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CONTROL OF ORGAN AND TISSUE DOSES TO PATIENTS DURING COMPUTED TOMOGRAPHY

INTRODUCTION

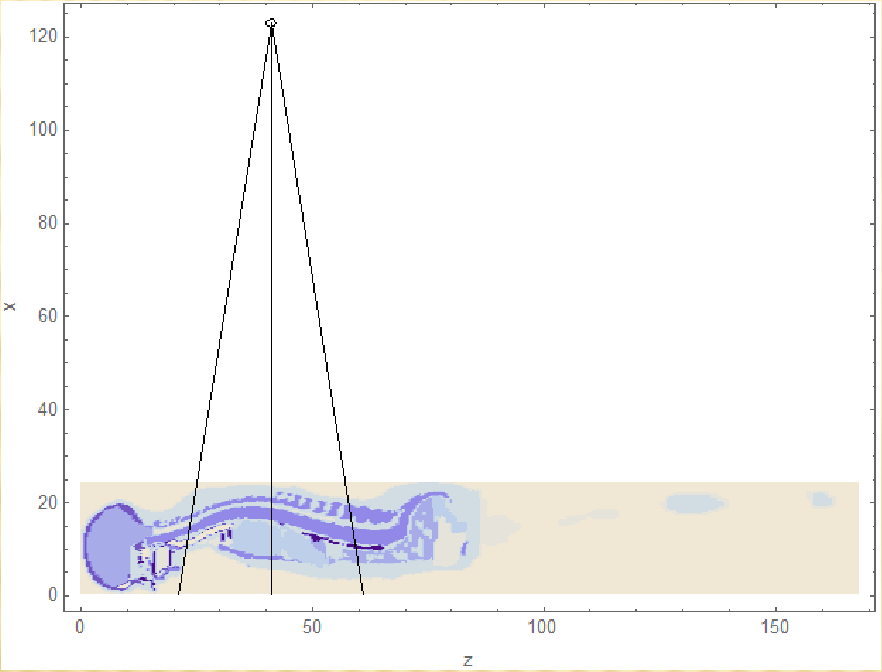
- Computed Tomography (CT) is an important medical diagnostic tool based on X-ray exposure.
- Radiation doses to individual patients caused by CT are relatively high and should be carefully estimated.

EFFECTIVE RADIATION DOSE

- Effective dose is an integral quantity what is used to assess the harmful effect of the radiation.
- It is calculated using the following formula

- Liver (=0,04)
- Lungs (=0,12)
- Colon (=0,12)
- Stomach (=0,12)
- bone marrow (=0,12)
- Urinary bladder (=0,04)
- Oesophagus (=0,04)
- Testes (=0,08)
- Breasts (=0,12)
- Thyroid (=0,04)…

WHY ARE THE ORGAN AND TISSUE DOSES IMPORTANT?



- During Computed Tomography only a part of human body is usually exposed.
- When an organ or tissue is exposed to the direct beam its dose may be relatively high.
- At the same time the effective dose is by an order of magnitude less because of low tissue weighting factor ω_t.

HOW ARE RADIATION DOSES ESTIMATED?

- Radiation doses are estimated using Monte-Carlo simulation of radiation transport in reference phantoms as recommended by International Commission on Radiological Protection.
- The simulation of the exposure is performed in several steps

MEASURING THE RADIATION OUTPUT OF CT

- CTDI (Computed tomography dose index) – a basic dosimetric quantity for assessment of dose to the patient during the procedure.

