

# Assessment of doses to embryo and fetus - external dosimetry

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The EURADOS logo consists of the word "EURADOS" in a blue, sans-serif font, followed by a blue arrow pointing to the right. The logo is set against a white rectangular background.

EURADOS

EURADOS Working Group 12  
Dosimetry in Medical Imaging  
SG2/Task 4: «Dosimetry in pregnancy»

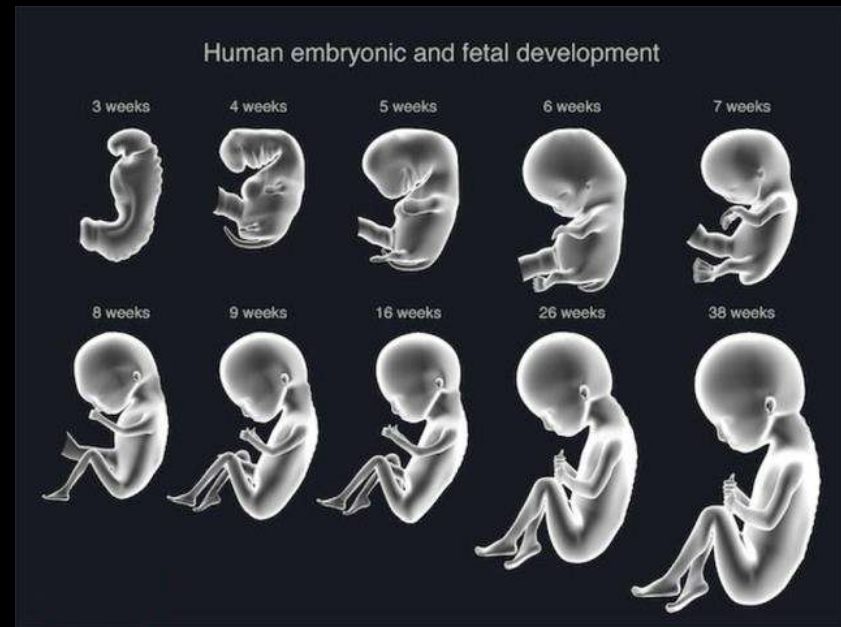
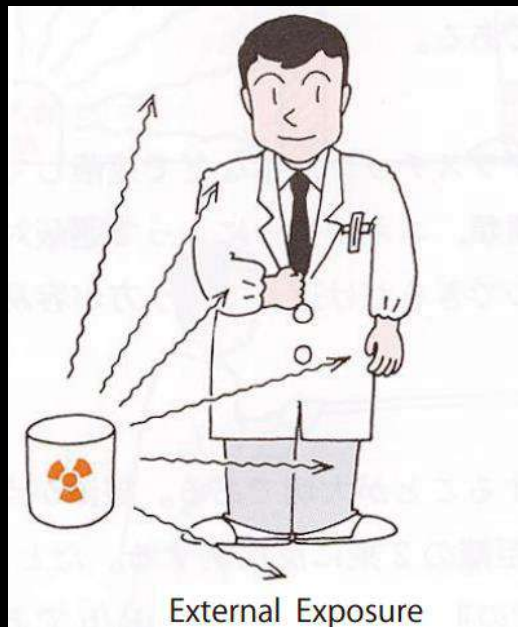
# Effects of ionising radiation

## Deterministic effects

- lethal effect (miscarriage)
- mental retardation
- malformation

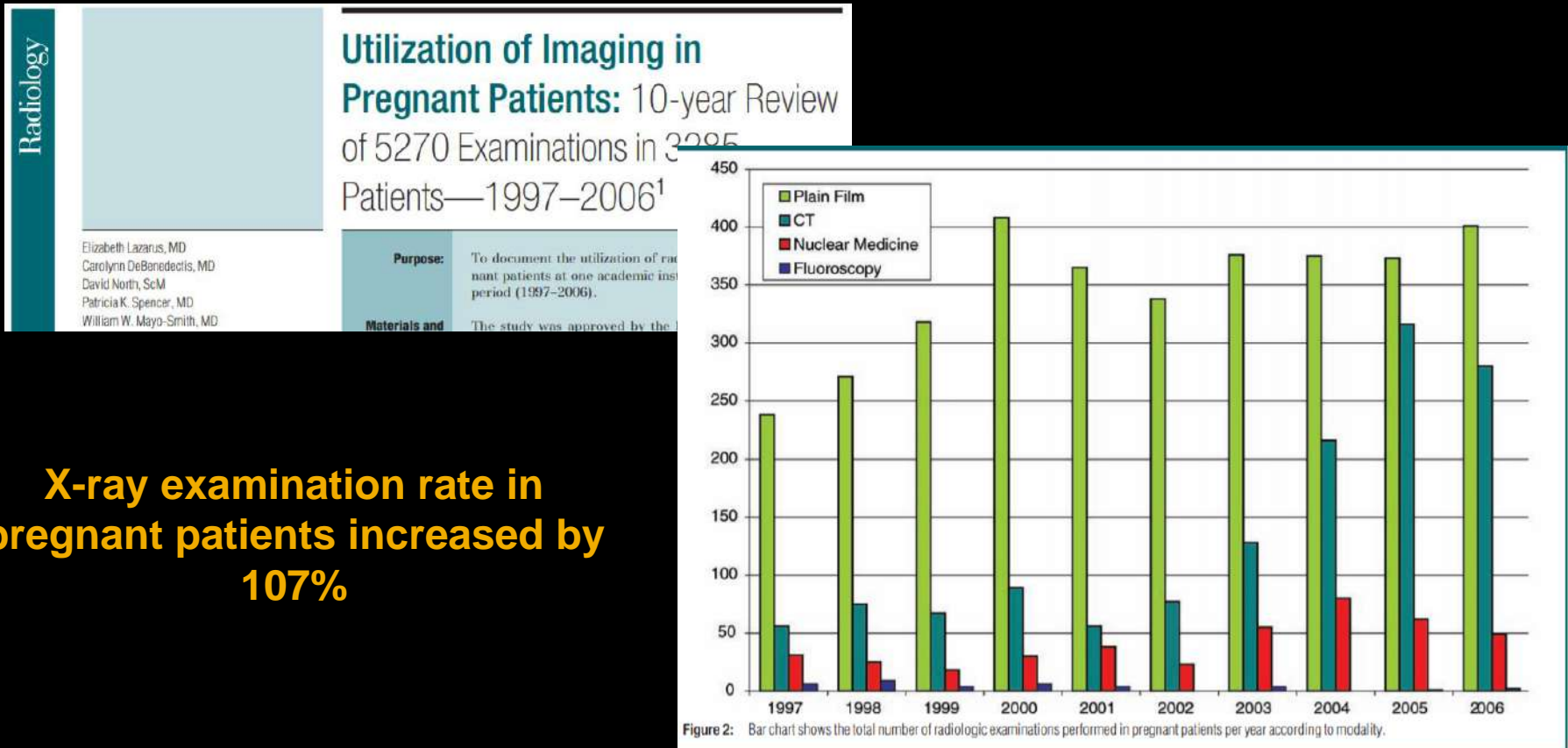
## Stochastic effects

- cancer
- leukemia
- hereditary effects



# Status quo

- The safety of diagnostic imaging during pregnancy is a significant concern for all clinicians
- Number of radiological examinations performed in pregnant patients is constantly growing



# Justification principle

- Alternative non-ionising imaging modalities, such as ultrasound (US) and magnetic resonance imaging (MRI) can be suggested
- In some cases the radiological examinations are justified
  - Kidney stone (not visualized on US)
  - Trauma
- In some cases the pregnancy status is only discovered after x-ray examination



Transverse image of the female patients with 30 and 8 weeks of pregnancy underwent CT in emergency department of USZ

# Conceptus dose assessment

1. Normalized standard dose values
2. Measurements
3. MC Simulations

# Standard dose metrics

- Radiography
  - Entrance skin dose (ESD)
  - Air Kerma
- Fluoroscopy
  - Dose Area Product (DAP)
  - ESD
- CT
  - CTDI

# Conceptus dose assessment

- ESD is the measure of the radiation dose that is absorbed (mGy) by the skin as it reaches the patient
- ESD dose is a directly measurable quantity, often, measured using TLDs

$$ESD = Output \times \left(\frac{kV}{80}\right)^2 \times \left(\frac{100}{FSD}\right)^2 \times mAs \times BSF$$

- Where Output – output mGy/mAs of the tube at 80 kV at the distance of 100 cm normalized by 10 mAs and BSF is a backscatter factor

Fetal dose can be conservatively estimated as 0.15 times the entrance skin dose



# Conceptus dose assessment

- The normalized doses can be converted to a study-specific values by applying several correction factors
  - Parameters of the examination in the study (kV, gestation age of the patient)
  - Type of the examination

> Med Phys. 2003 Oct;30(10):2594-601. doi: 10.1118/1.1605511.

## Conceptus radiation dose assessment from fluoroscopically assisted surgical treatment of hip fractures

J Damilakis<sup>1</sup>, N Theocharopoulos, K Perisinakis, G Papadokostakis, A Hadjipavlou, N Gourtsoyiannis

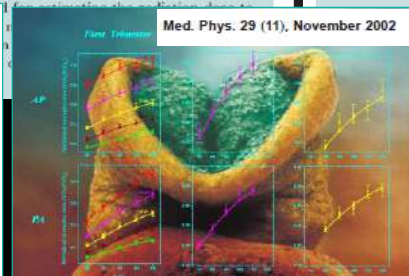
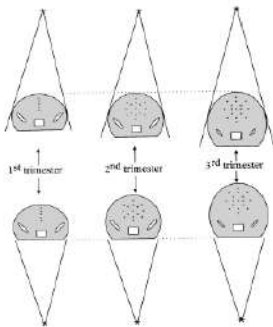
Affiliations + expand

PMID: 14596295 DOI: 10.1118/1.1605511

## Radiation Dose to the Cor from Multidetector CT du

Early Gestation: A Method that  
Allows for Variations in Maternal Body

Normalized conceptus doses for abdominal radiographic examinations calculated using a Monte Carlo technique



$$D_c = D_n(K_{air}) \left( \frac{(SED' - T')(SED - T + d)}{(SED - T)(SED' - T' + d)} \right)^2$$

