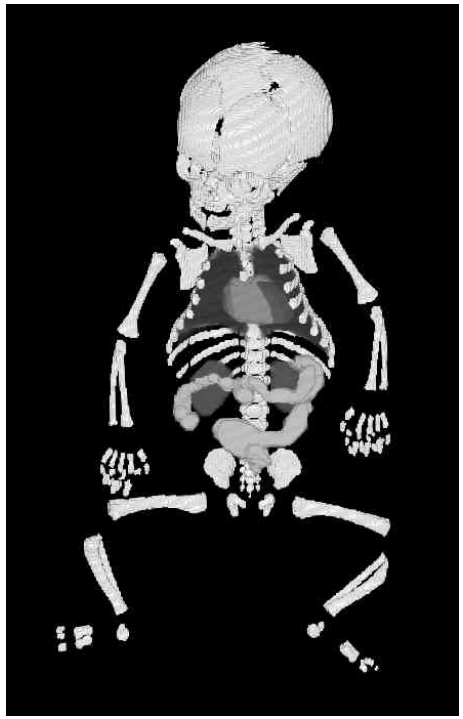
Voxel models

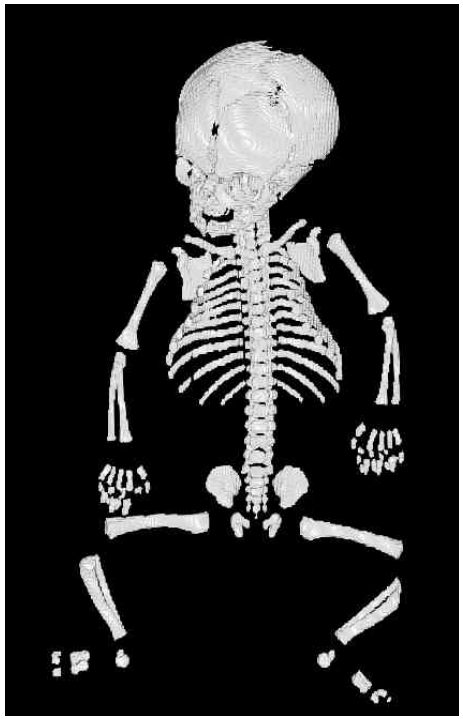
- Currently published pediatric models
  - Voxel models < 1y

Model	Gender	Weight [kg]	Age	Voxel volume [mm³]	Modality	Author
BABY	F	4,2	2 months	2,9	CT	Zankl et al
UF-newborn (original)	F	3,8	6 days	0,35	CT	Nipper et al
UF 2 month	M	5,4	2 months	0,30	CT	Nipper et al
UF 9 month	M	6,9	9 months	0,56	CT	Lee et al
UFH-NURBS	M/F	3,5	6 days	surfaces	CT	Lee et al
Phantom 1	M	1,9	0 days	0,922	CT/MRI	Smans et al
Phantom 2	M	0,6	0 days	0,548	CT/MRI	Smans et al

Voxel models

- Voxel model[1]: 32 weeks, 1910 g, male

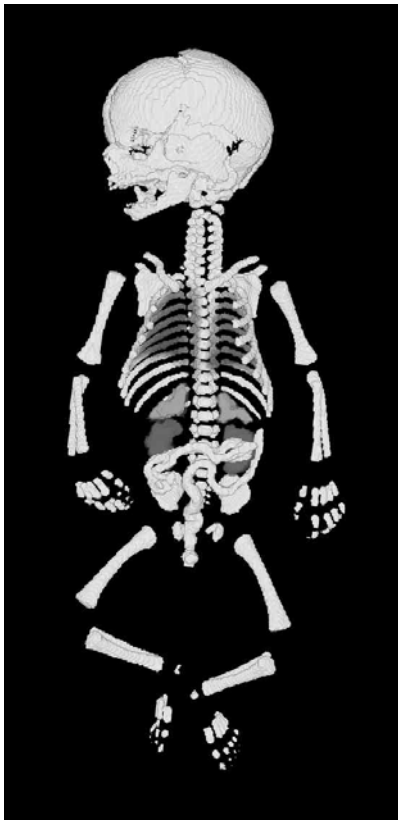


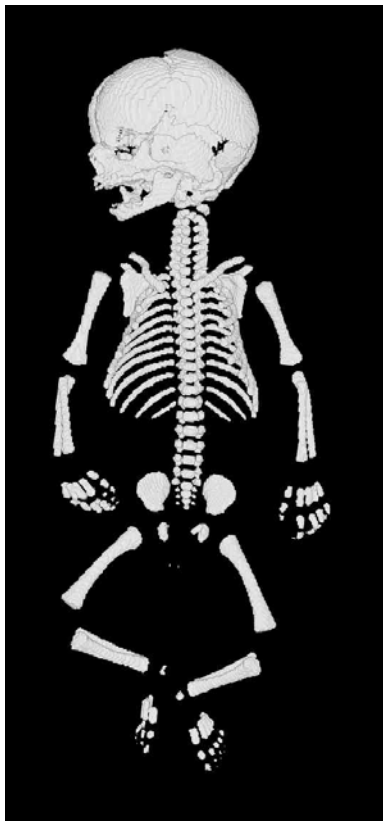


(1) K. Smans et al., “Calculation of organ doses in X-ray examinations of premature babies,” Med. Phys. (February 2008)

