Assessment of doses to embryo and fetus - external dosimetry

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

USZ Universitäts Spital Zürich

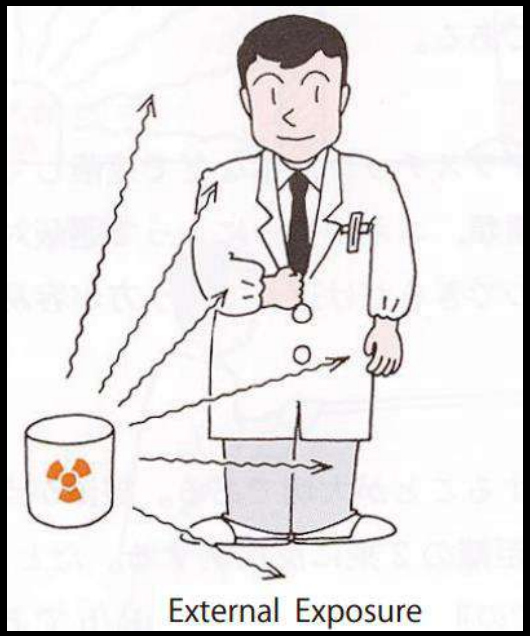
Effects of ionising radiation

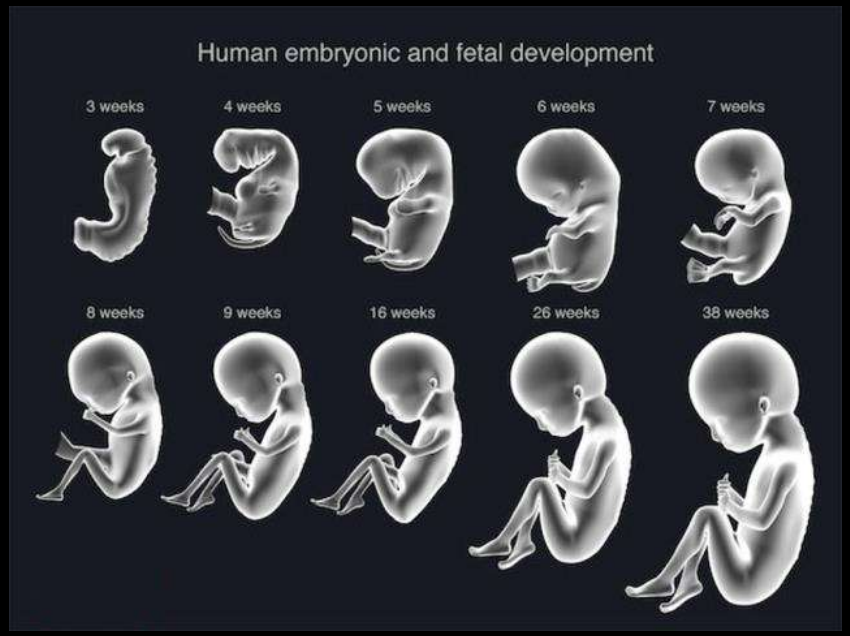
Deterministic effects

- lethal effect (miscarriage)
- mental retardation
- malformation

Stochastic effects

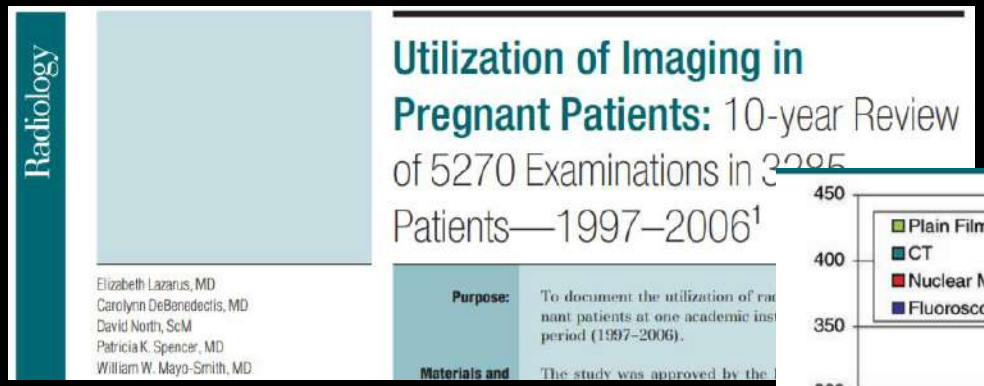
- cancer
- leukemia
- hereditary effects





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


Radiology

Utilization of Imaging in Pregnant Patients: 10-year Review of 5270 Examinations in 3285 Patients—1997–2006[1]

Elizabeth Lazarus, MD
Carolynn DeBenedectis, MD
David North, ScM
Patricia K. Spencer, MD
William W. Mayo-Smith, MD

Purpose: To document the utilization of rad... nant patients at one academic inst... period (1997–2006).

Materials and The study was approved by the ...

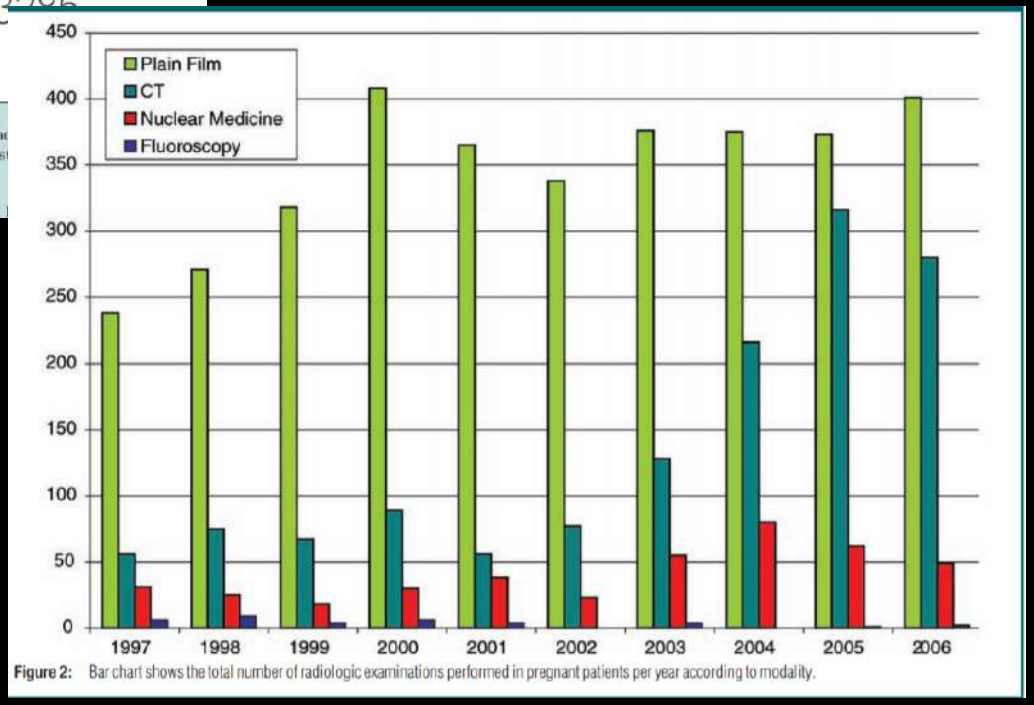


Figure 2: Bar chart shows the total number of radiologic examinations performed in pregnant patients per year according to modality.

X-ray examination rate in pregnant patients increased by 107%

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

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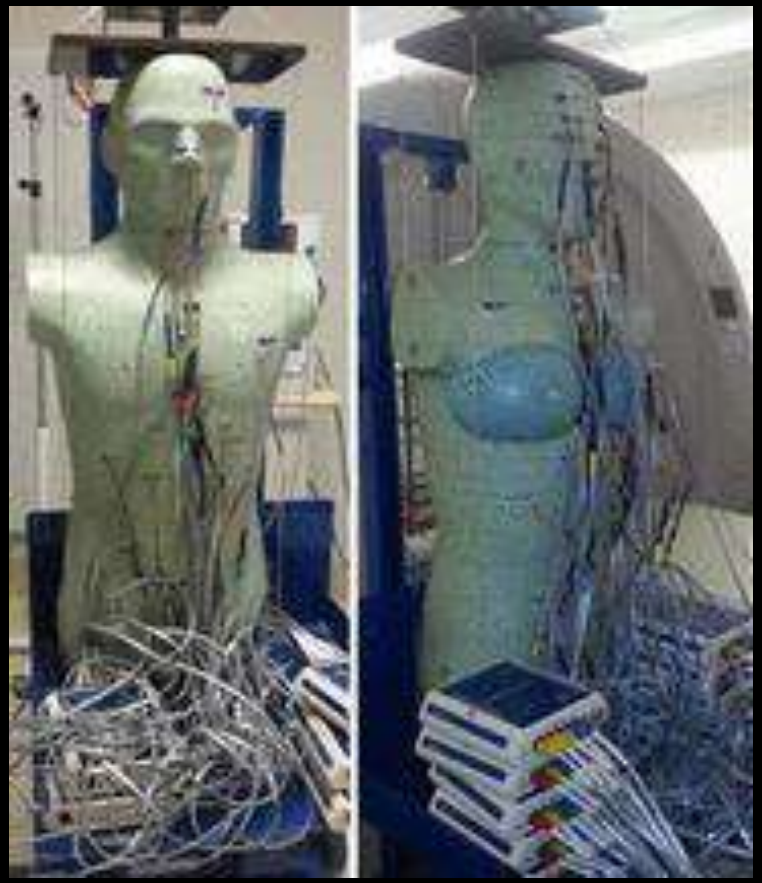
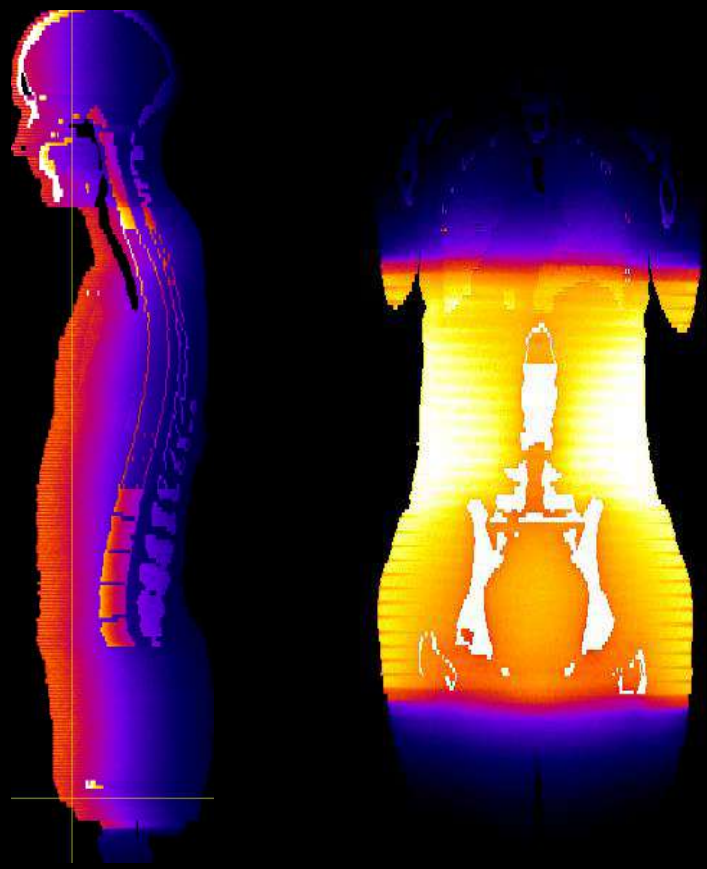
Conceptus dose assessment