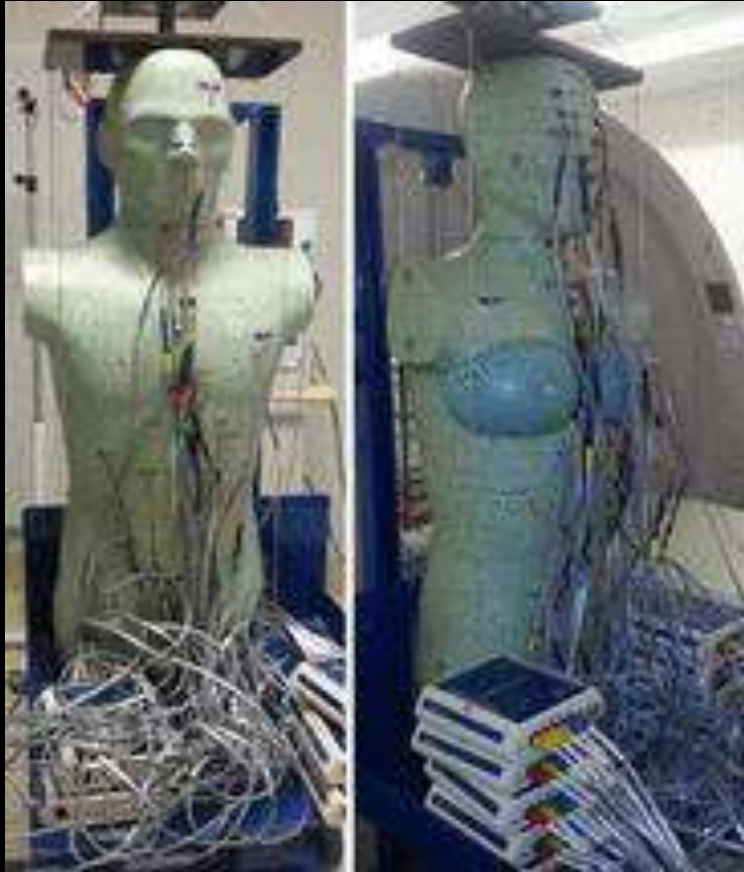
## Radiation Dose to the Fetus for Pregnant Patients Undergoing Multidetector CT Imaging: Monte Carlo Simulations Estimating Fetal Dose for a Range of Gestational Age and Patient Size<sup>1</sup>

Purpose: To use Monte Carlo simulations of a current technology

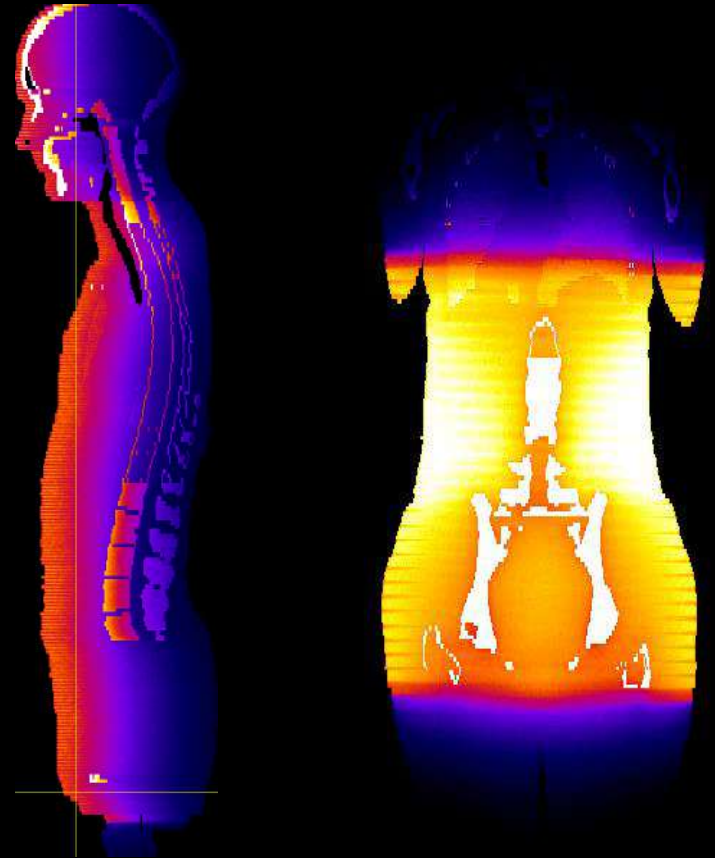


# Conceptus dose assessment

## Measurements



## MC Simulations



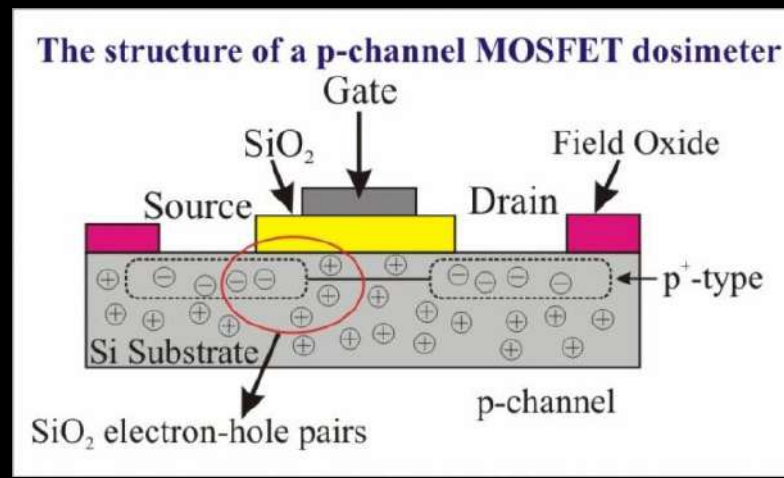
# Measurements

- Thermoluminescent dosimeters (TLD)
  - ✓ most commonly used in medical dosimetry
  - ✓ various shapes and sizes
    - Hardware is needed ( oven, analyzer)
    - Time-consuming



# Measurements

- Metal-oxide-semiconductor field-effect transistor (MOSFET) dosimeters
  - ✓ small size
  - ✓ provide direct and simultaneous dose readout
  - upper dose limit ~200 Gy
  - Artifact if used in patients



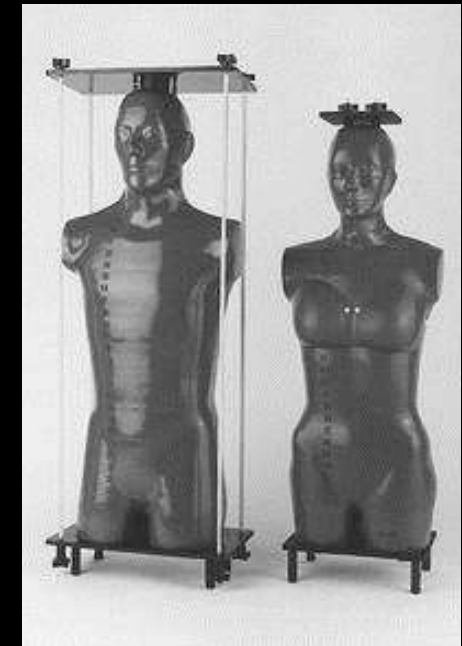
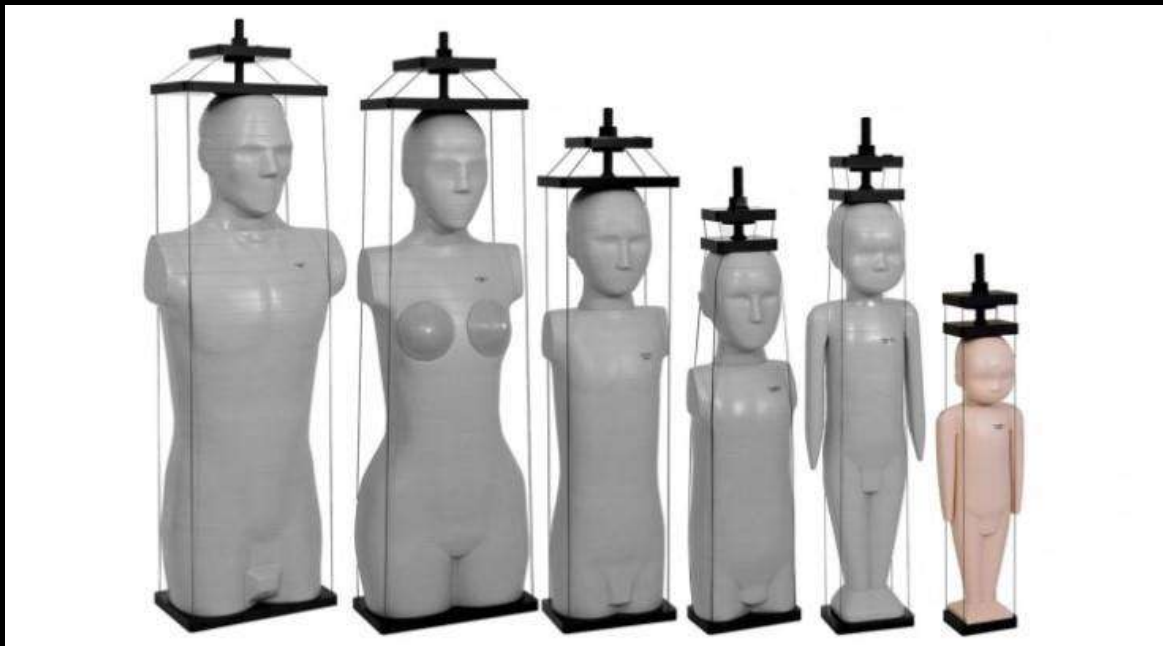
# Measurements

- Patient-> Dose on the surface
- Anthropomorphic Phantoms



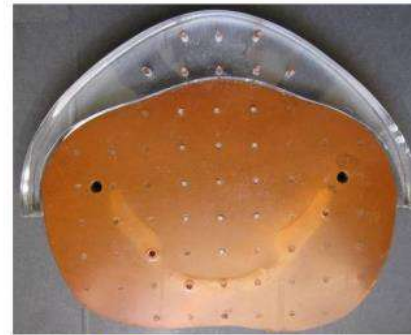
# Anthropomorphic phantoms

- Simulate human body at various body sizes and ages
- Tissues formulated with polymers equivalent to soft tissue, bones, lungs etc
- Manufactured in ~2 cm thick sections with holes
- TLDs can be positioned in each slice



# Anthropomorphic phantoms

- For 1<sup>st</sup> trimester unmodified adult phantom can be used
- For 2<sup>nd</sup> and 3<sup>rd</sup> trimester phantom should be modified to account for pregnant anatomy