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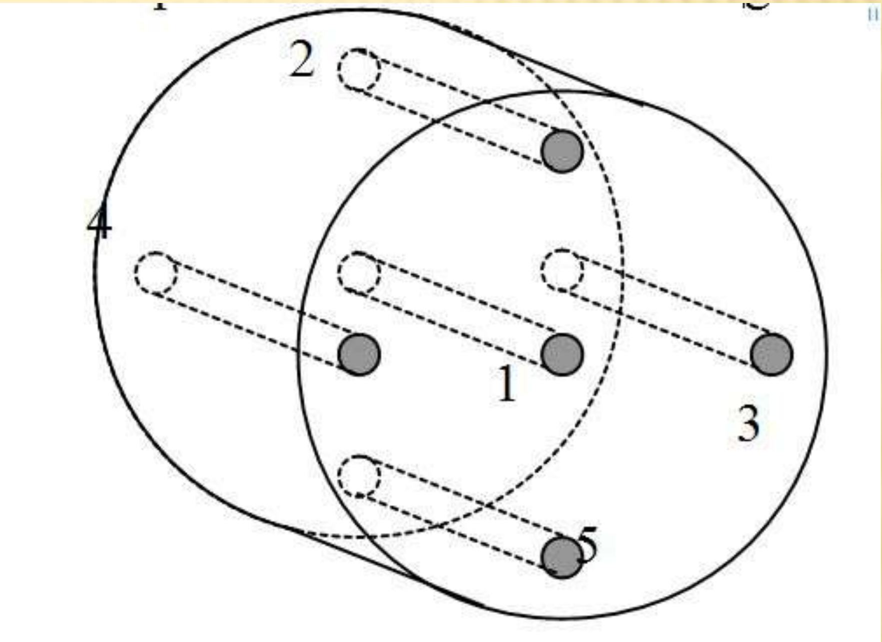
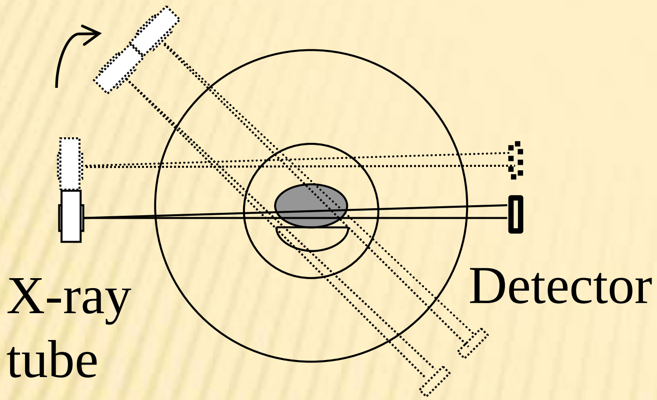
- CTDI is measured using 10 cm long ionization chamber
- Dose-length product (DLP) shows the radiation output over the entire procedure