Measurements



MC Simulations



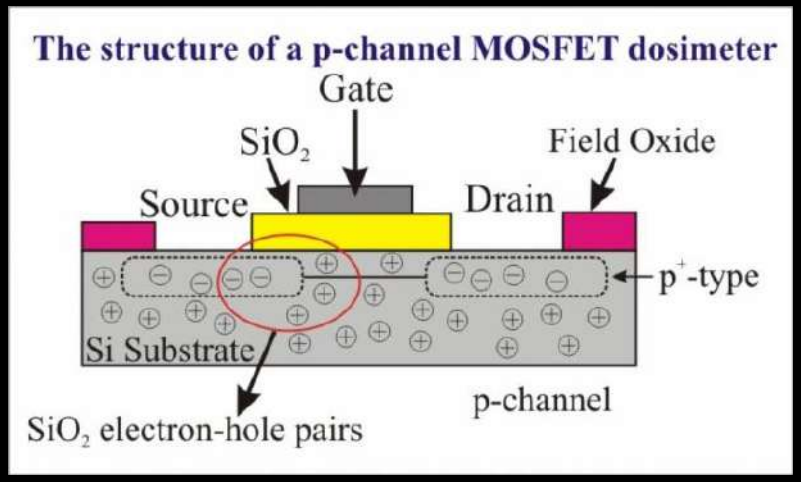
Measurements

- 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

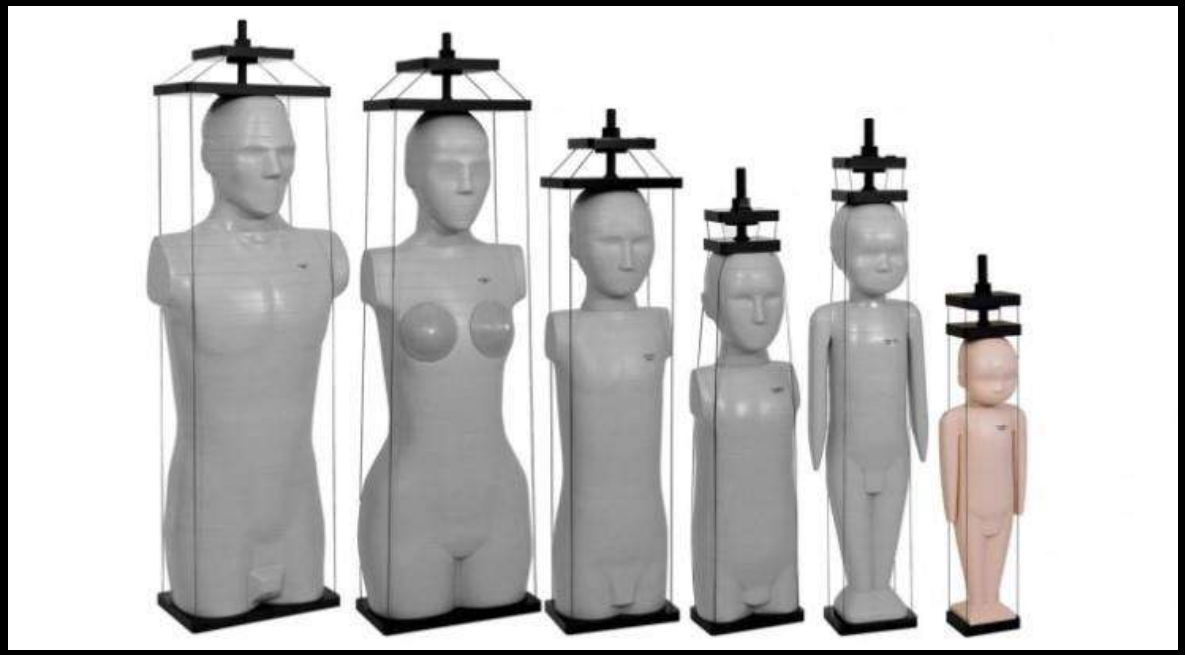


Measurements

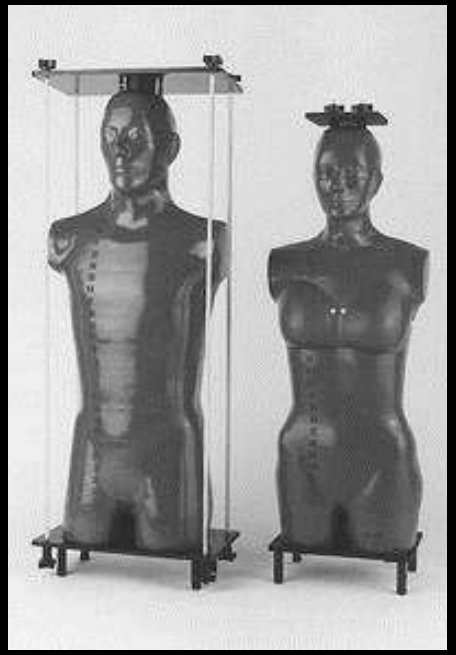
- Patient-> Dose on the surface
- Anthropomorphic Phantoms

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



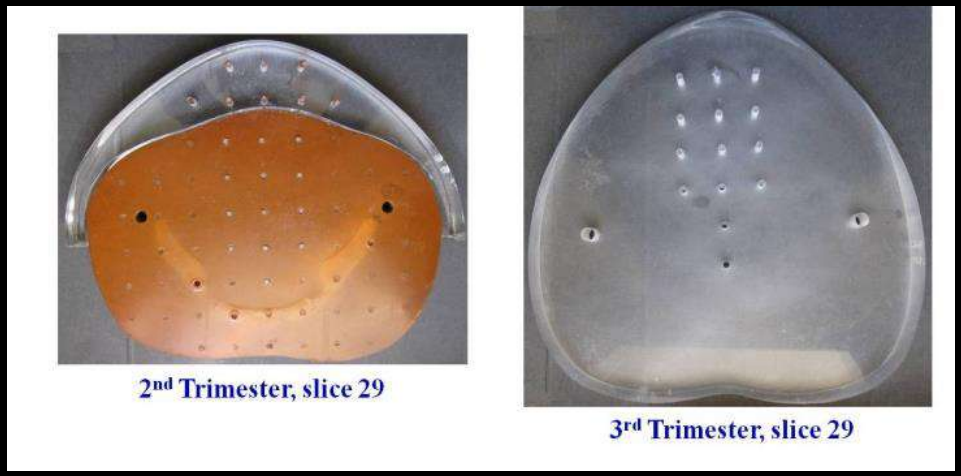
ATOM Dosimetry phantoms, CIRS family



Rando Alderson

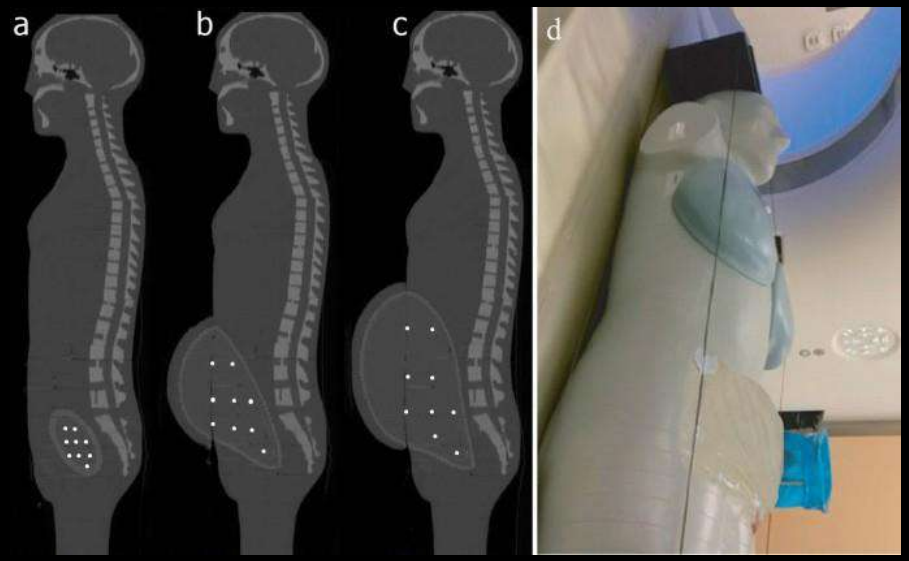
Anthropomorphic phantoms

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



J. Damilakis, University of Crete

Anthropomorphic phantoms



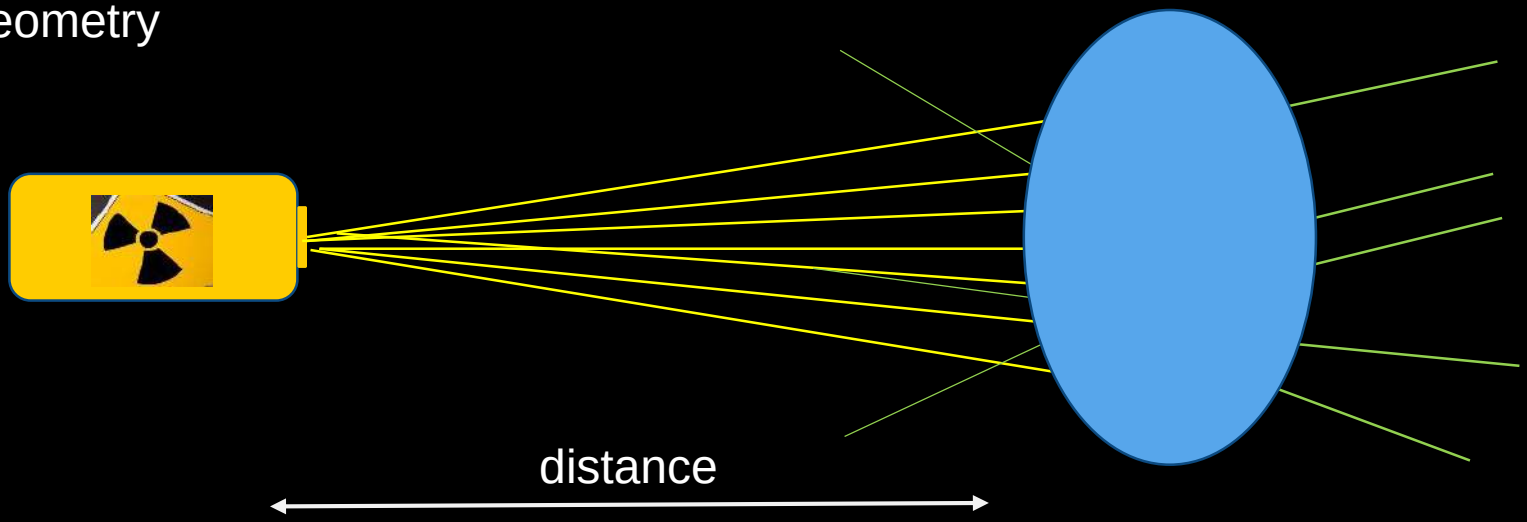
Images of gelatin boluses representing pregnancy at (**b**) 6 and (**c**) 9 months. White dots in images represent TLDs distributed in uterus. Saeed et al., 2021