Voxel models

- Voxel model[1]: 22 weeks, 590 g, male





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Dose and risk Overview

- Protocols
- ESD
- DAP

- Organ dose

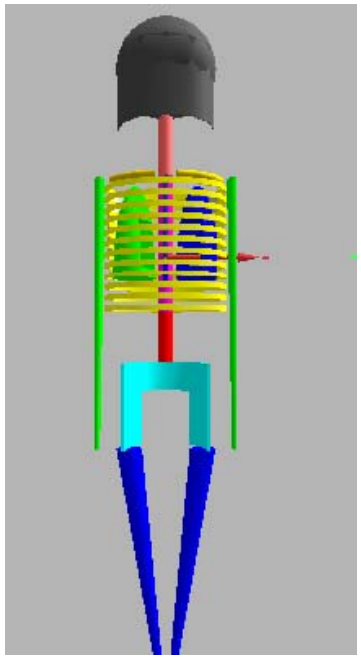
- Conversion factors
  - NRPB
  - PCXMC
  - Simulations with Monte Carlo software

Step 3: Calculations

III. Organ doses

Organ doses

- Different “models” give different organ doses
- Example Baby 590 g
  - Voxel phantom (MCNP)
  - Scaled mathematical phantom (PCXMC)



Organ dose Baby 590 g

Dose (µGy)	PCXMC (scaled)	MCNP (voxel)
Lung	20.2	23.8
Heart	22.8	22.3
Thymus	26.6	23.3
Liver	4.8	7.0
Bone	12.3	12.5
RBM	2.2	3.3

EAK: 25 µGy

Organ dose Baby 590 g

Dose (µGy)	PCXMC (scaled)	MCNP (voxel)
Lung	20.2	23.8
Heart	22.8	22.3
Thymus	26.6	23.3
Liver	4.8	7.0
Bone	12.3	12.5
RBM	2.2	3.3

EAK: 25 µGy

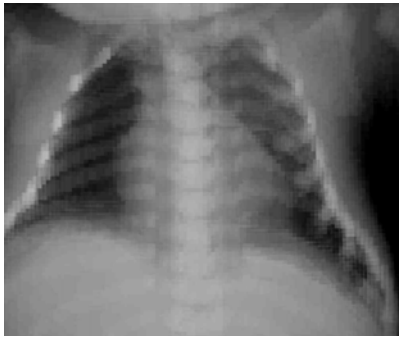
Within the field

Organ dose Baby 590 g

Partially within the field

Dose (µGy)	PCXMC (scaled)	MCNP (voxel)
Lung	20.2	23.8
Heart	22.8	22.3
Thymus	26.6	23.3
Liver	4.8	7.0
Bone	12.3	12.5
RBM	2.2	3.3

EAK: 25 µGy



Same field size (7x5 cm)

Organ dose Baby 590 g

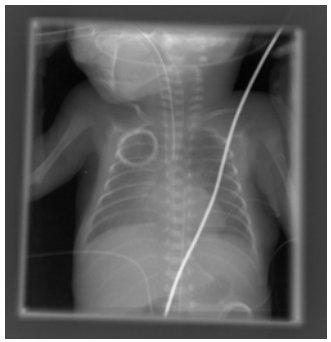
Dose (µGy)	PCXMC (scaled)	MCNP (voxel)
Lung	20.2	23.8
Heart	22.8	22.3
Thymus	26.6	23.3
Liver	4.8	7.0
Bone	12.3	12.5
RBM	2.2	3.3

EAK: 25 µGy

Widely distributed tissues

Conclusion

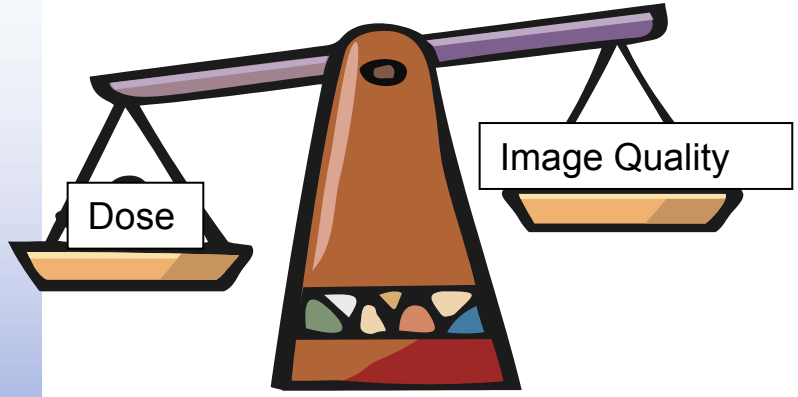
- It is important to investigate radiation exposures in the neonatal unit
  - Training to radiographers
  - There is room for optimization



- One has to be careful for:
  - Organ doses for organs partially in the radiation field
  - Dose to the bone/red bone marrow

Conclusion

- Image Quality



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Patient doses in paediatric radiology

Thank you for your attention!