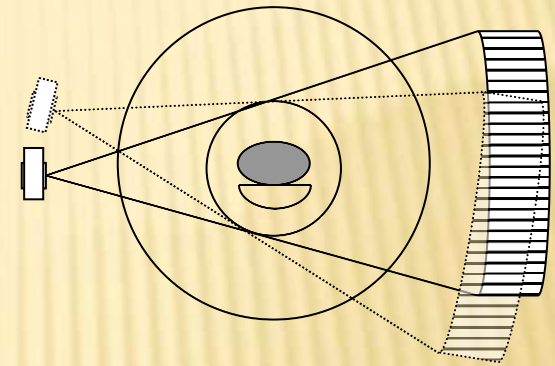


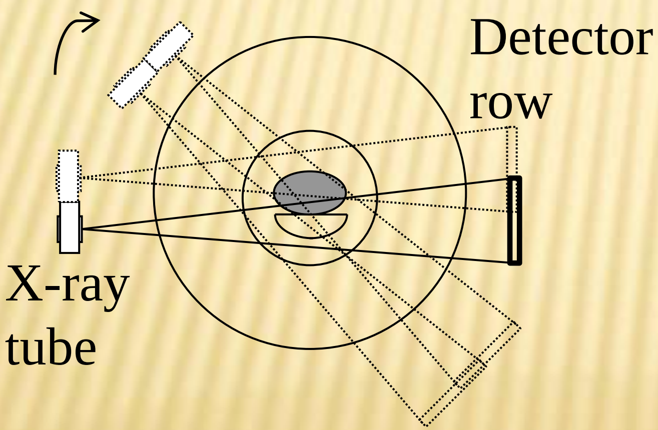
PMMA phantom for measurement of CTDI

RADIATION FIELD OF A CT SCANNER

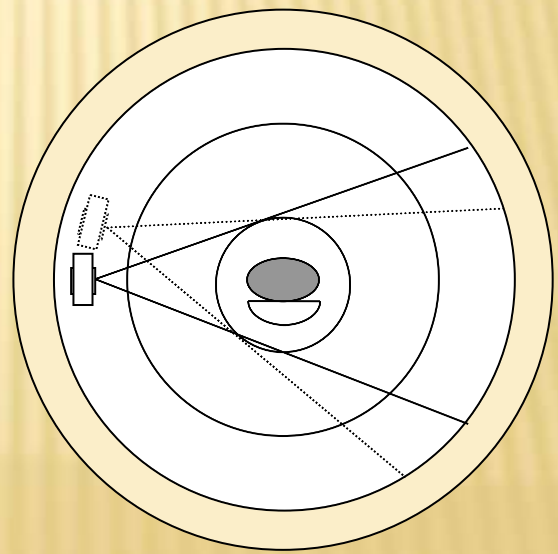


First generation CT


Third generation CT



Second generation CT

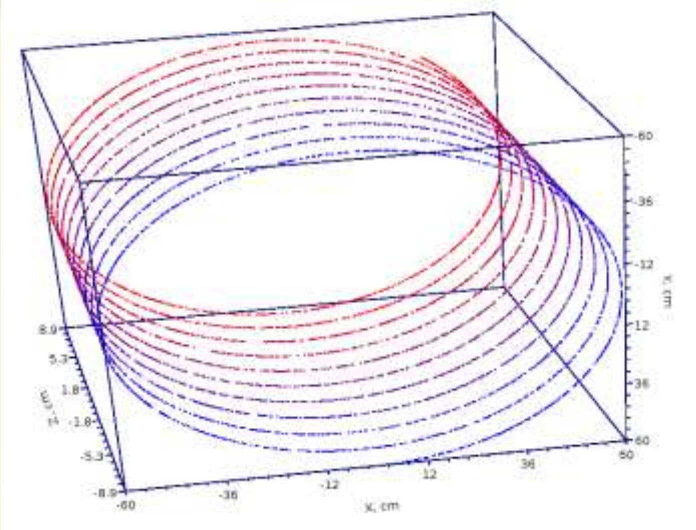

Fourth generation CT

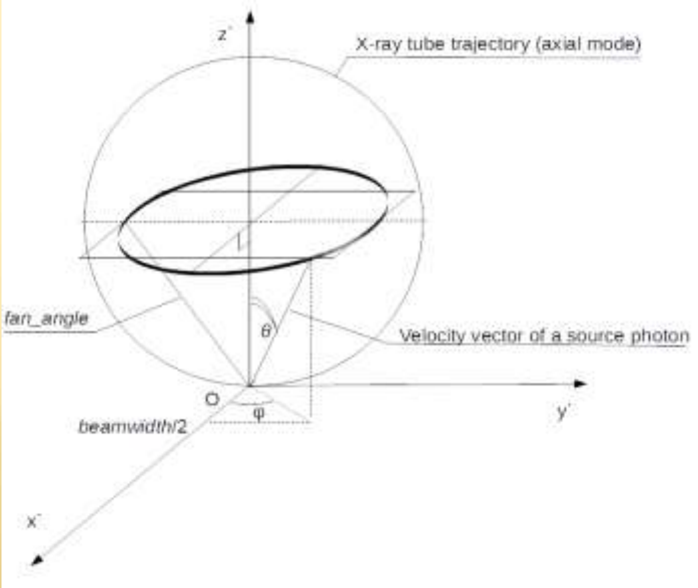
SIMULATION OF ROTATIONAL GEOMETRY

- Rotational geometry is rarely simulated using Monte-Carlo codes and requires either a series of time-intensive calculations or using of effective source.
- An approach to simulate the exposure of a patient during CT procedure proposed by M. Ghita in 2009 was used.
- A single Computed Tomography procedure is simulated for one Monte-Carlo run.
- An equivalent source was simulated.

MODEL OF DYNAMIC SOURCE OF CT SCANNER

- The starting points were distributed along the trajectory of the X-ray tube. Every starting point is sampled along the trajectory.
- Depending on the starting point the vector of photon propagation is calculated based on the fan angle and slice thickness.