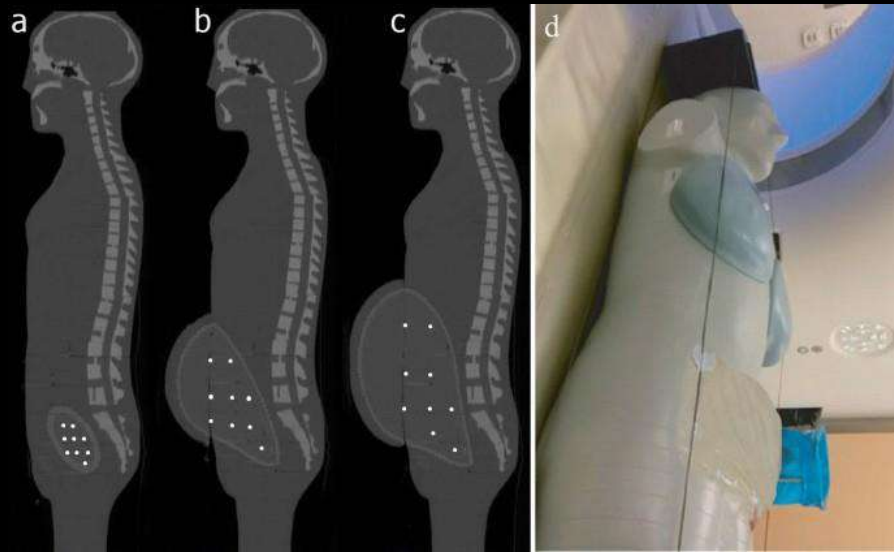
2<sup>nd</sup> Trimester, slice 29



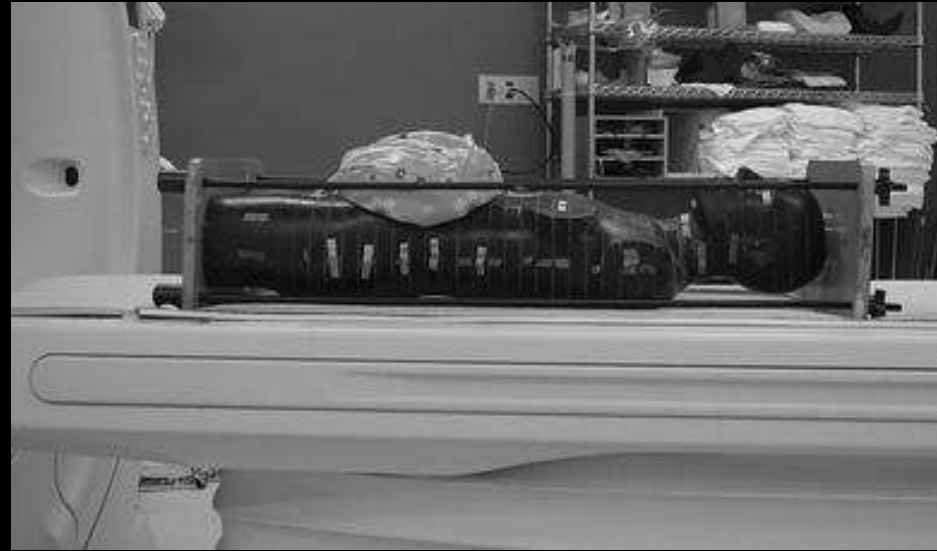
3<sup>rd</sup> Trimester, slice 29

J. Damilakis, University of Crete

# Anthropomorphic phantoms



Images of gelatin boluses representing pregnancy at (b) 6 and (c) 9 months. White dots in images represent TLDs distributed in uterus. Saeed et al., 2021

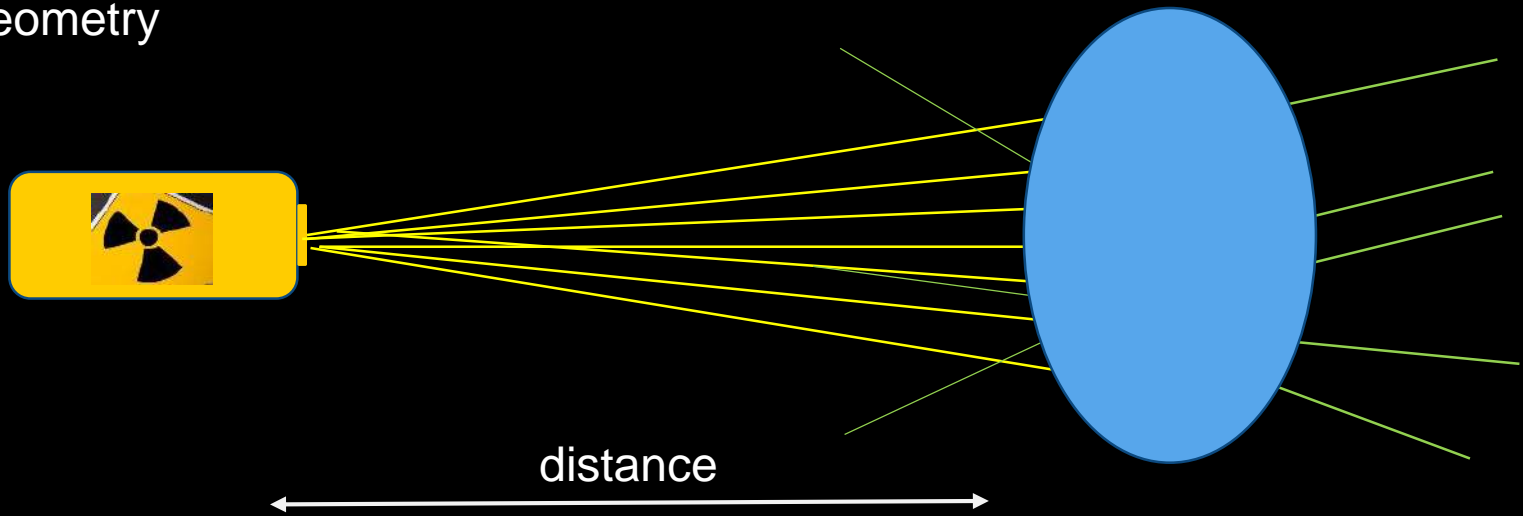


Alderson RANDO phantom and a beach ball containing water. Matsunaga et al., 2017

**! Measurements do not provide the dose to the exact patient / conceptus  
Patients geometry is different from a standard anthropomorphic phantom**

# MC Simulations

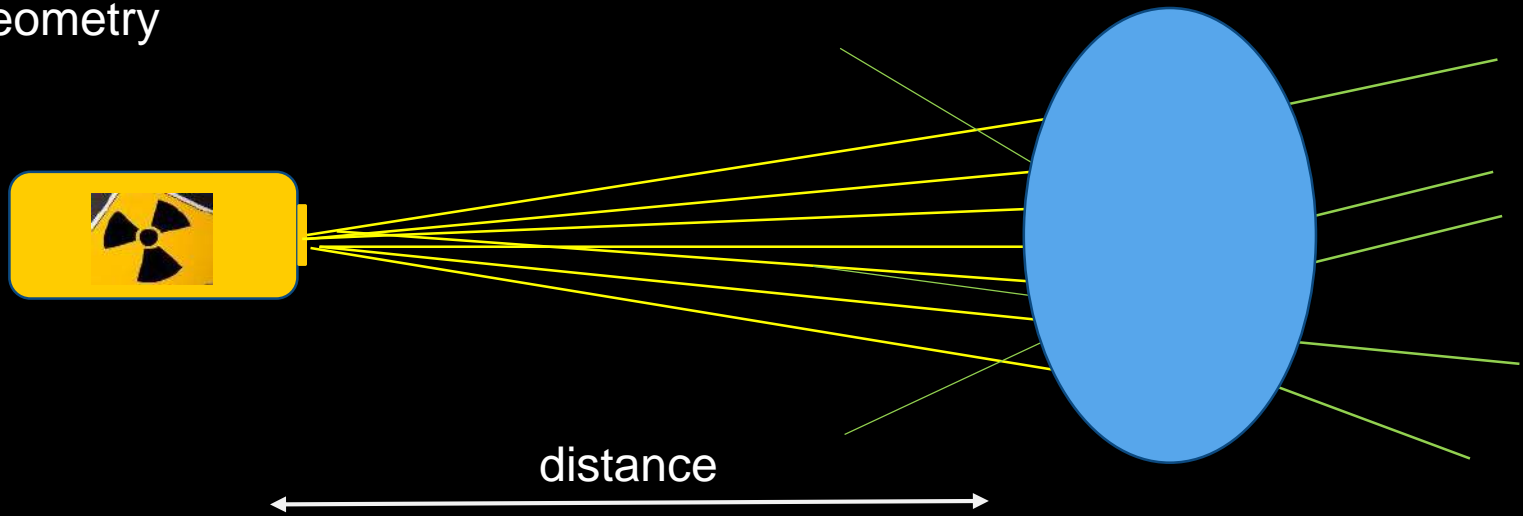
- Computational method
- Considered to be the «new gold standard»
- 3 main components
  - ✓ Object/subject
  - ✓ X-ray source
  - ✓ Geometry