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



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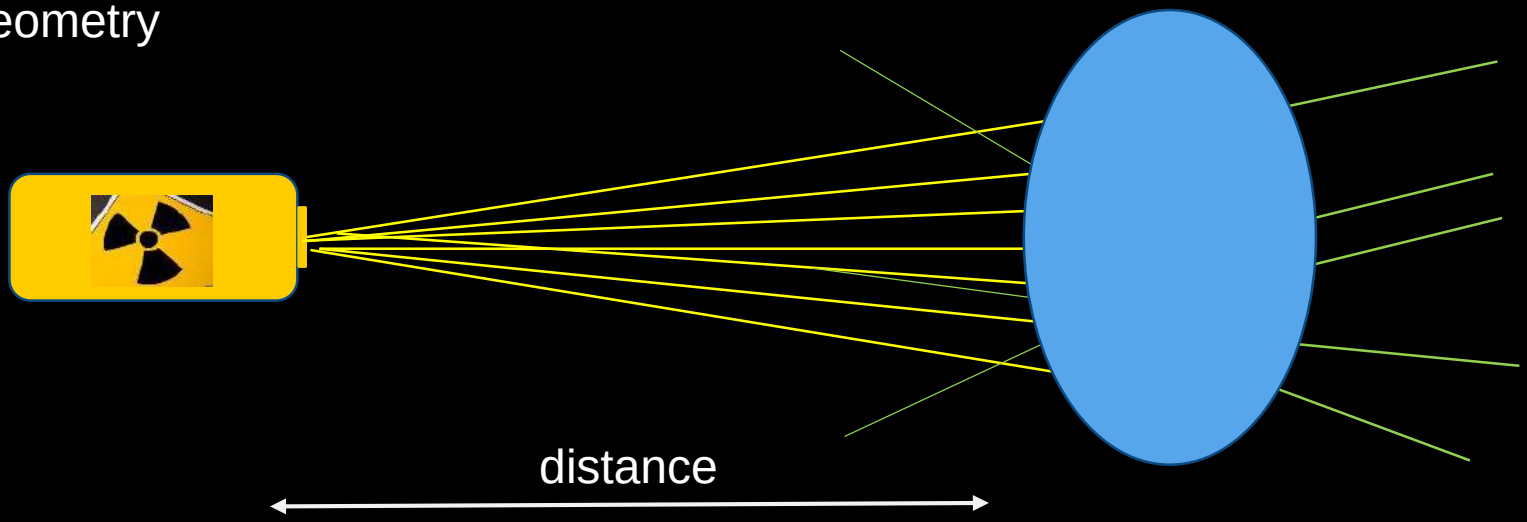
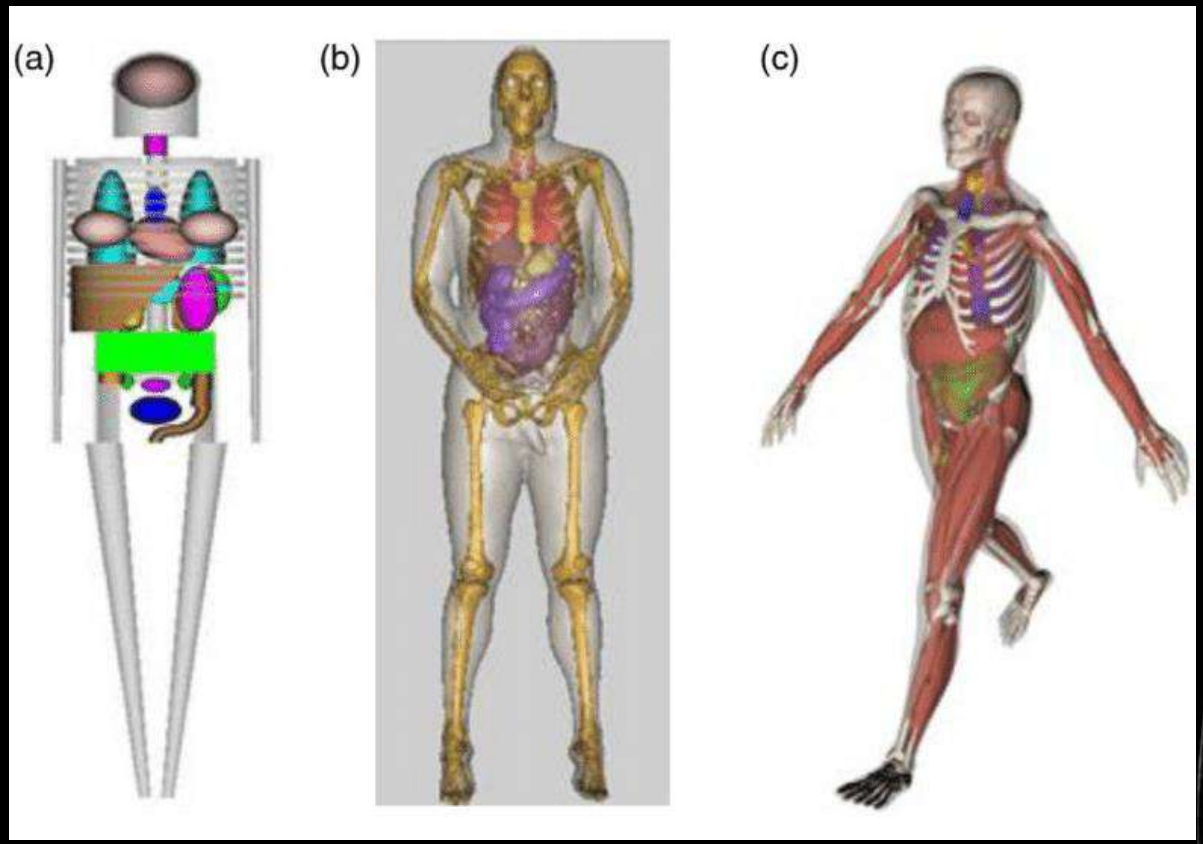


MC Simulations

- 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

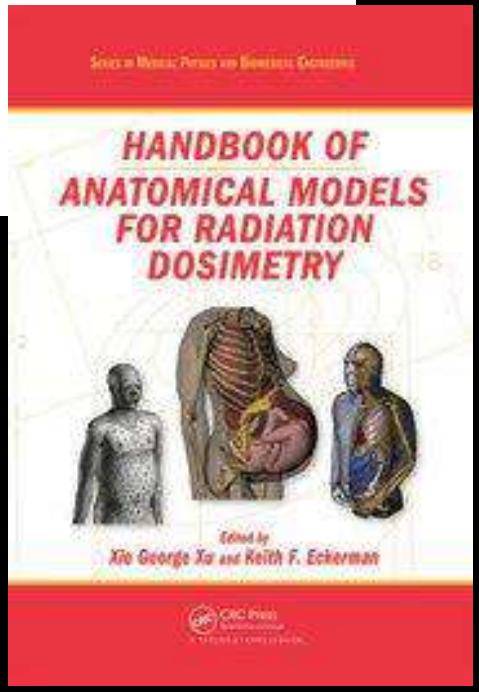
Phys. Med. Biol. **59** (2014) R233–R302 doi:10.1088/0031-9155/59/18/R233

Topical Reviews

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

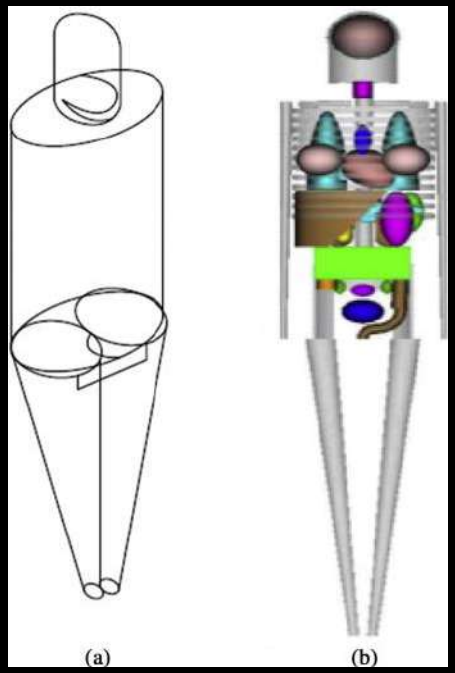
X George Xu

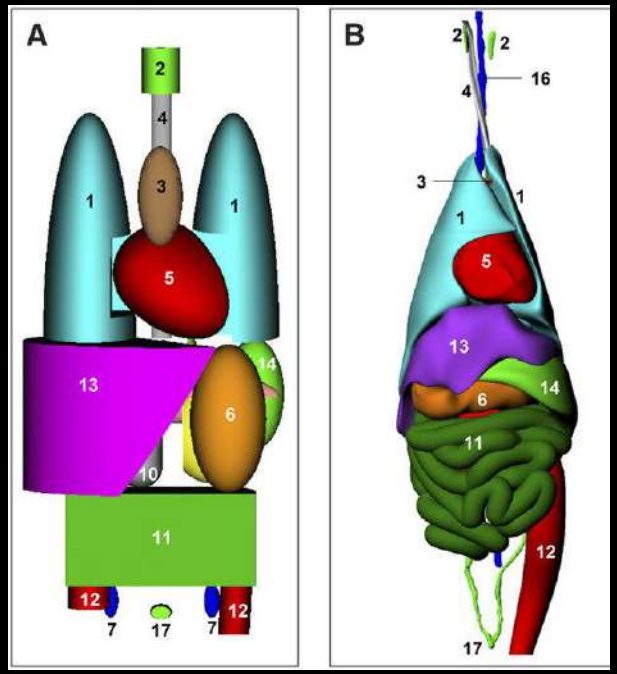
Rensselaer Polytechnic Institute Troy, New York, USA