MODEL OF THE RADIATION SOURCE

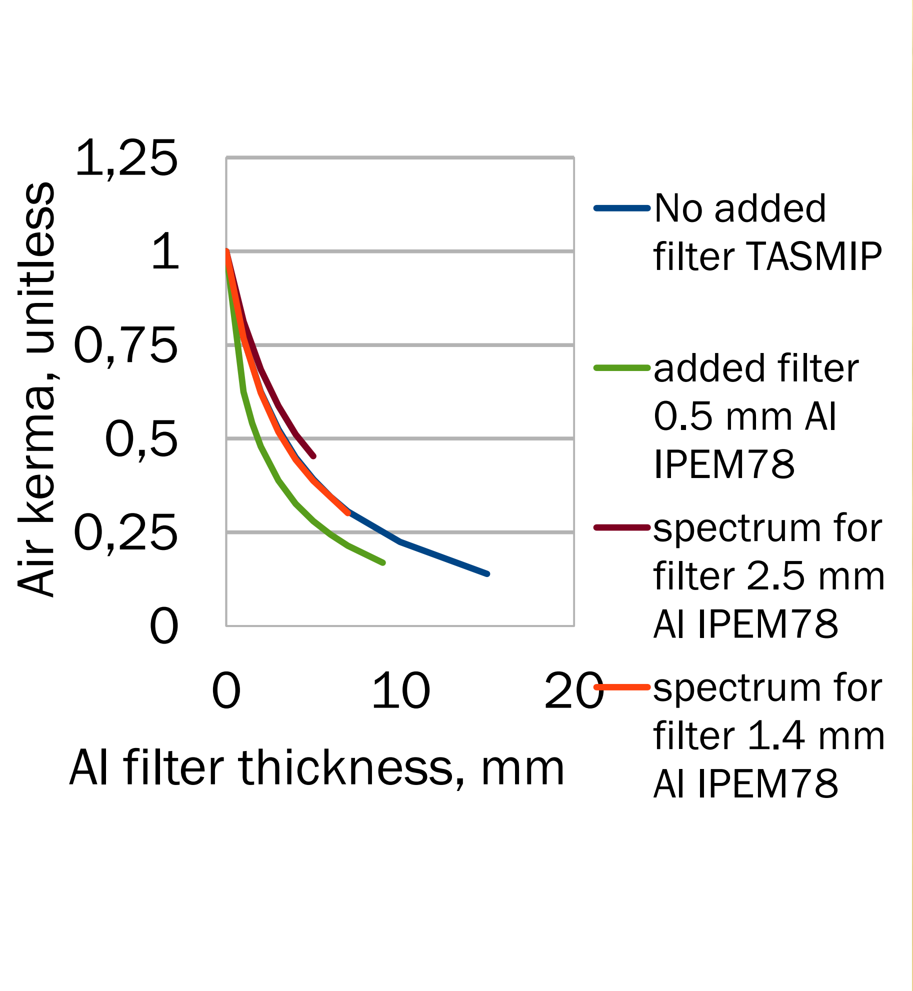
- The energy spectrum of the X-ray tube was taken from TASMIP semiempirical model.
- X-ray spectrum is determined by the following parameters