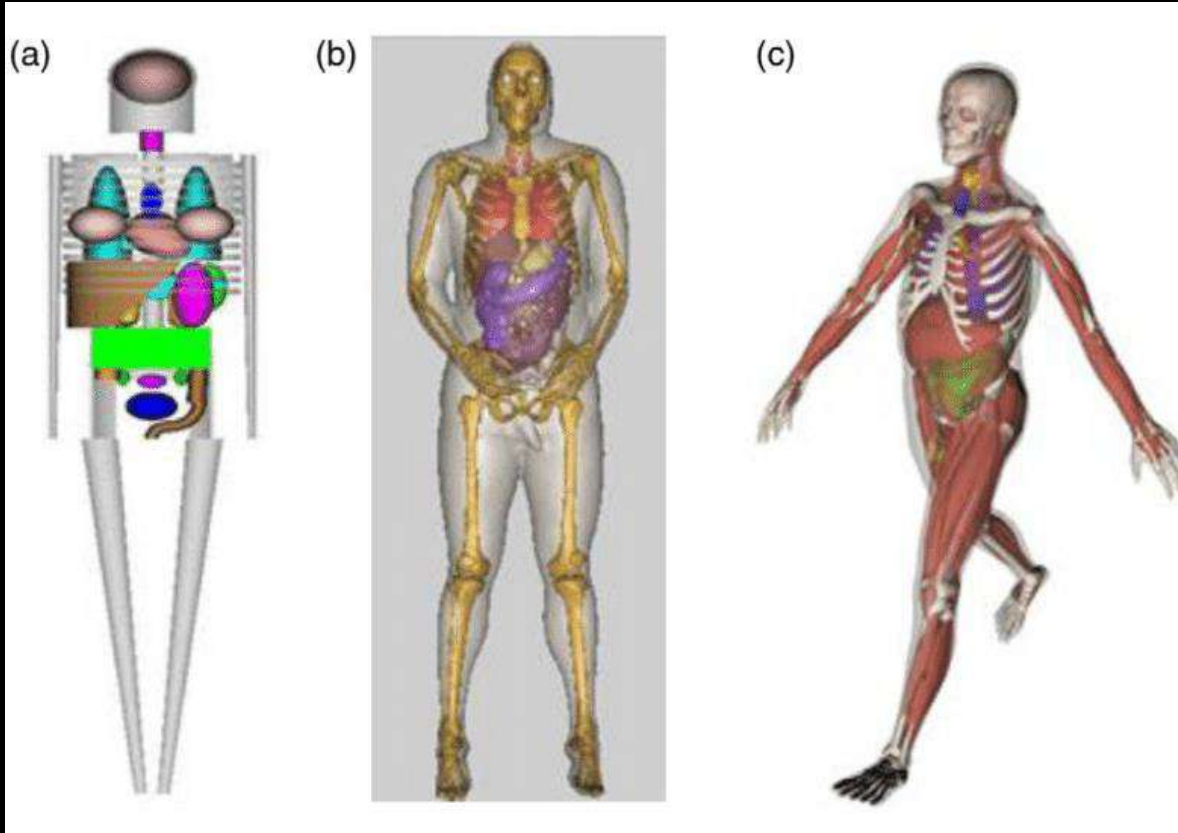
# MC Simulations

- Computational method
- Considered to be the «new gold standard»
- 3 main components
  - ✓ Object/subject
  - ✓ X-ray source
  - ✓ Geometry



# MC Simulations

- As an object one can either use phantom or patients images



by Jorge Borbinha

# Computational phantoms

IOP Publishing | Institute of Physics and Engineering in Medicine

Physics in Medicine & Biology

Phys. Med. Biol. 59 (2014) R233–R302

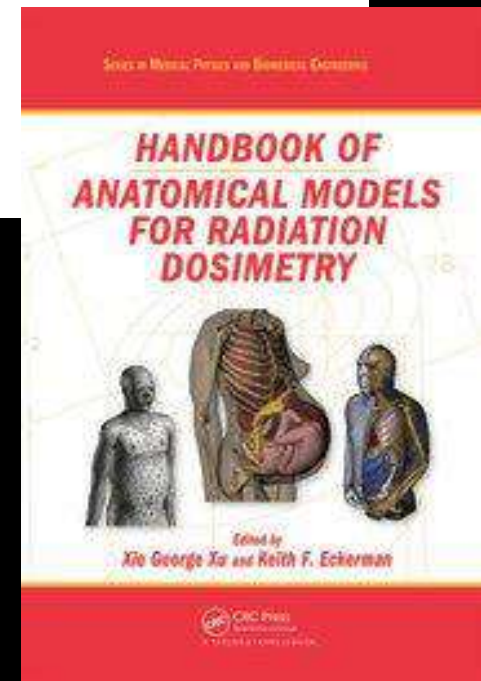
doi:10.1088/0031-9155/59/18/R233

## Topical Reviews

### An exponential growth of computational phantom research in radiation protection, imaging, and radiotherapy: a review of the fifty-year history

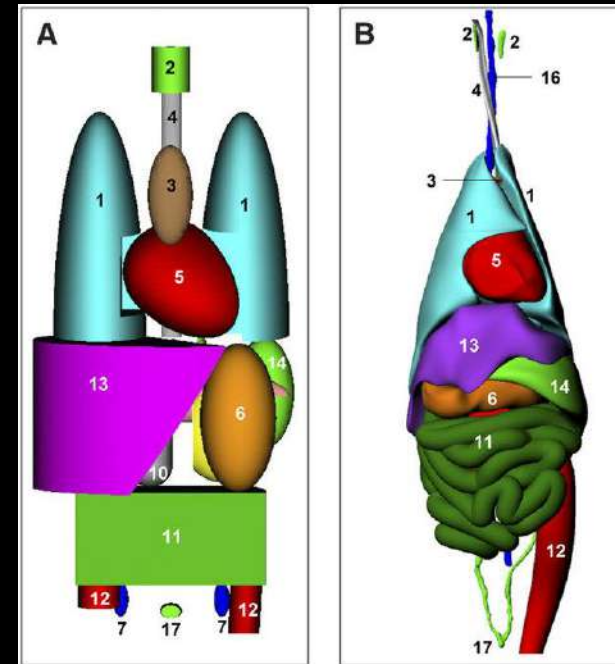
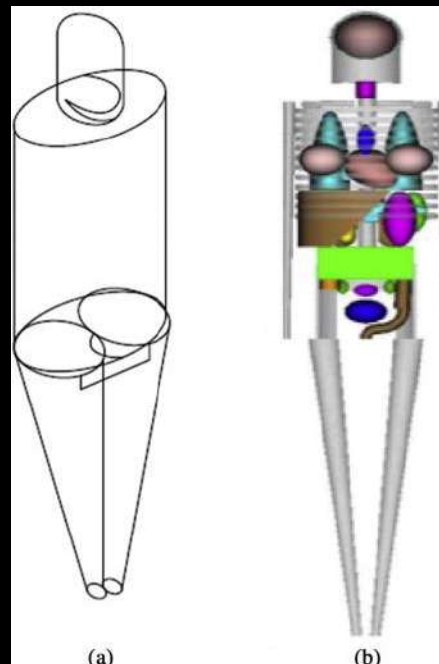
X George Xu

Rensselaer Polytechnic Institute Troy, New York, USA



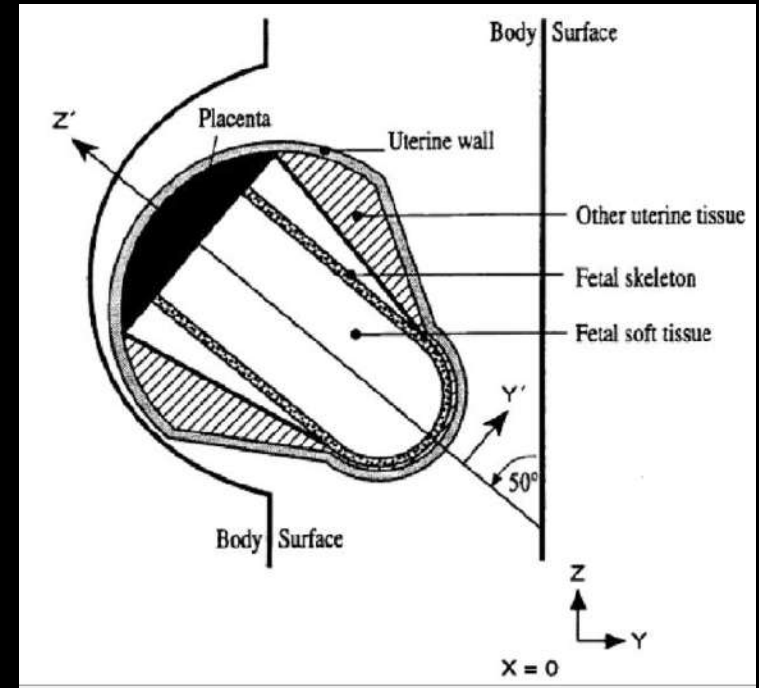
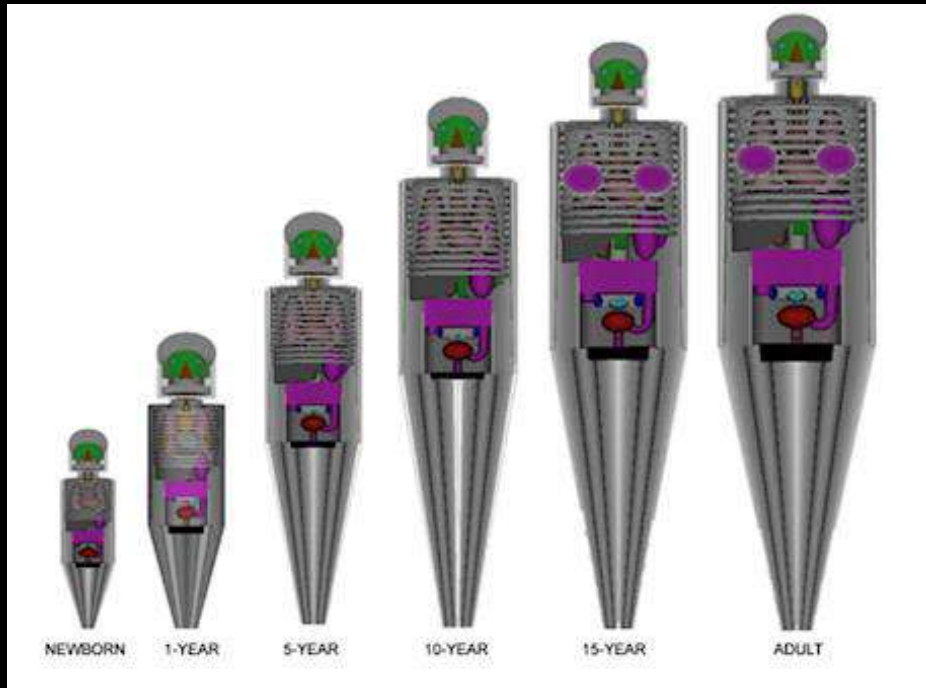
# Computational phantoms

- Stylized Phantoms
- Organs are simulated using surfaces described by equations, such as cylinders, spheres and cones
- 1960 first-generation of stylized anthropomorphic phantoms Oak Ridge National Laboratory (ORNL)



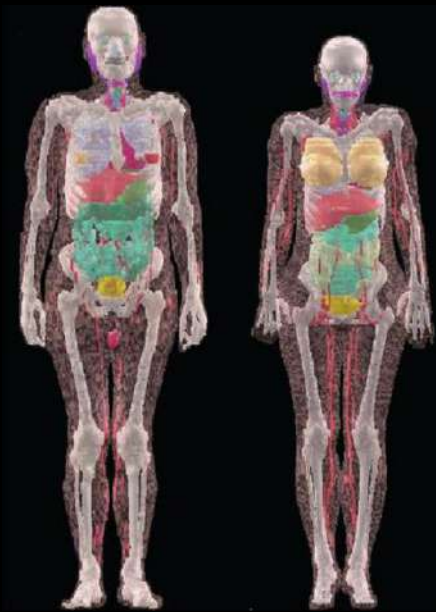
# Computational phantoms

- In 1995, Stabin and his colleagues at ORNL adapted adult female phantom to represent a woman at the 3, 6 and 9 month of pregnancy