Computational phantoms

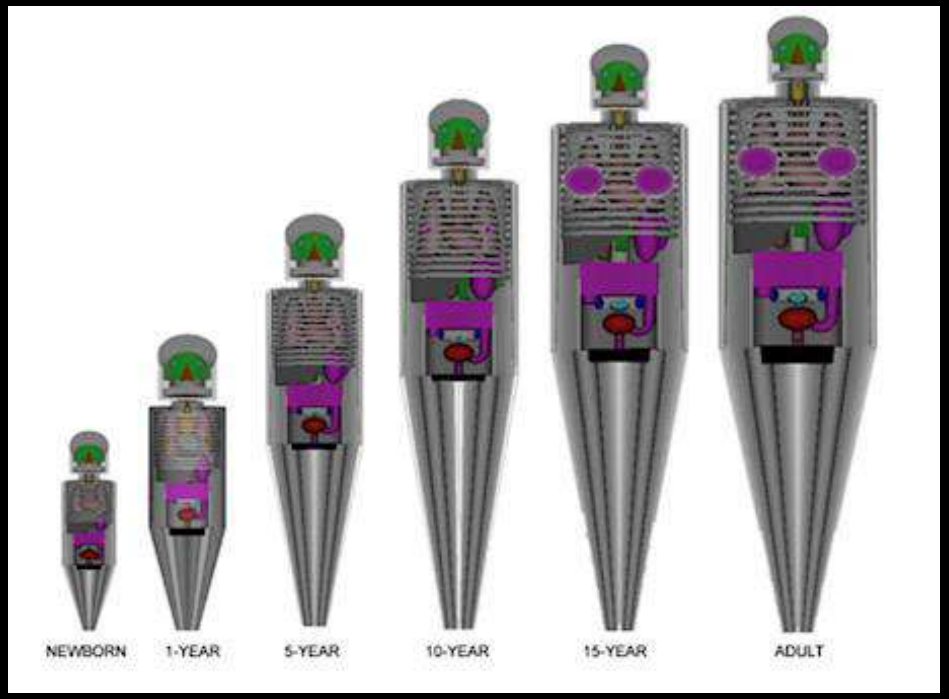
- Stylized Phantoms
- Organs are simulated using surfaces described by equations, such as cylinders, spheres and cones
- 1960 first-generation of stylized anthropomorphic phantoms Oak Ridge National Laboratory (ORNL)

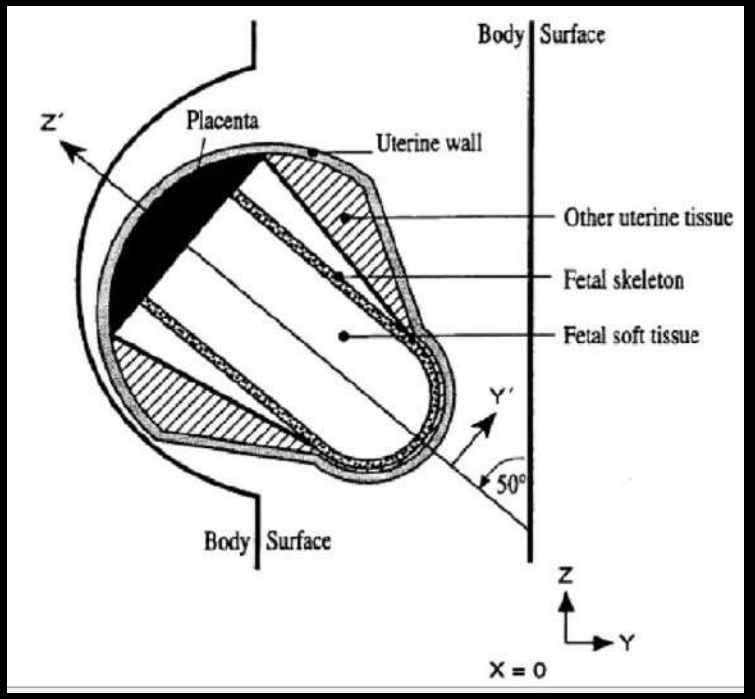




Computational phantoms

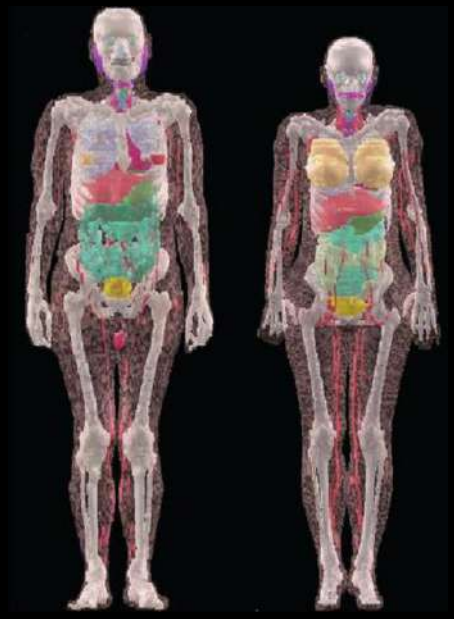
- In 1995, Stabin and his colleagues at ORNL adapted adult female phantom to represent a woman at the 3, 6 and 9 month of pregnancy



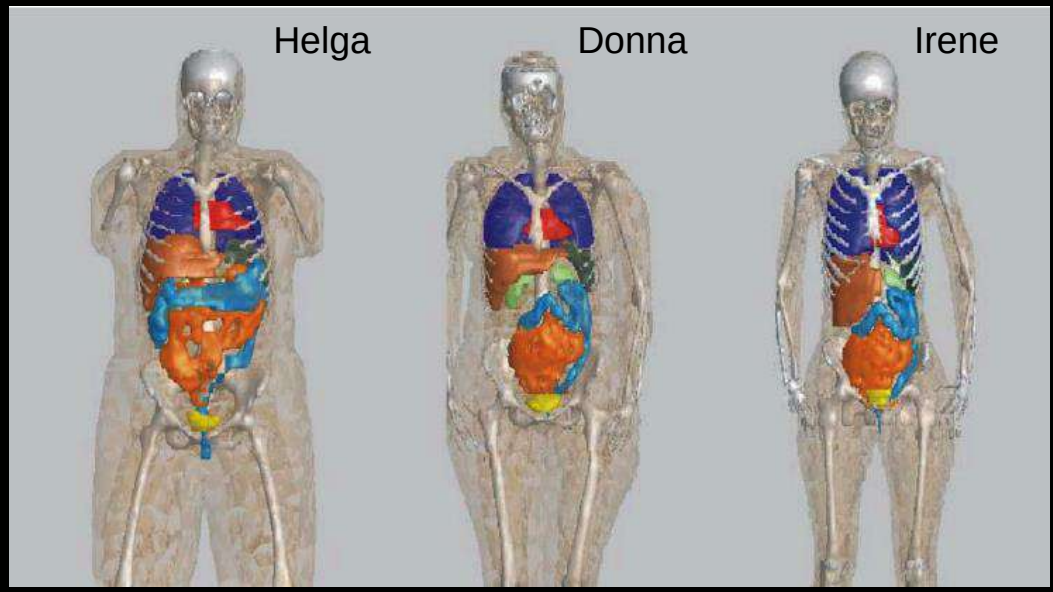


Computational phantoms

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



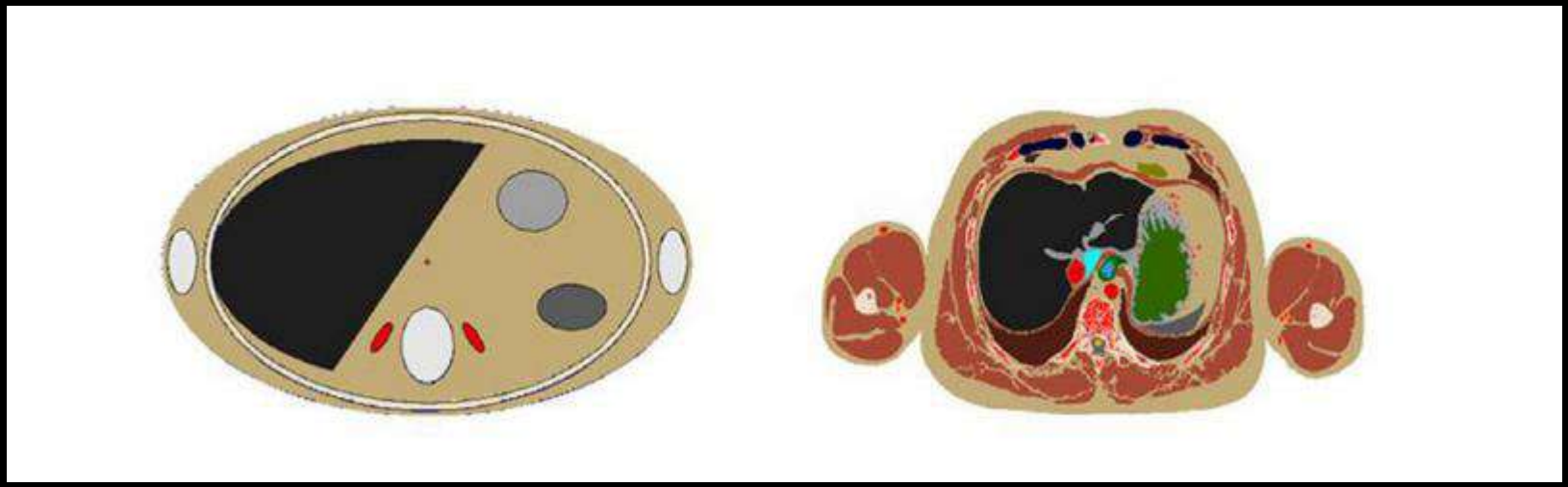
ICRP reference Male and Female



Zankl et al. GSF, Germany

Computational phantoms

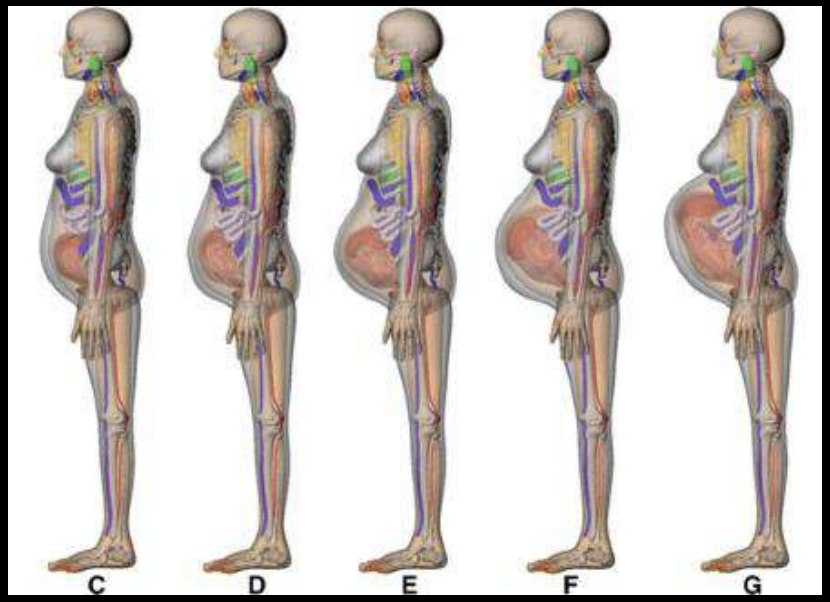
- Comparison of stylized adult phantom (left) and VIP-Man phantom (reproduced with permission from Taylor and Francis, Xu et al 2000) (right)