1. Anode material
2. Anode angle
3. High voltage
4. Equivalent thickness

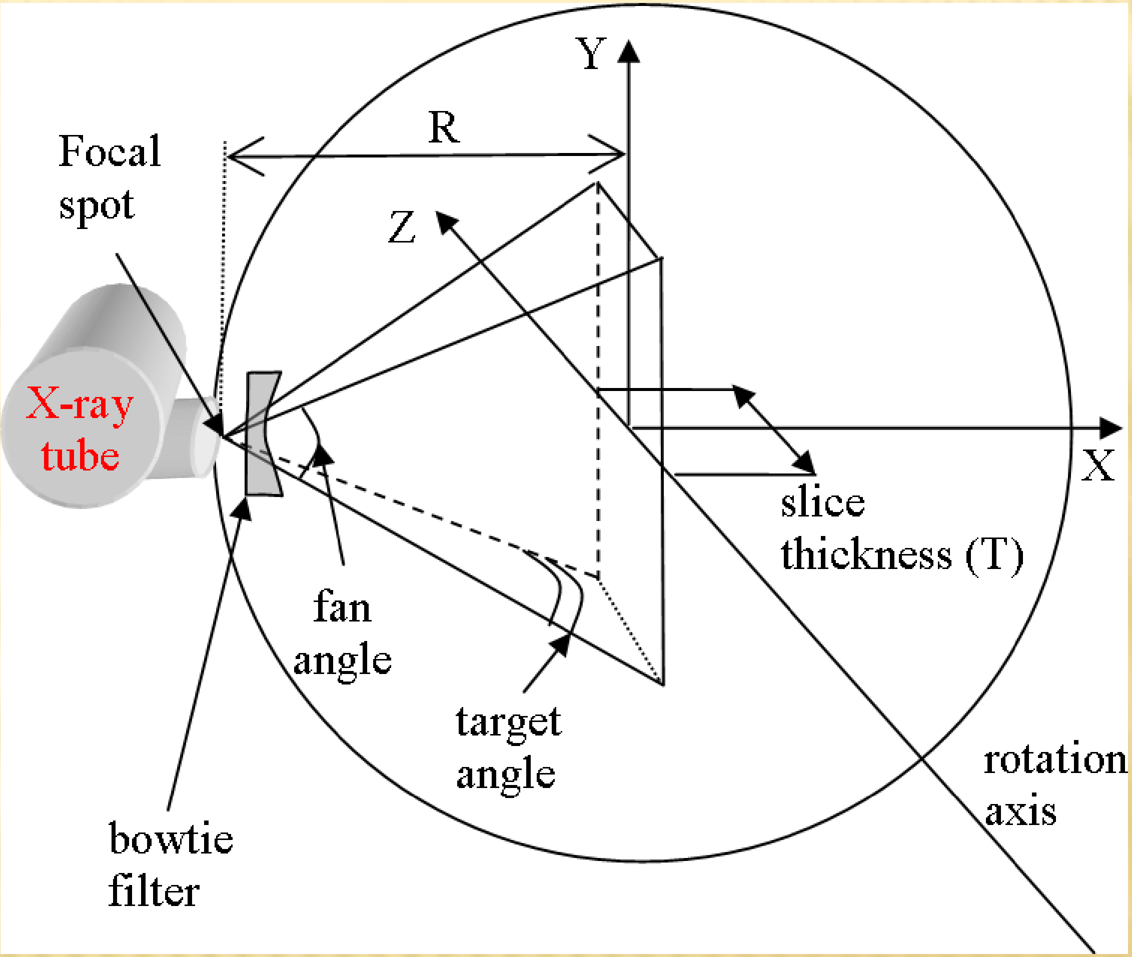
- Several models are available: IPEM78, XCOMP (R. Nowotny, 1985), TASMIP (Boone, 1997), SpekCalc (Poludniowski, 2007)

ATTENUATION PROFILE

- X-ray beams are characterized by half-value layer of aluminium (HVL1) and by beam quality (HVL2/HVL1)
- The models differ by the set of parameters.
- The comparison of the attenuation profiles seems to be a reasonable way to compare the models.