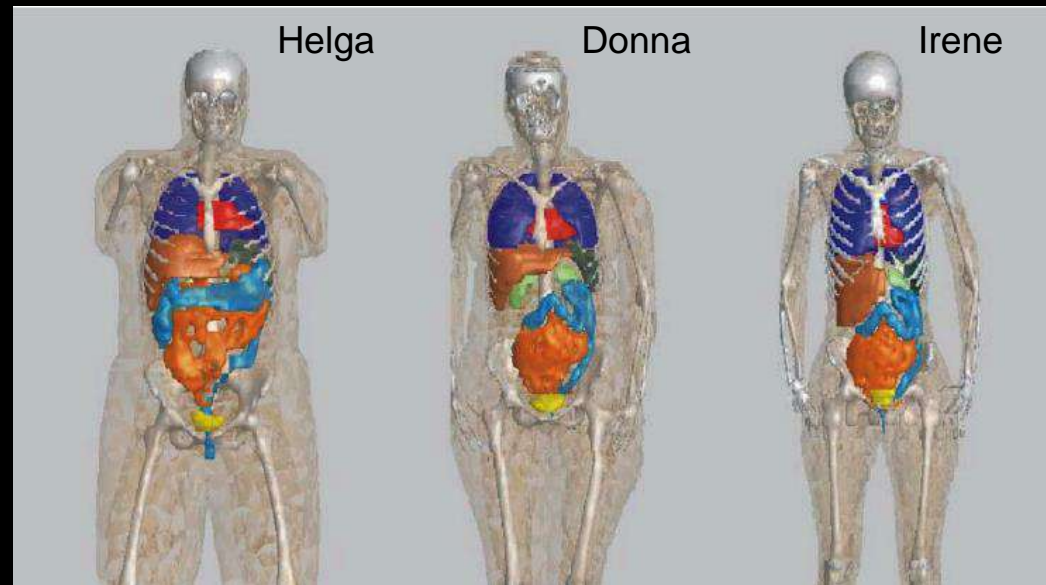


# Computational phantoms

- Voxel phantoms
- Based on data obtained from real CT and MRI scans with segmented organ components



ICRP reference Male and Female



Zankl et al. GSF, Germany

# Computational phantoms

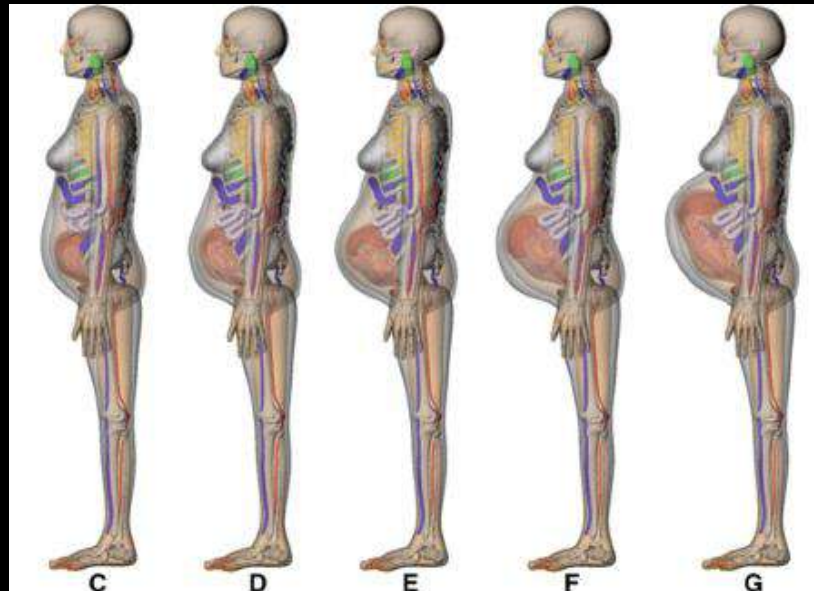
- Comparison of stylized adult phantom (left) and VIP-Man phantom (reproduced with permission from Taylor and Francis, Xu et al 2000) (right)



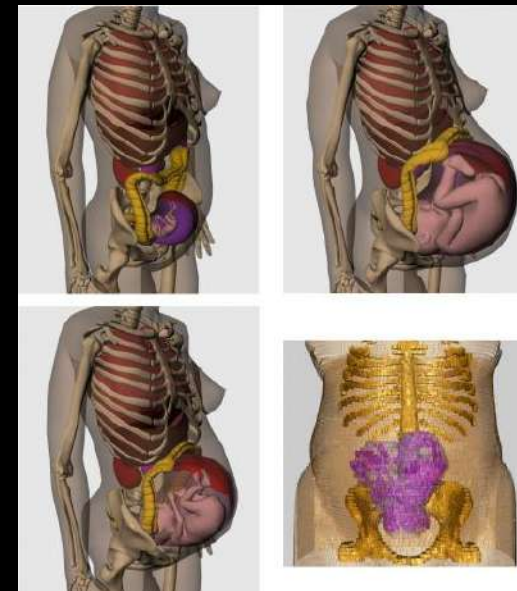
- Such anatomical differences can influence the accuracy of radiation dose estimates

# Computational phantoms

- Boundary representation phantoms (BREP)
- Designed by Non-Uniform Rational B-Spline (NURBS) method or mesh method
- Compared to the voxel phantoms, BREP phantoms are better suited for geometry deformation and adjustment



UF phantoms, SOLO



RPI phantoms



# Patient Images

- DICOM images can be used as an input
  - ✓ Shape and position of the fetus
  - ✓ Maternal habitus

A



Transverse image of the female patients with 8 weeks of pregnancy

B

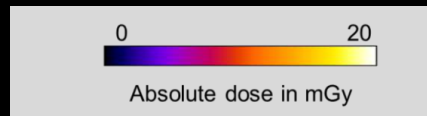
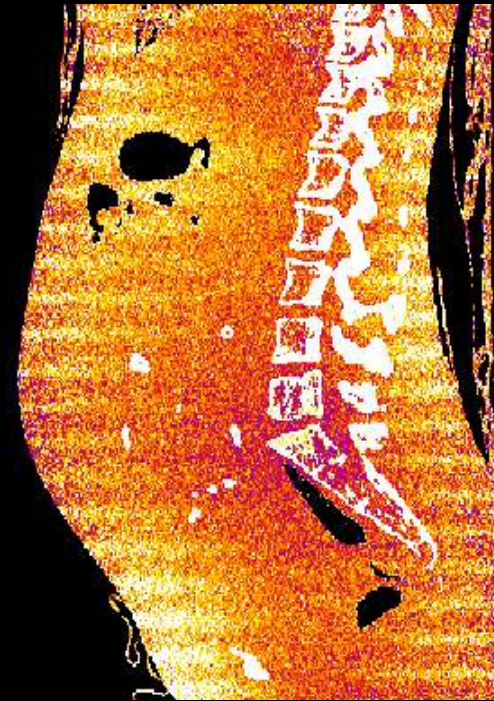
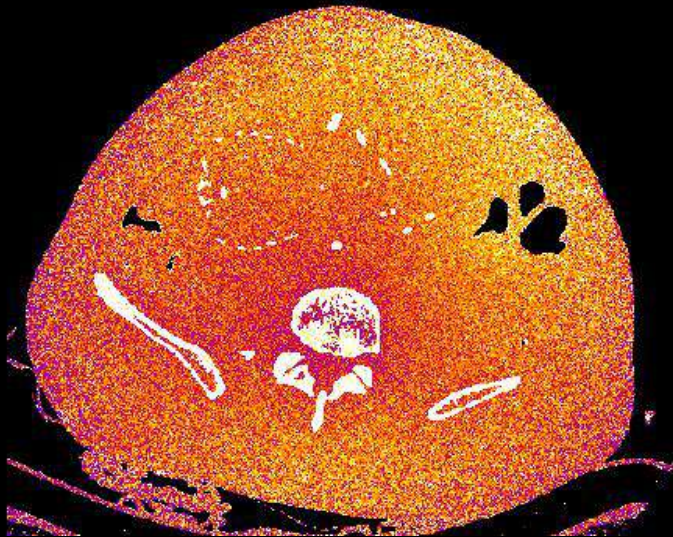


Transverse image of the female patients with 35 weeks of pregnancy



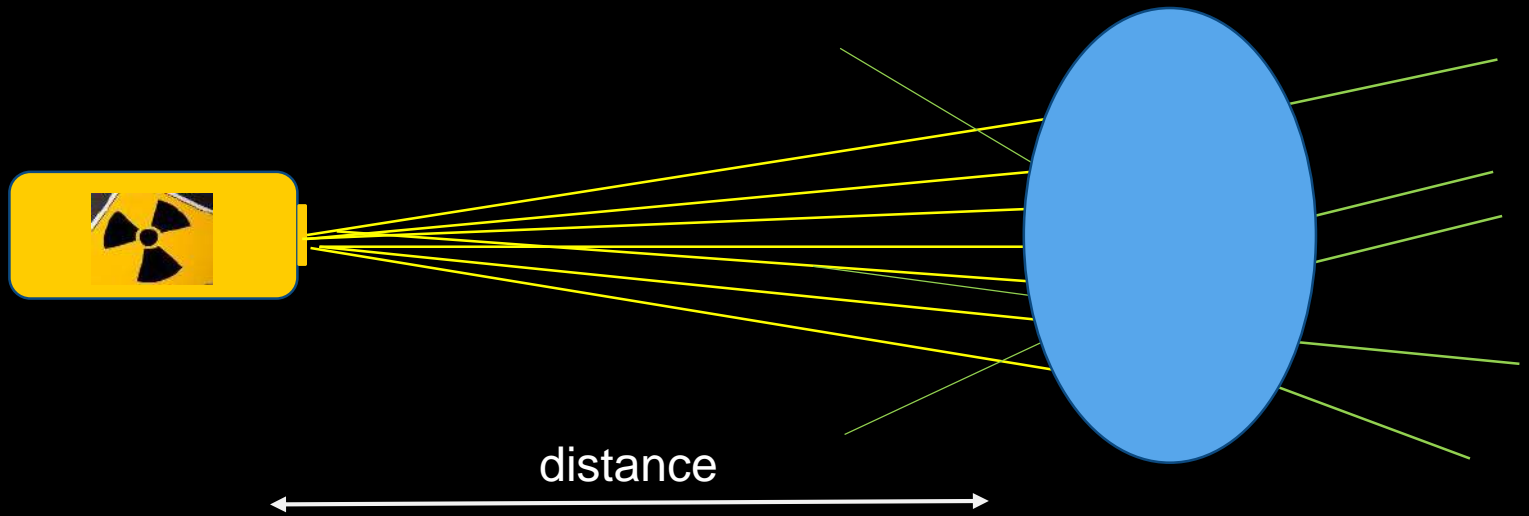
# Patient Images

- Organs are not delineated
- No information outside of the scan FOV ( can not be used for estimations in chest CT)
- Not an option for fluoroscopy