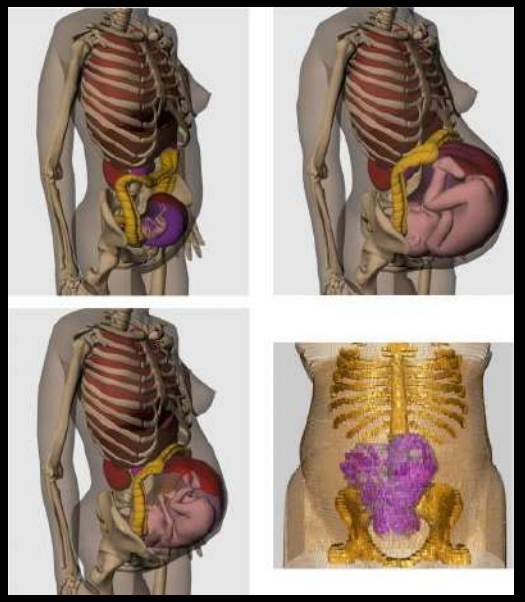
- Such anatomical differences can influence the accuracy of radiation dose estimates

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



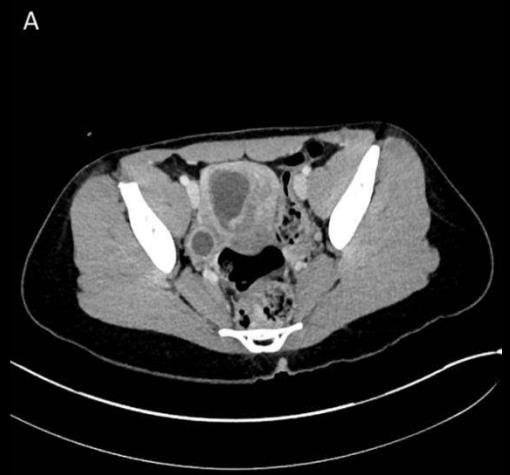
UF phantoms, SOLO



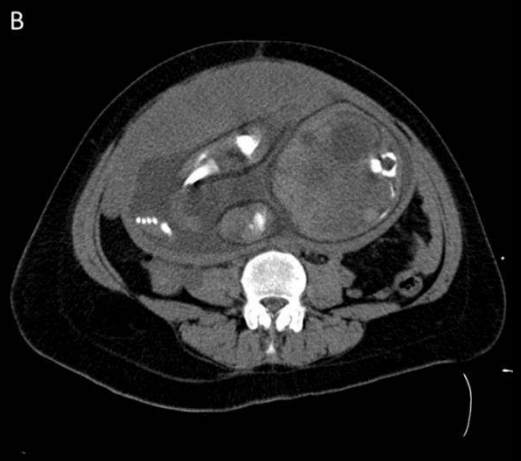
RPI phantoms

Patient Images

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



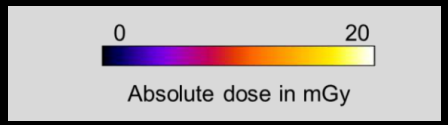
Transverse image of the female patients with 8 weeks of pregnancy



Transverse image of the female patients with 35 weeks of pregnancy

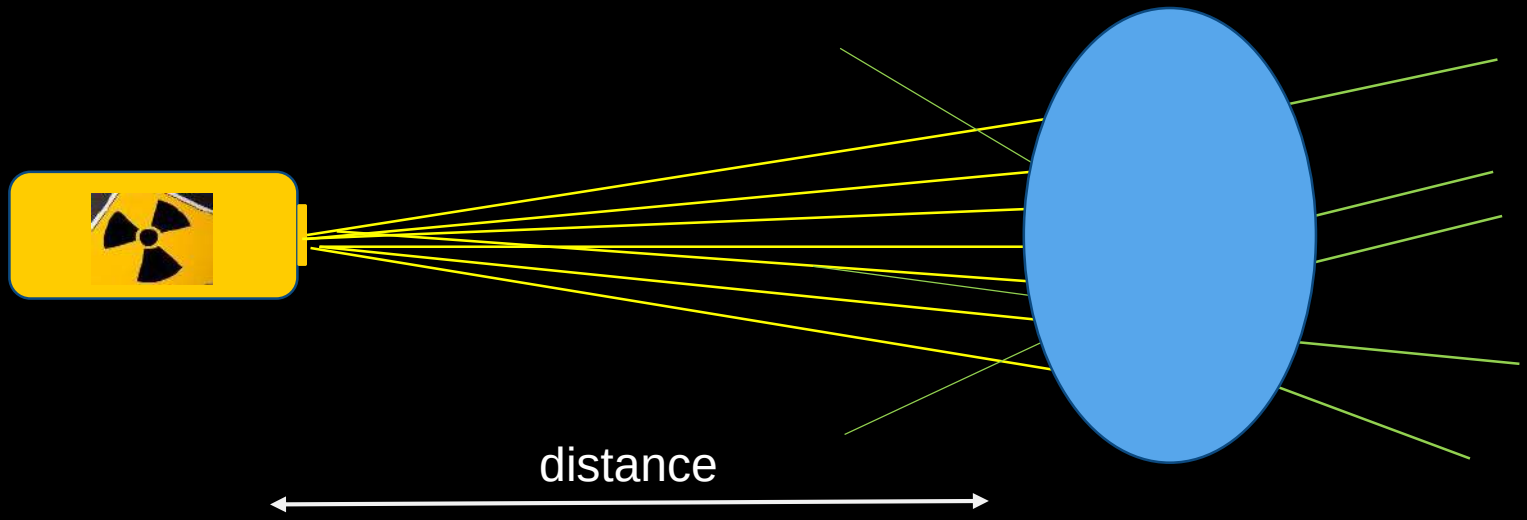
Patient Images

- 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



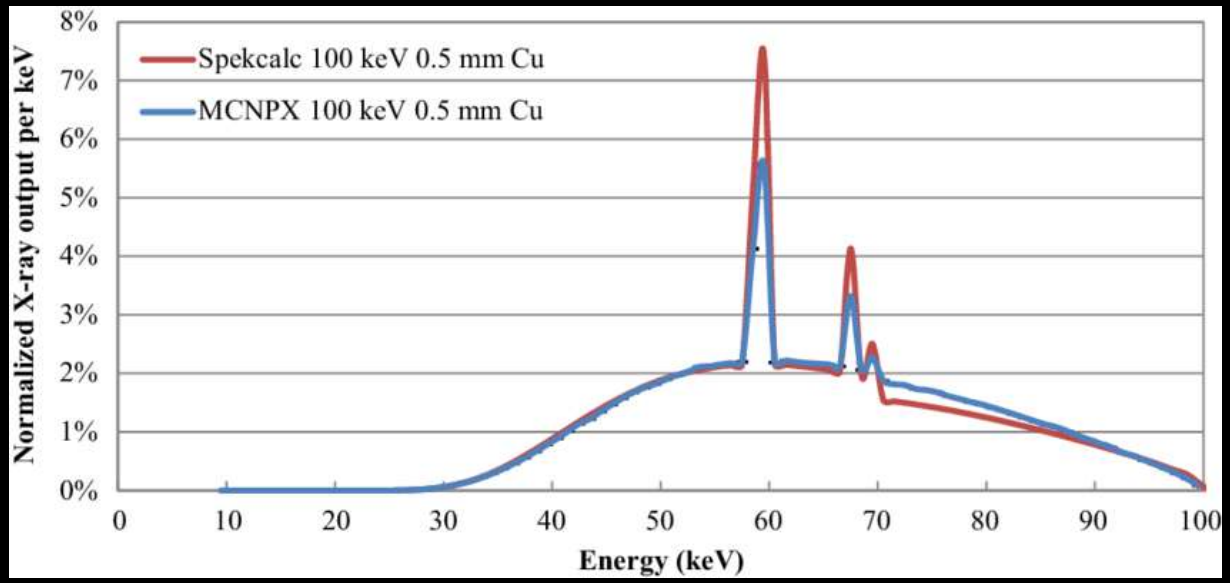
MC Simulation

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



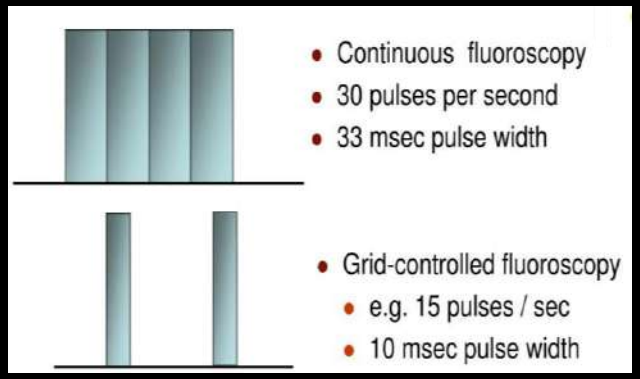
X-ray source

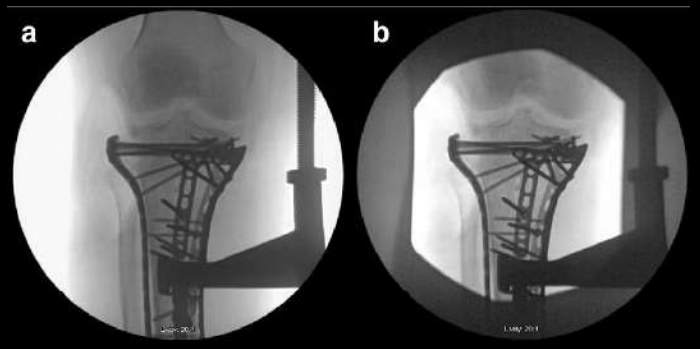
- Energy spectra
- mA and automatic exposure algorithm
- Filtration