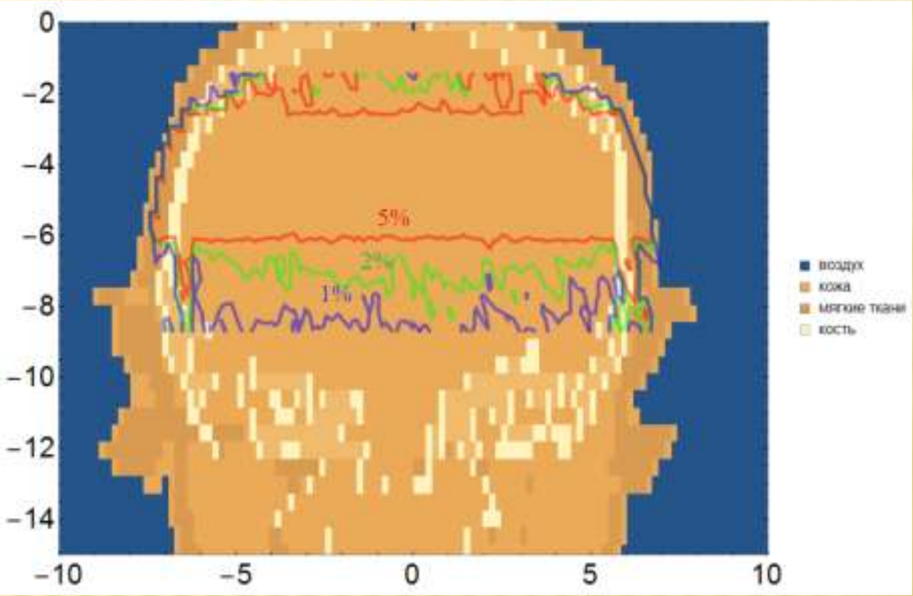


MAIN PARAMETERS OF THE BEAM



VOXEL PHANTOM

- ICRP reference voxel phantom of an adult female was taken as a model of the body of the patient. The phantom was cropped for reduction of calculation time. The effect of this crop was studied by analyzing the dose distribution in frontal and sagittal planes.

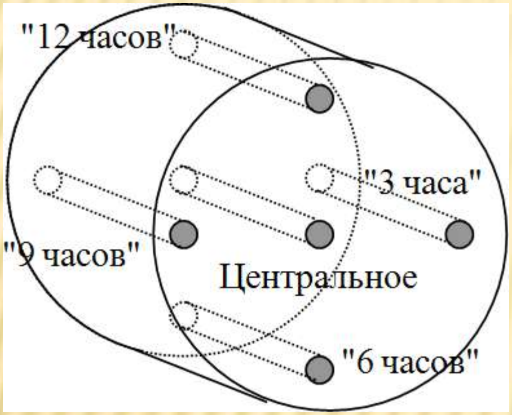


RESULTS

- We performed the simulation of patient exposure during the CT to get the conversion coefficients from CTDI to organ/tissue doses
- Two quantities were calculated for the determination of radiation dose: the organ/tissue dose itself and CTDI.

CTDI CALCULATION

the geometry corresponds to Toshiba Aquilion ONE CT scanner



Position	Air kerma, Gy/photon
Center	$3{,}07 \cdot 10^{-40}$
«3 hours»	$4{,}32 \cdot 10^{-40}$
«6 hours»	$3{,}88 \cdot 10^{-40}$
«9 hours»	$4{,}23 \cdot 10^{-40}$
«12 hours»	$4{,}50 \cdot 10^{-40}$
CTDI	$3{,}84 \cdot 10^{-40}$