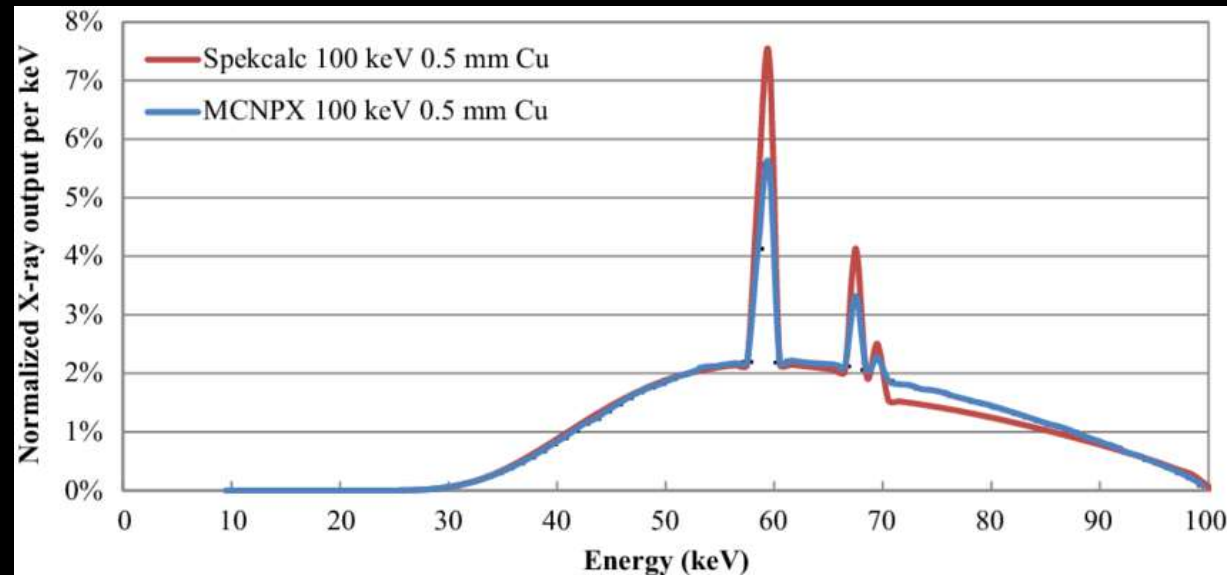
# MC Simulation

- 3 main components
  - ✓ Object/subject
  - ✓ X-ray source
  - ✓ Geometry



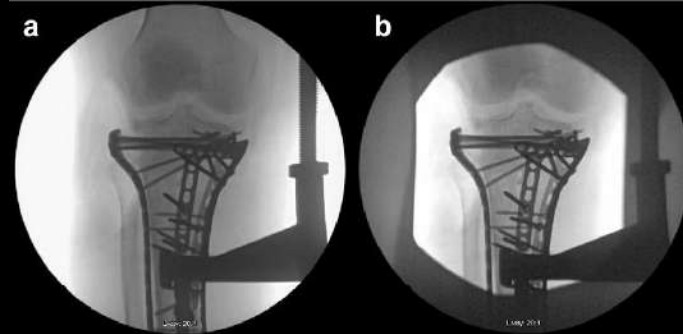
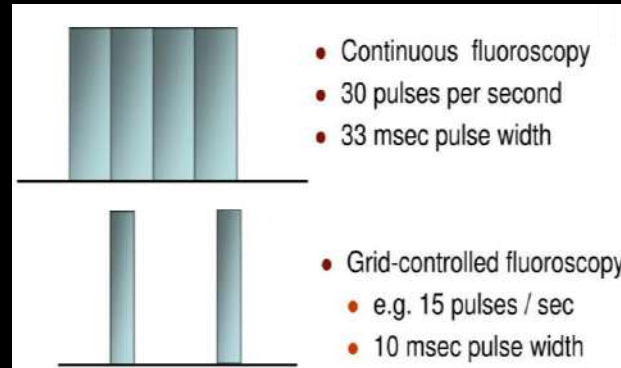
# X-ray source