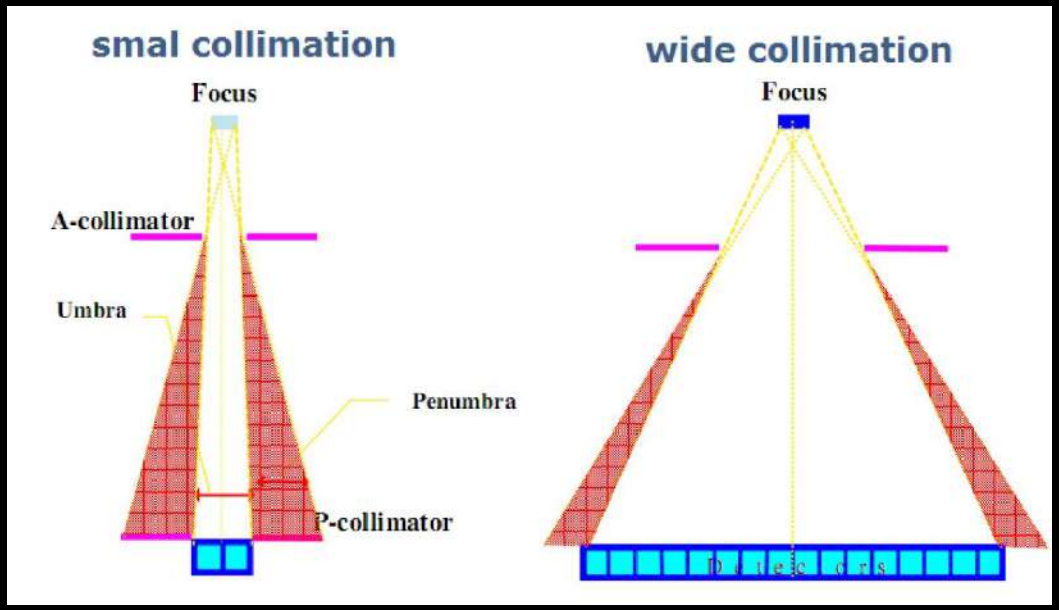
X-ray source

- Fluroscopy
  - Pulse rate
  - Collimation



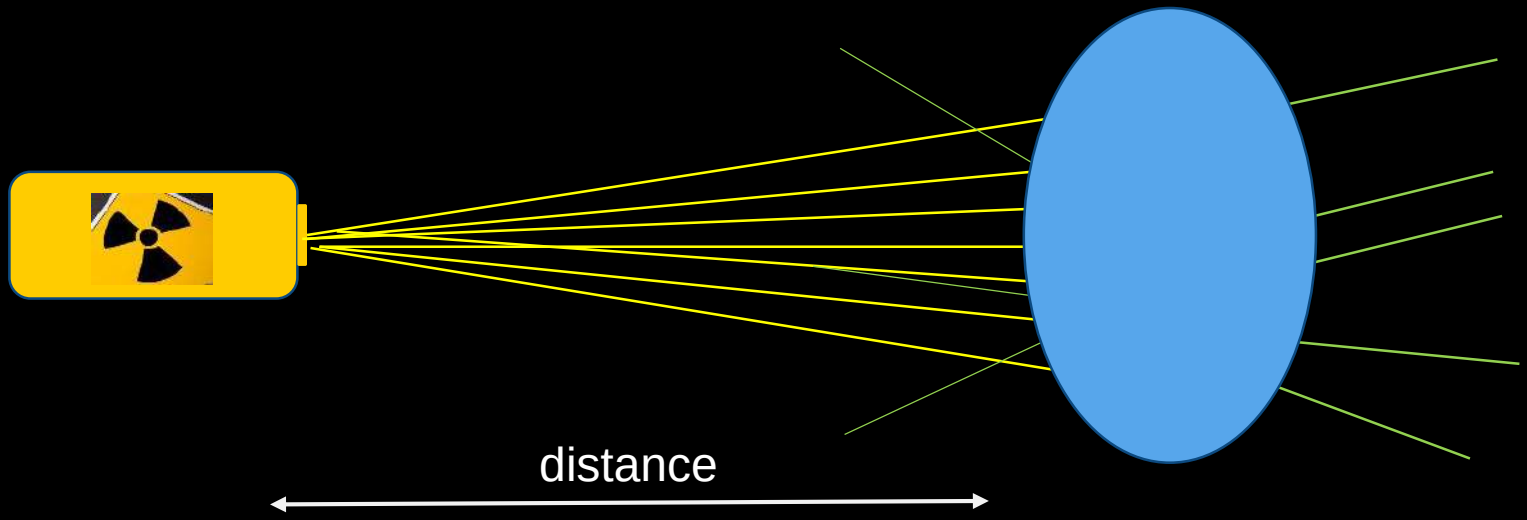


- CT
  - Focus
  - Total beam width



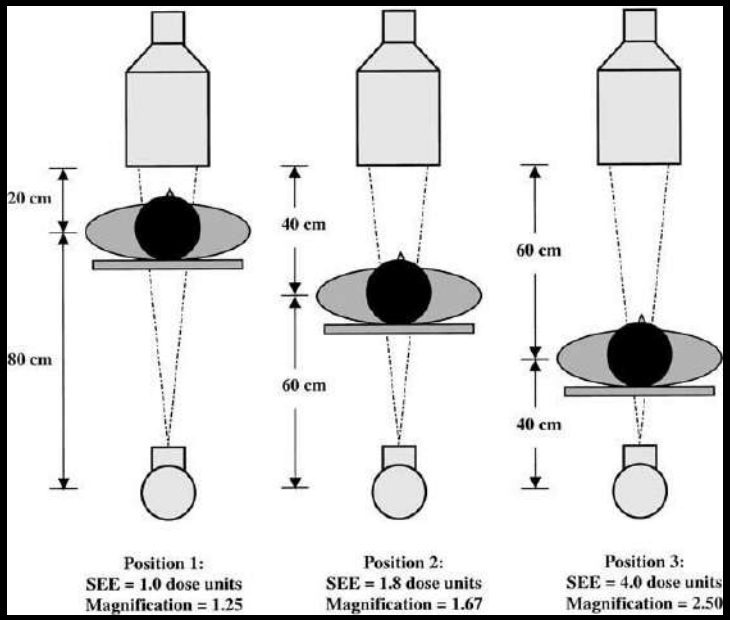
Geometry

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

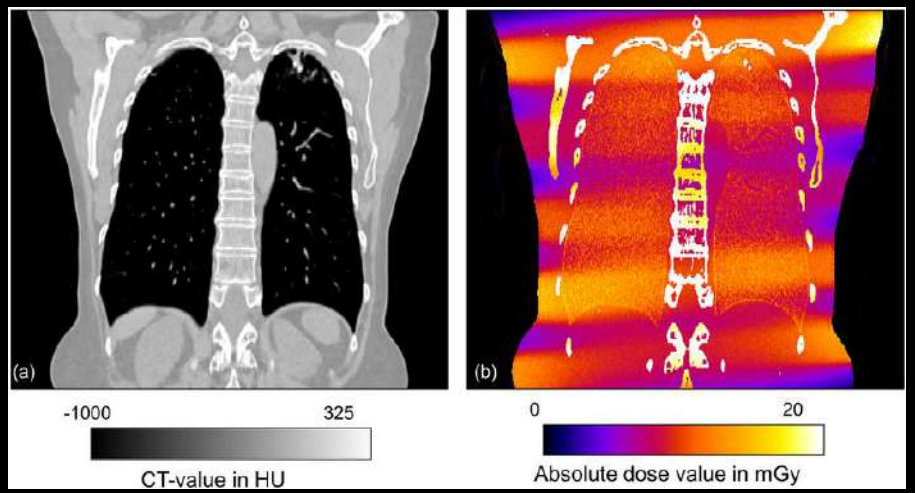


Geometry

- Fluoroscopy
  - Distance
  - Projection angles

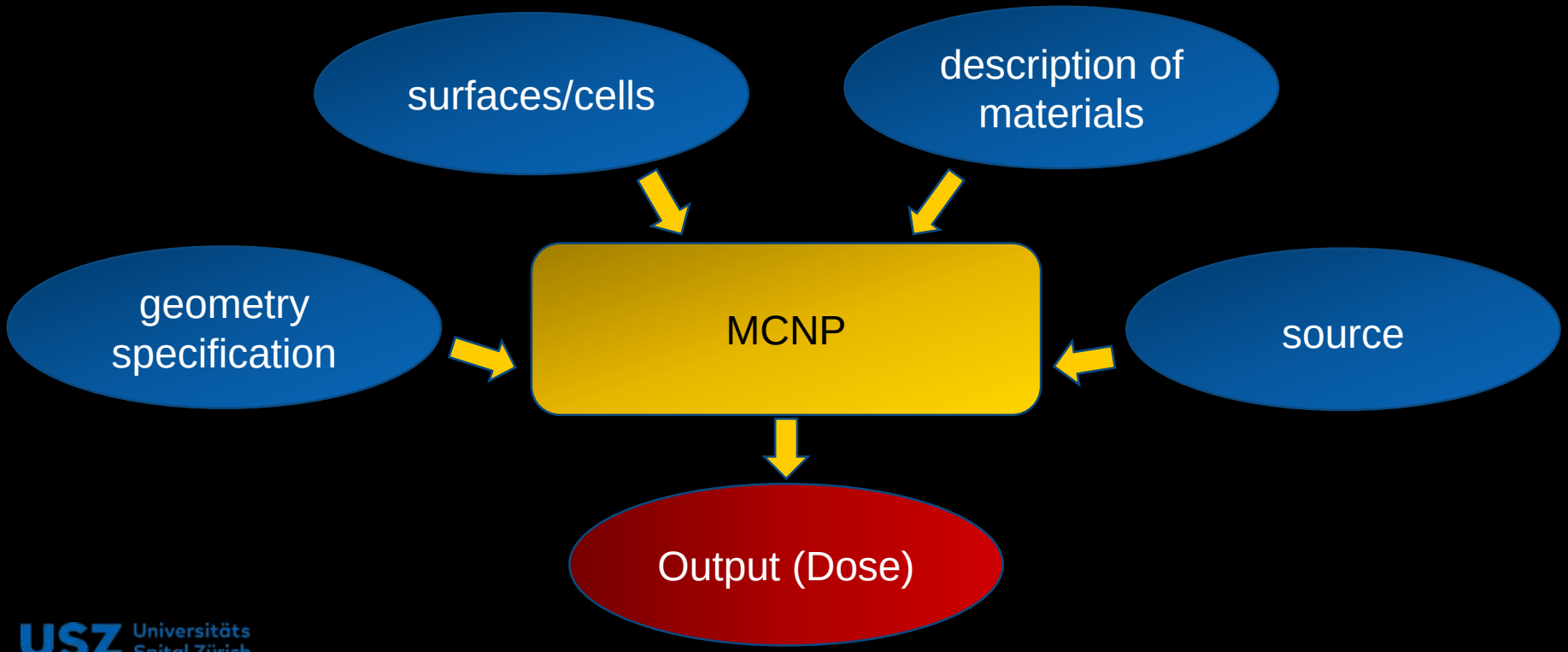


- CT
  - Scan length
  - Trajectory (spiral vs sequentional)