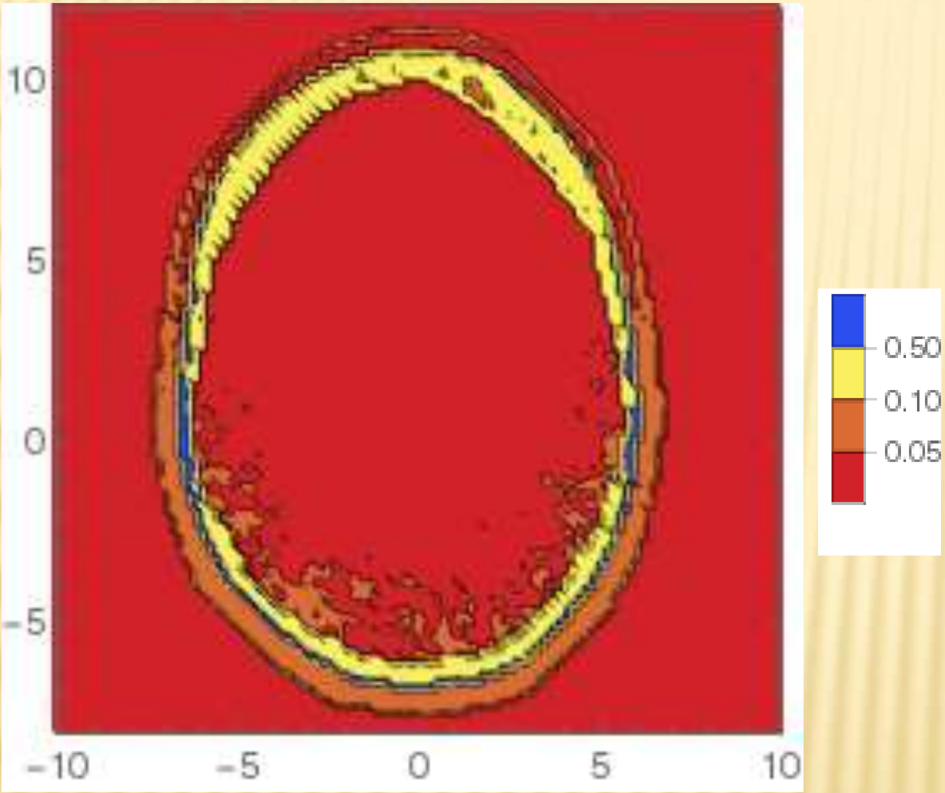
Monte Carlo errors are less than 1%

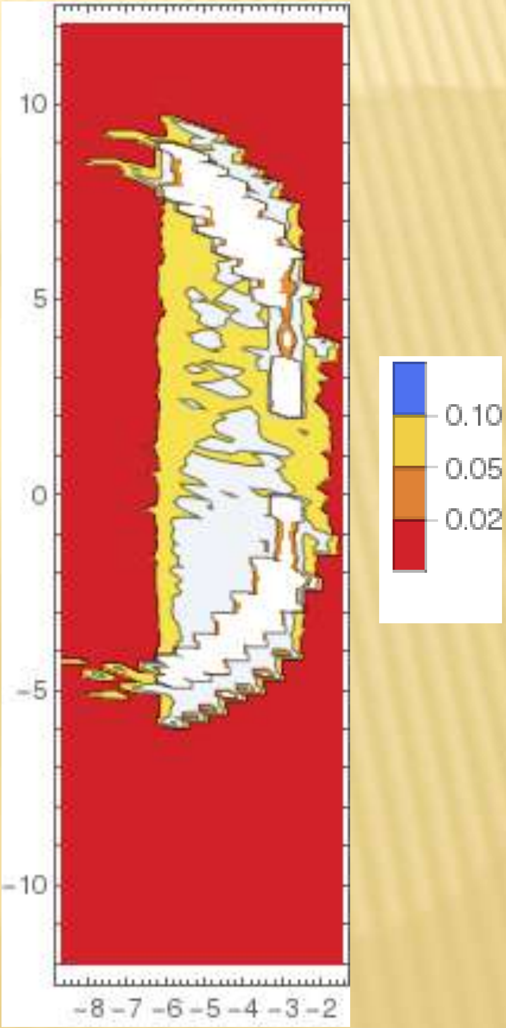
THE ORGAN AND TISSUE DOSES

Organ/tissue	Relative dose with bowtie filter, Sv/photon		Rel. diff. (S-M)/S
	Small-S	Medium-M	
Brain	$2{,}47 \cdot 10^{-40}$	$2{,}42 \cdot 10^{-40}$	2%
Skin	$9{,}74 \cdot 10^{-42}$	$9{,}64 \cdot 10^{-42}$	1%
Red bone marrow	$1{,}41 \cdot 10^{-40}$	$1{,}39 \cdot 10^{-40}$	2%
Muscle tissue	$3{,}09 \cdot 10^{-43}$	$3{,}05 \cdot 10^{-43}$	1%
Effective dose	$1{,}95 \cdot 10^{-41}$	$1{,}92 \cdot 10^{-41}$	2%

Organ/tissue	Conversion coefficient with bowtie filter, Sv/Gy		Rel. diff. (S-M)/S
	Small-S	Medium-M	
Brain	0,649	0,613	6%
Skin	$2{,}55 \cdot 10^{-2}$	$2{,}44 \cdot 10^{-2}$	5%
Red bone marrow	0,370	0,352	5%
Muscle tissue	$8{,}10 \cdot 10^{-4}$	$7{,}74 \cdot 10^{-4}$	5%
Effective dose	$5{,}12 \cdot 10^{-2}$	$4{,}87 \cdot 10^{-2}$	5%

RELATIVE DOSE DISTRIBUTIONS





CONCLUSIONS

- Neither Computed tomography dosimetric index nor effective dose can fully indicate the radiation effects on the patient during computed tomography.
- Scattered radiation is negligible in some part of the phantom, so that the phantom can be cropped for calculations.
- the bowtie filter have an effect on organ doses and effective dose of about 5%.

ACKNOWLEDGEMENTS

- The research was carried out with the financial support from the Belarusian Republican Fund Fundamental Research (grant F16M-037) and Republican Program of Scientific Research "Convergention-2020" (project 3.08).

THANK YOU FOR YOUR ATTENTION