- Energy spectra
- mA and automatic exposure algorithm
- Filtration

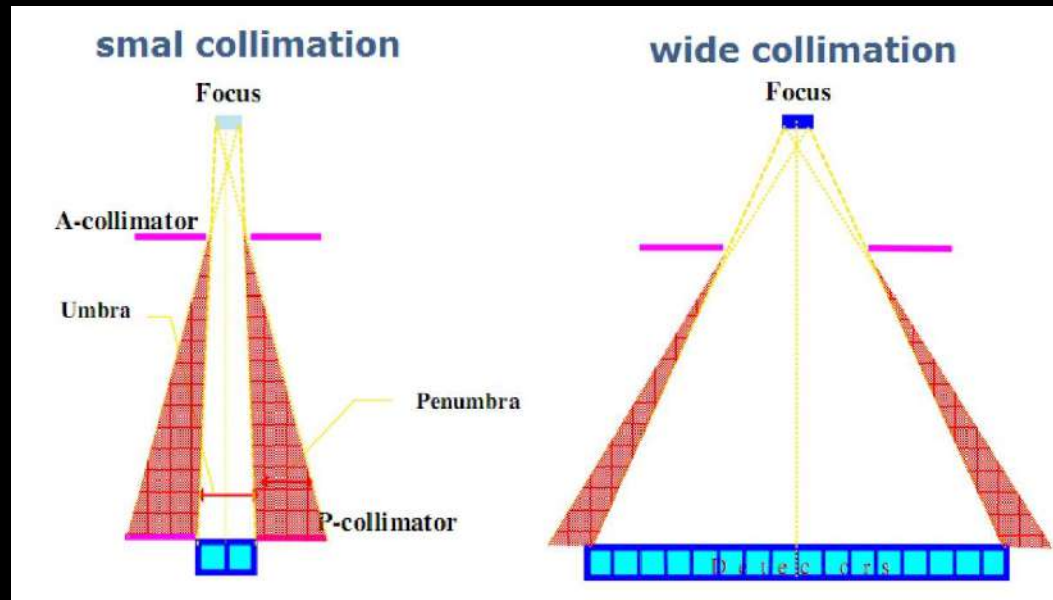


# X-ray source

- Fluoroscopy
  - Pulse rate
  - Collimation

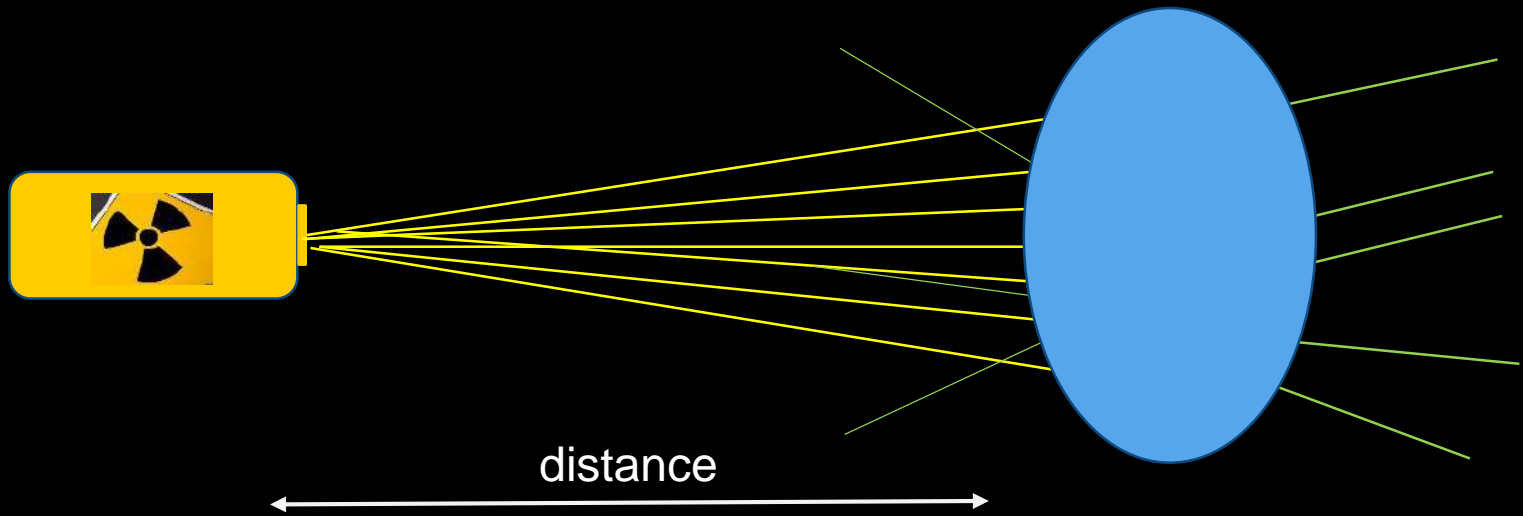


- CT
  - Focus
  - Total beam width



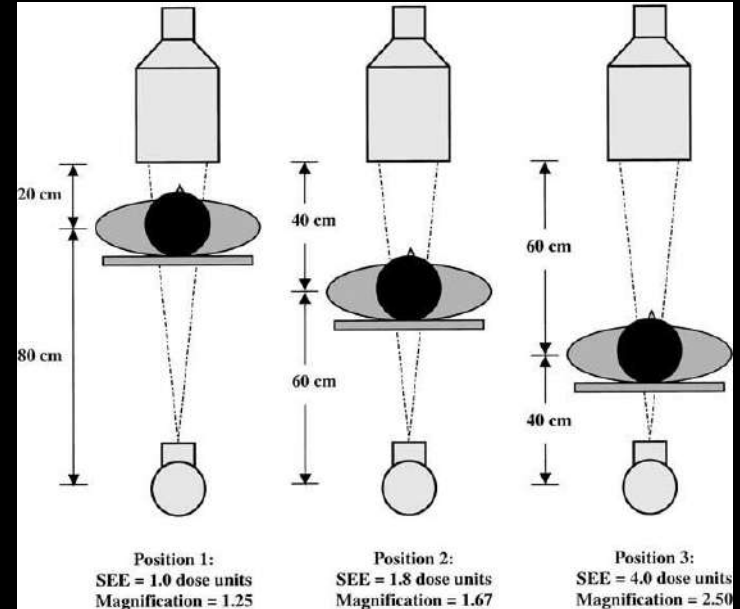
# Geometry

- 3 main components
  - ✓ Object/subject
  - ✓ X-ray source
  - ✓ Geometry

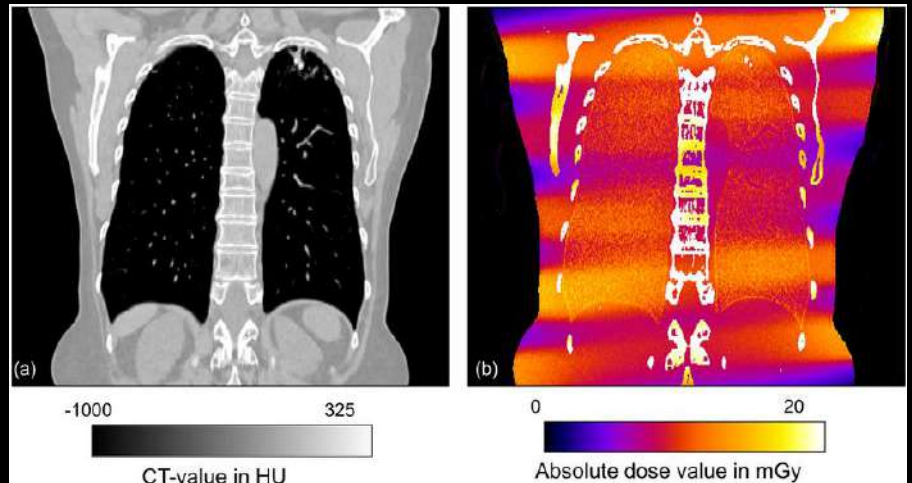


# Geometry

- Fluoroscopy
  - Distance
  - Projection angles

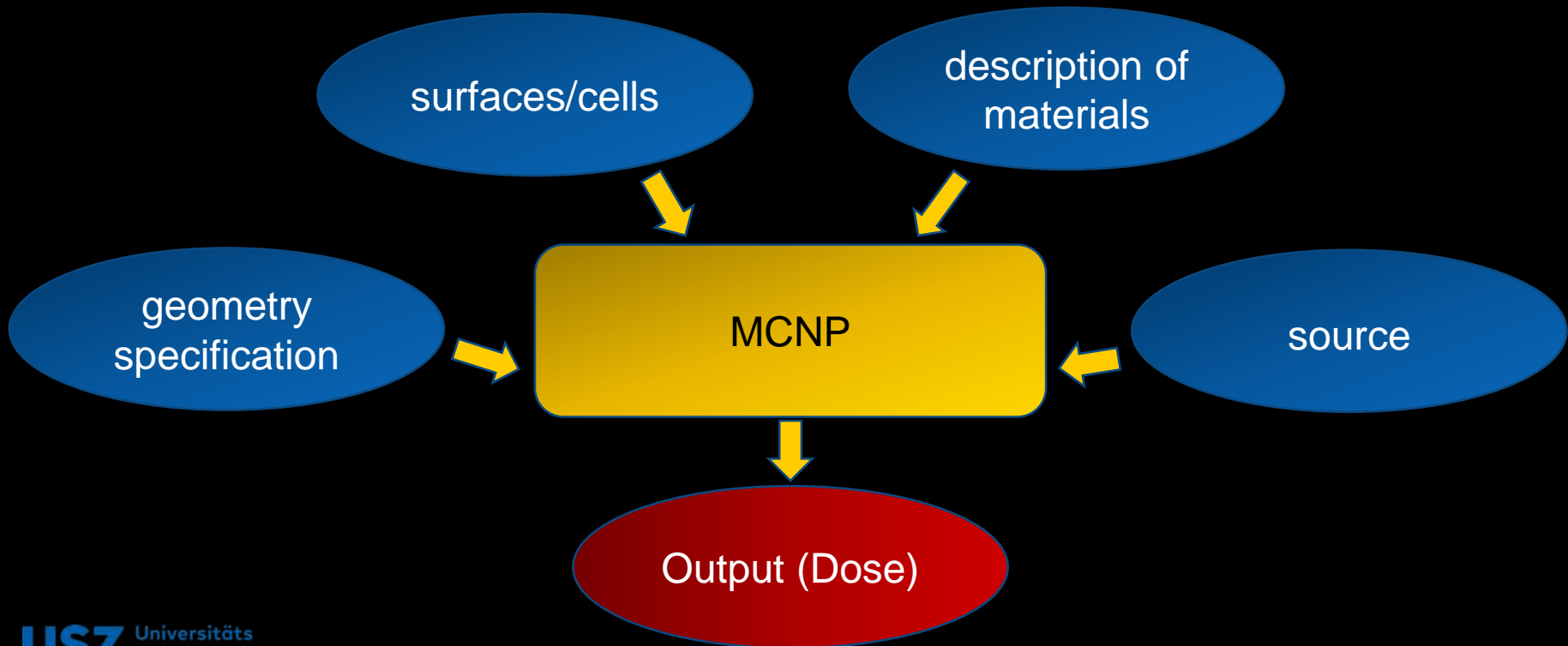


- CT
  - Scan length
  - Trajectory (spiral vs sequential)



# MC Simulation

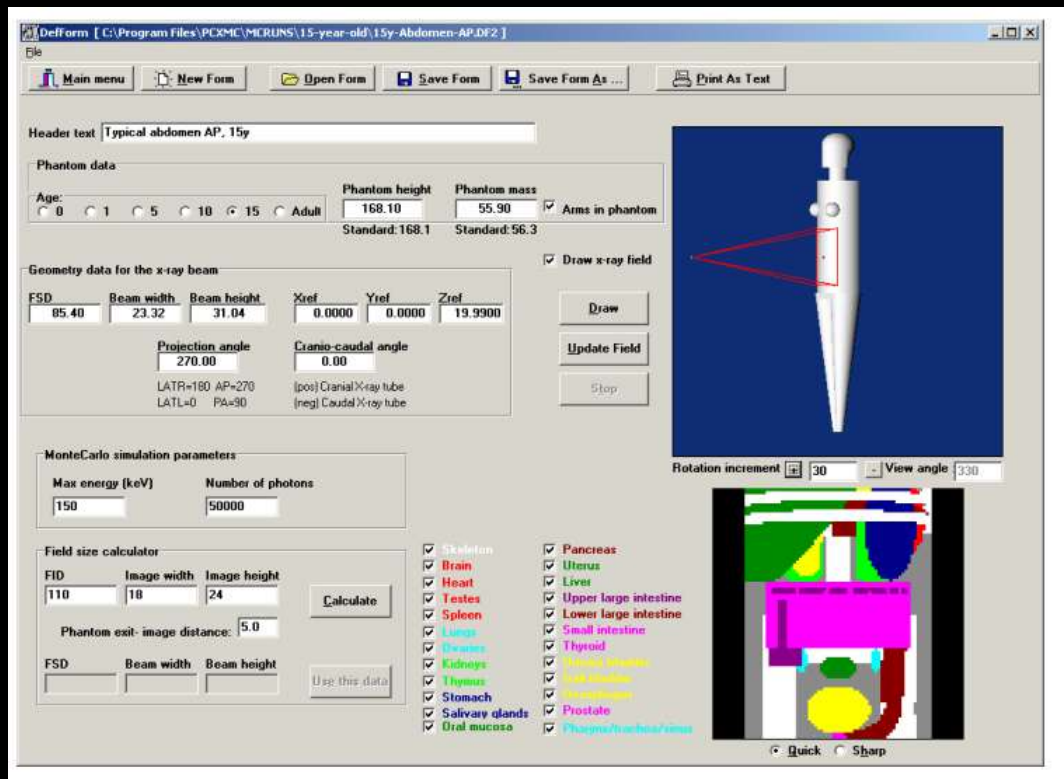
- Computational Environment
- Monte Carlo N-Particle (MCNP) Transport Code
  - General purpose Monte Carlo radiation transport code that tracks all particles up to GeV range (n, e,  $\gamma$ )
  - generalized-geometry (all modalities)





# MC Simulation

- PCXMC 2.0, STUK, Finland
  - Program for calculating patients' organ doses and effective doses in medical x-ray examinations (radiography and fluoroscopy)
  - adjustable-size paediatric and adult patient models



# MC-based calculators

- ImPACT CT, UK
- Allows calculation of organ and effective doses to patients undergoing CT scans
- The ImPACT CTDosimetry spreadsheet + Monte Carlo data sets (NRPB SR250)

**ImPACT CT Patient Dosimetry Calculator**  
Version 1.0.4 27/05/2011

**Scanner Model:**  
 Manufacturer: Siemens  
 Scanner: Siemens Balance, Emotion  
 kV: 130  
 Scan Region: Head  
 Data Set: MCSET14  
 Current Data: MCSET14

**Acquisition Parameters:**  
 Tube current: 30 mA  
 Rotation time: 1 s  
 Spiral pitch: 1  
 mAs / Rotation: 30 mAs  
 Effective mAs: 30 mAs  
 Collimation: 10 mm  
 Rel. CTDI: 1.00 at selected collimation  
 CTDI (air): 33.2 mGy/100mAs  
 CTDI (soft tissue): 35.5 mGy/100mAs  
 $nCTDI_w$ : 24.1 mGy/100mAs

**Scan range:**  
 Start Position: 32.5 cm  
 End Position: 62 cm

**Organ weighting scheme:** ICRP 103

Organ	$w_r$	$H_r$ (mGy)	$w_r \cdot H_r$
Gonads	0.08	0.038	0.003
Bone Marrow	0.12	1.6	0.19
Colon	0.12	0.24	0.029
Lung	0.12	5.4	0.64
Stomach	0.12	3.8	0.46
Bladder	0.04	0.021	0.00083
Breast	0.12	4.5	0.54
Liver	0.04	4.2	0.17
Oesophagus (Thymus)	0.04	6.1	0.24
Thyroid	0.04	0.28	0.011

Remainder Organs	$H_r$ (mGy)
Adrenals	5.2
Small Intestine	0.28
Kidney	3
Pancreas	4.5
Spleen	4.4
Thymus	6.1
Uterus / Prostate (Bladder)	0.04
Muscle	1.2
Gall Bladder	2.3
Heart	6