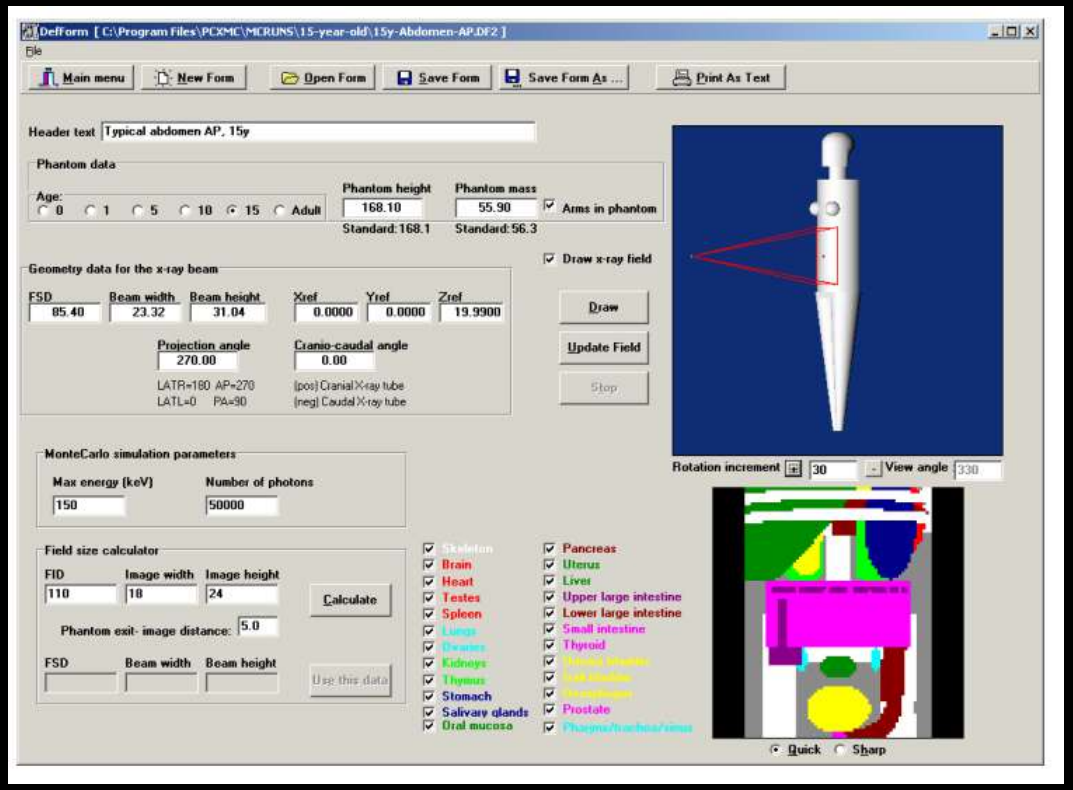
MC Simulation

- 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, ɣ)
  - generalized-geometry (all modalities)



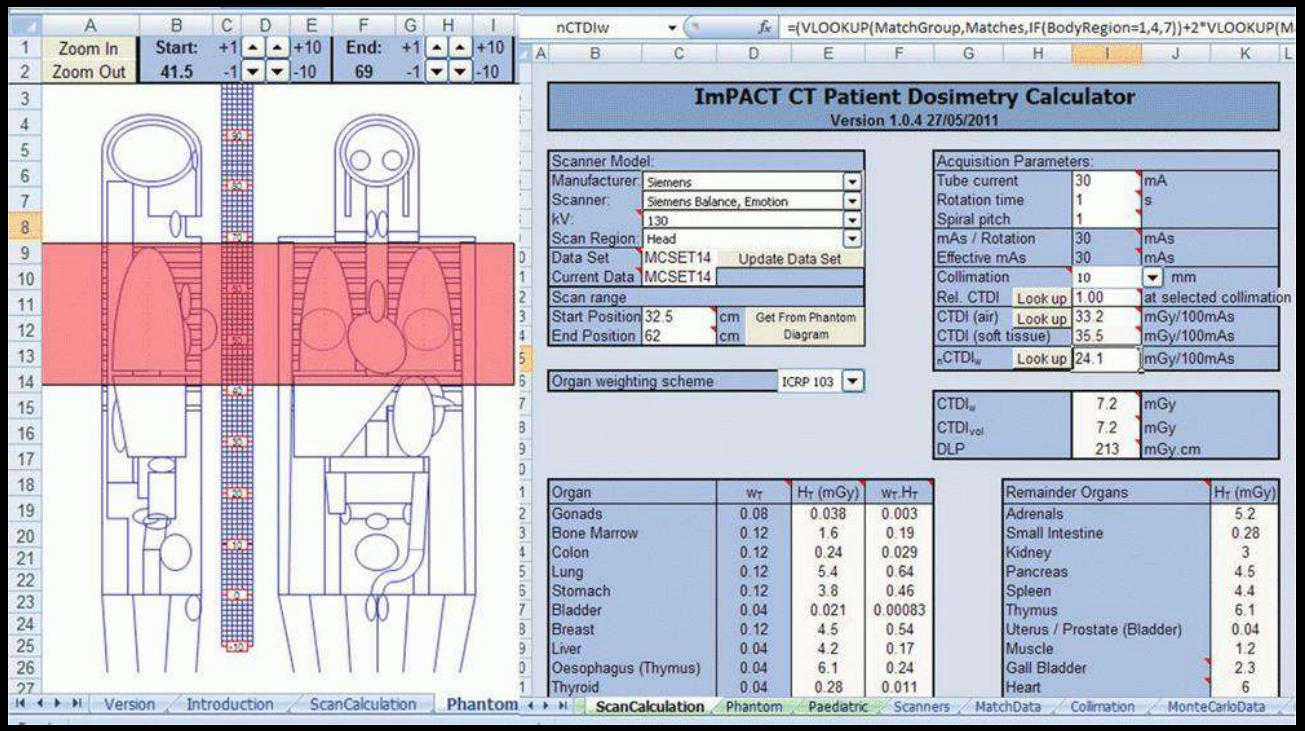
MC Simulation

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



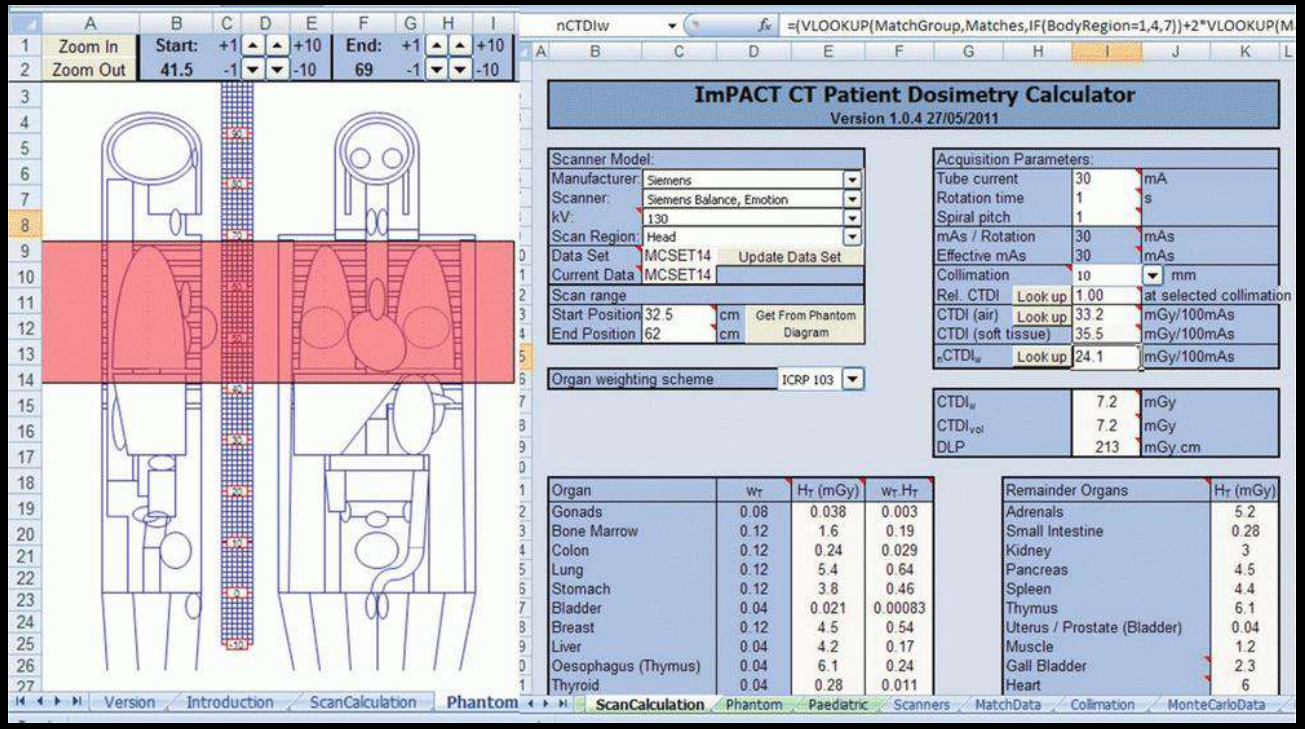
MC-based calculators

- 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)



MC-based calculators

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



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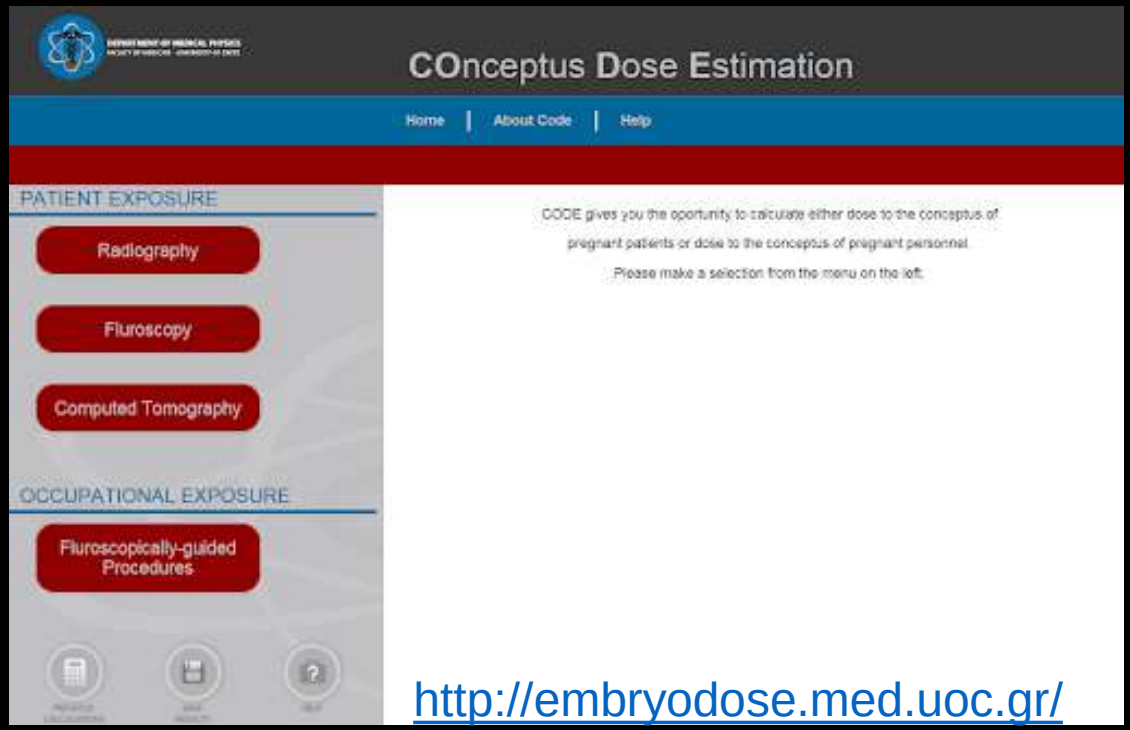
MC-based calculators

- Conceptus radiation doses and risks from imaging with ionizing radiation (CONCERT) - research project with the aim to optimize radiological procedures for pregnant women