**Summary Results:**  
 $CTDI_w$ : 7.2 mGy  
 $CTDI_{vol}$ : 7.2 mGy  
 DLP: 213 mGy.cm

# MC-based calculators

- ImPACT CT, UK
  - CT modality only
  - No specific dose estimations for pregnant patients i.e. conceptus

**ImPACT CT Patient Dosimetry Calculator**  
Version 1.0.4 27/05/2011

**Scanner Model:**  
 Manufacturer: Siemens  
 Scanner: Siemens Balance, Emotion  
 kV: 130  
 Scan Region: Head  
 Data Set: MCSET14 Update Data Set  
 Current Data: MCSET14

**Acquisition Parameters:**  
 Tube current: 30 mA  
 Rotation time: 1 s  
 Spiral pitch: 1  
 mAs / Rotation: 30 mAs  
 Effective mAs: 30 mAs  
 Collimation: 10 mm  
 Rel. CTDI: Look up 1.00 at selected collimation  
 CTDI (air): Look up 33.2 mGy/100mAs  
 CTDI (soft tissue): 35.5 mGy/100mAs  
 $_{w}CTDI_w$ : Look up 24.1 mGy/100mAs

**Scan range:**  
 Start Position: 32.5 cm Get From Phantom  
 End Position: 62 cm Diagram

**Organ weighting scheme:** ICRP 103

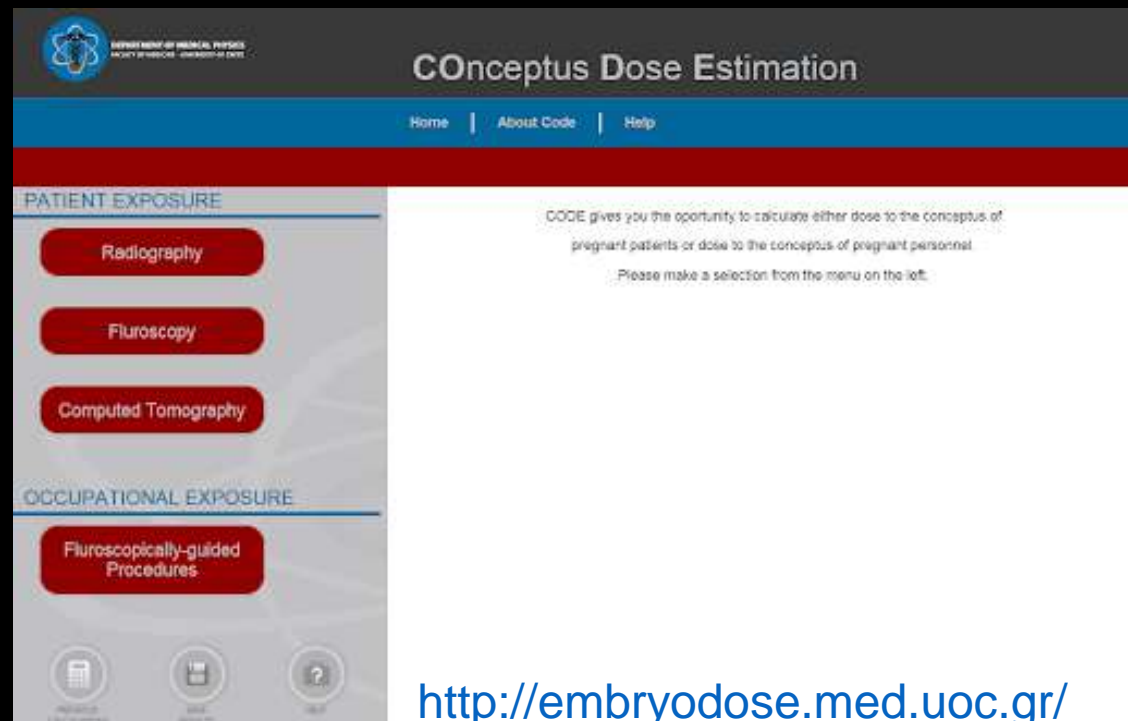
Organ	$w_r$	$H_T$ (mGy)	$w_r \cdot H_T$
Gonads	0.08	0.038	0.003
Bone Marrow	0.12	1.6	0.19
Colon	0.12	0.24	0.029
Lung	0.12	5.4	0.64
Stomach	0.12	3.8	0.46
Bladder	0.04	0.021	0.00083
Breast	0.12	4.5	0.54
Liver	0.04	4.2	0.17
Oesophagus (Thymus)	0.04	6.1	0.24
Thyroid	0.04	0.28	0.011

Remainder Organs	$H_T$ (mGy)
Adrenals	5.2
Small Intestine	0.28
Kidney	3
Pancreas	4.5
Spleen	4.4
Thymus	6.1
Uterus / Prostate (Bladder)	0.04
Muscle	1.2
Gall Bladder	2.3
Heart	6

**CTDI<sub>w</sub>**: 7.2 mGy  
**CTDI<sub>vol</sub>**: 7.2 mGy  
**DLP**: 213 mGy.cm

# MC-based calculators

- Conceptus radiation doses and risks from imaging with ionizing radiation (CONCERT) - research project with the aim to optimize radiological procedures for pregnant women
- Develop a software expert system ['COnceptus Dose Estimation' (CODE)] that allows to calculate conceptus dose and risk from radiological procedures
  - patients
  - workers



# MC-based calculators

- CODE
- Web-based
- Free of Charge
- User has to provide
  - CTDI free in air
  - beam collimation
  - CTDI normalized by 100mAs

Computed Tomography (CT)

0-12 week

Embryo Depth (cm)

Tube Load (mAs)

Tube Voltage (kV)


Pitch

Beam Collimation (mm)

Patient Circumference (cm)

CTDI<sub>free in air</sub> (mGy/100 mAs)

CTDI<sub>w</sub> (mGy / 100 mAs)



Start of scan  cm End of scan  cm

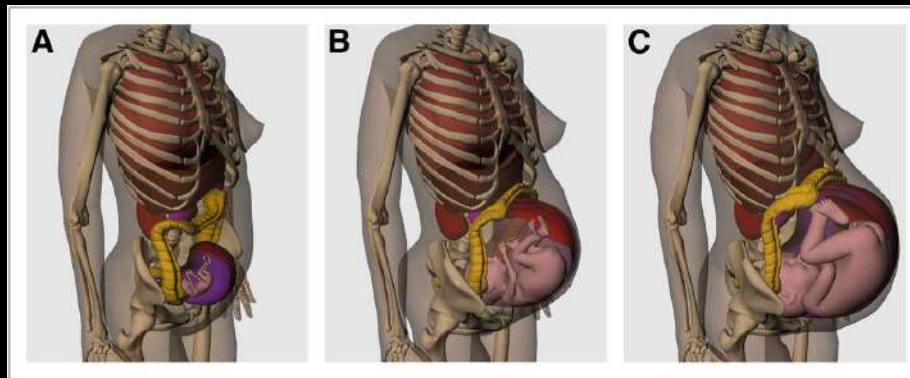
Embryo Dose  Risk for childhood cancer

Embryo Dose (mGy)	Probability for the absence of any malformation (%)	Probability of being cancer free (0-19y) (%)
0 mGy	97	99.7
1.777 mGy	97	99.700

<http://embryodose.med.uoc.gr/>

# MC-based calculators

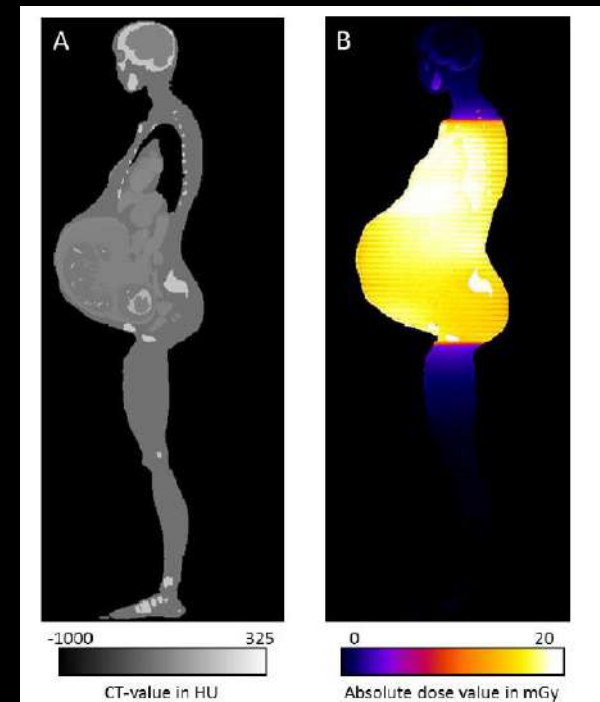
- Fetaldose.org
- Aim to create a tool for simple and accurate conceptus dose assessment from CT
- RPI phantoms representing female patients at 3, 6 and 9 month of pregnancy



> [Invest Radiol.](#) 2020 Dec;55(12):762-768. doi: 10.1097/RLI.0000000000000701.

## Radiation Dose to the Fetus From Computed Tomography of Pregnant Patients-Development and Validation of a Web-Based Tool

Natalia Saltybaeva <sup>1</sup>, Alexandra Platon <sup>2</sup>, Pierre-Alexandre Poletti <sup>2</sup>, Ricarda Hinzpeter <sup>1</sup>,  
Marta Sans Merce <sup>2</sup>, Hatem Alkadhi <sup>1</sup>



# MC-based calculators

- Web-based, free of charge, easy to use
- Validated
- CT only

fetaldose.org [Home](#) [Calculator](#) [About](#) [Publication](#) [Uncertainties](#)

Gestational age, month

Tube voltage, kVp


CTDIvol, mGy  
  
Volume CT Dose Index obtained from patient radiation dose report.

Maternal perimeter, mm (optional)  
  
Maternal perimeter in mm defined from the CT section containing the central area of the uterus.


Upper position, mm

Lower position, mm

Patient ID (optional)



Radiation dose to the fetus,  
mGy: **9.03**



# Take Home Message

- X-ray based procedures during pregnancy represent significant concern for caregivers and patients
- Conceptus dose and risk from such procedures should be evaluated
- Normalized standard dose metrics, MC simulations or measurements can be used to evaluate the dose
- MC-based calculators are very helpful for fast and accurate assessment of the conceptus dose



# Thank you for your attention!



EURADOS Working Group 12  
Dosimetry in Medical Imaging  
SG2/Task 4: «Dosimetry in pregnancy»