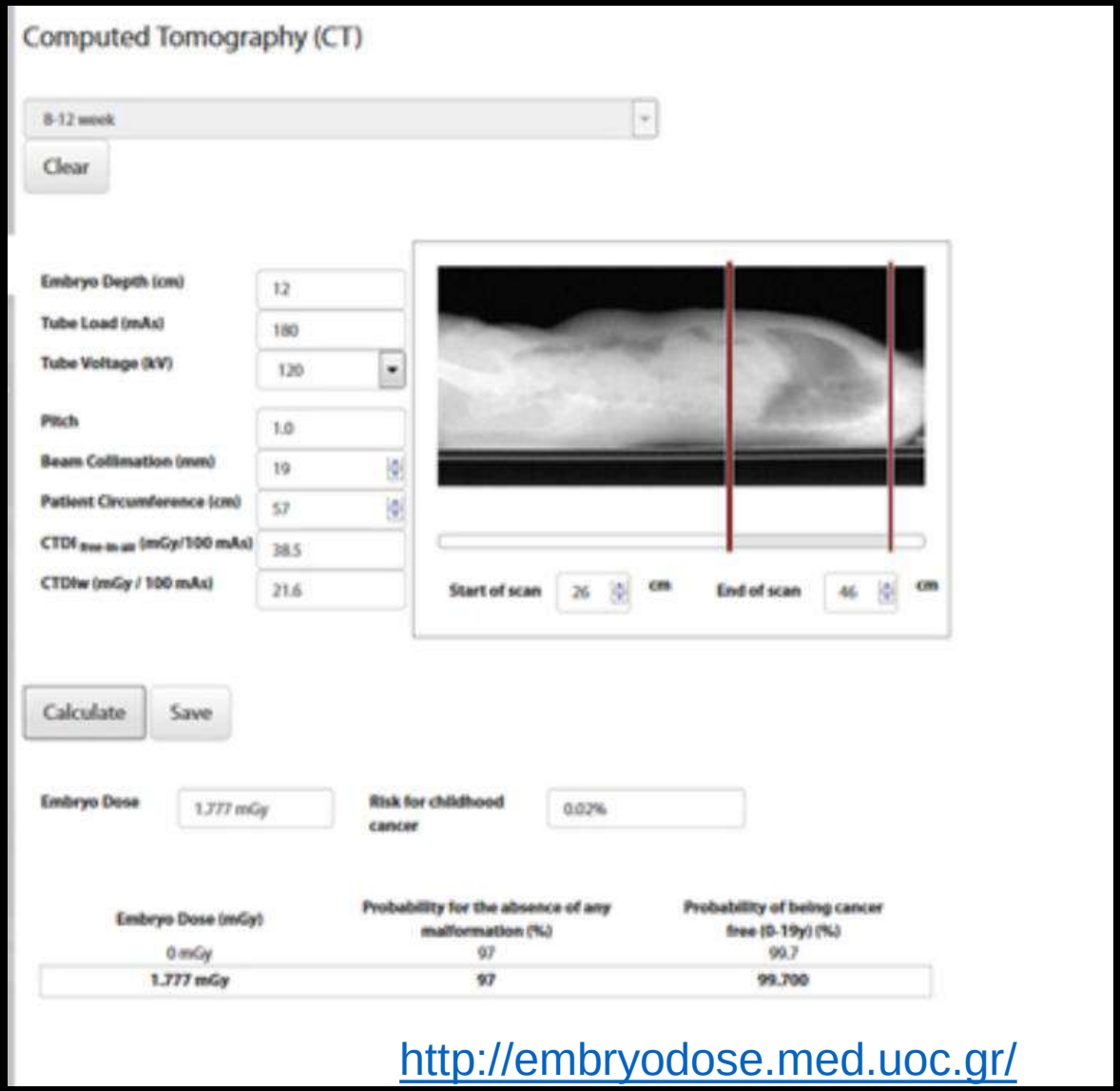
- Develop a software expert system ['COnceptus Dose Estimation' (CODE)] that allows to calculate conceptus dose and risk from radiological procedures
  - patients
  - workers



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

MC-based calculators

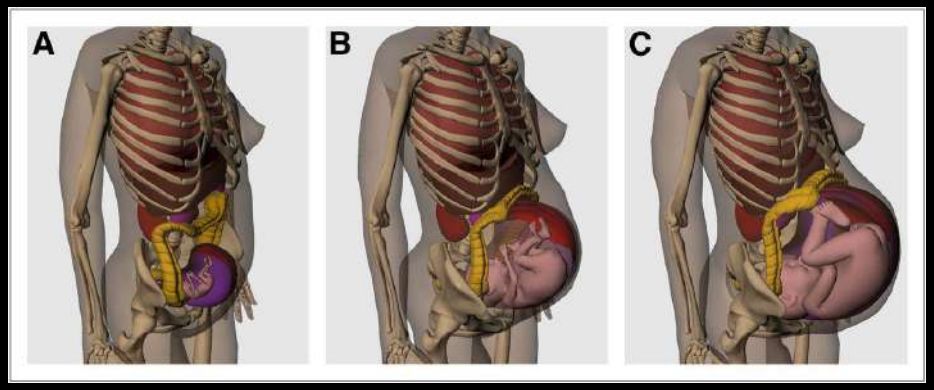
- CODE
- Web-based
- Free of Charge
- User has to provide
  - CTDI free in air
  - beam collimation
  - CTDI normalized by 100mAs



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

MC-based calculators

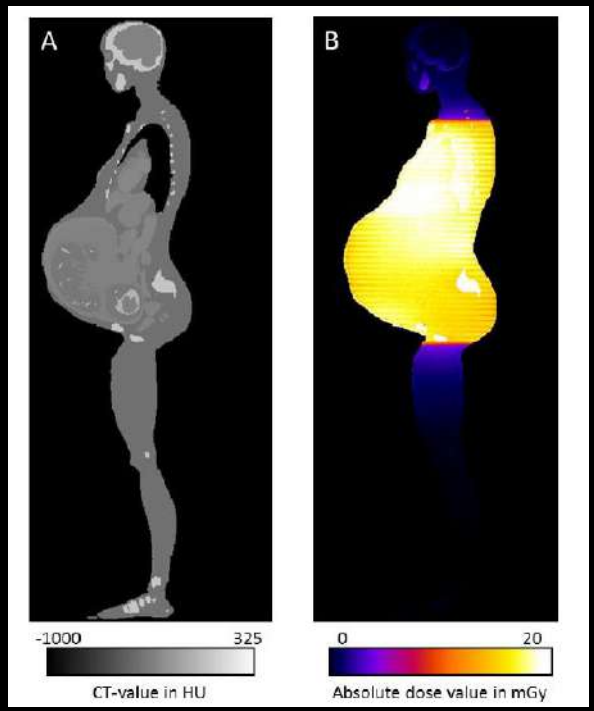
- Fetaldose.org
- Aim to create a tool for simple and accurate conceptus dose assessment from CT
- RPI phantoms representing female patients at 3, 6 and 9 month of pregnancy



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

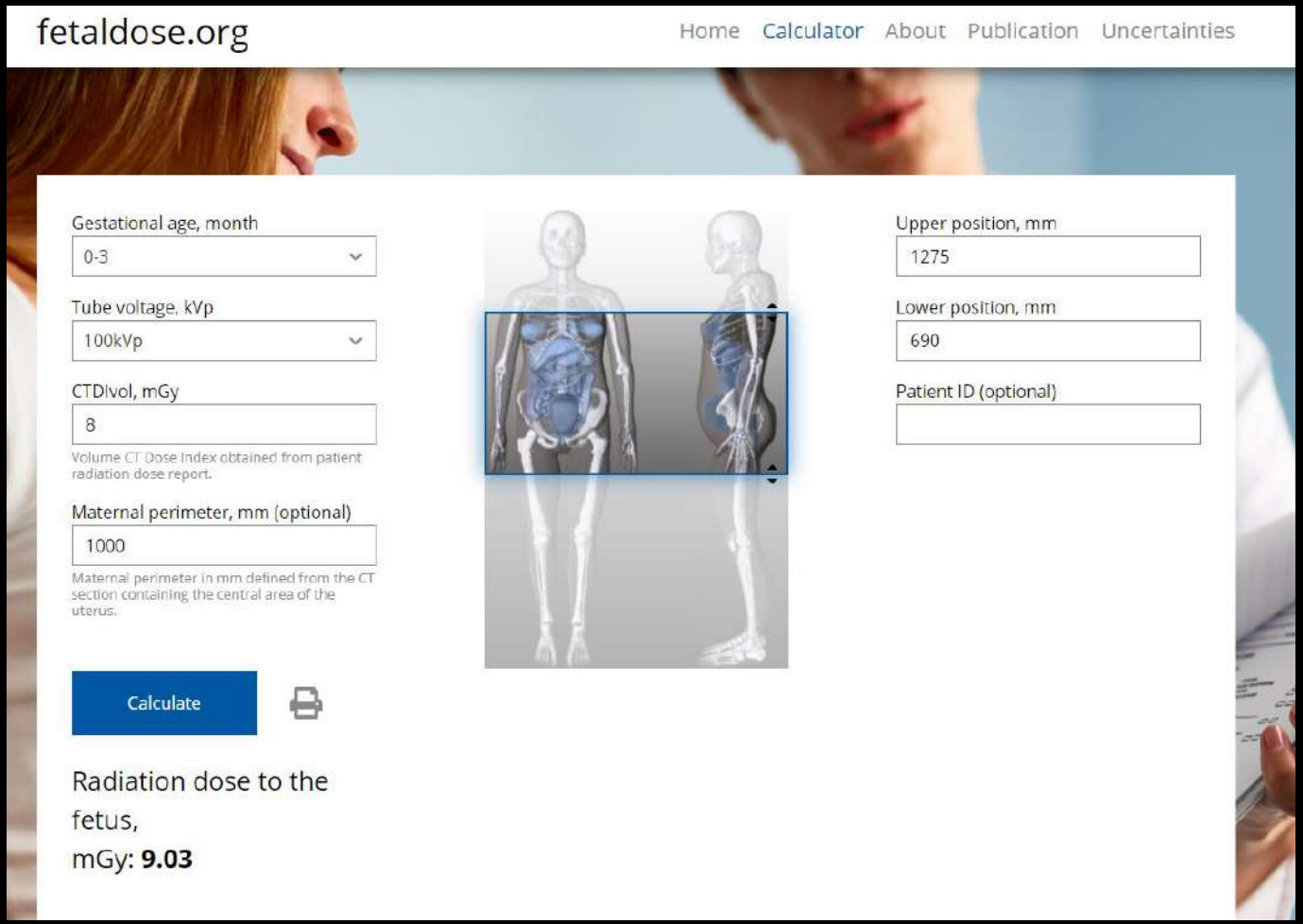
Radiation Dose to the Fetus From Computed Tomography of Pregnant Patients–Development and Validation of a Web-Based Tool

Natalia Saltybaeva [1], Alexandra Platon [2], Pierre-Alexandre Poletti [2], Ricarda Hinzpeter [1], Marta Sans Merce [2], Hatem Alkadhi [1]



MC-based calculators

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



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

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

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