An Update of “VirtualDose” Software Used for Assessing Patient Organ Doses from CT Examinations

Aiping Ding, X. George Xu

Rensselaer Polytechnic Institute

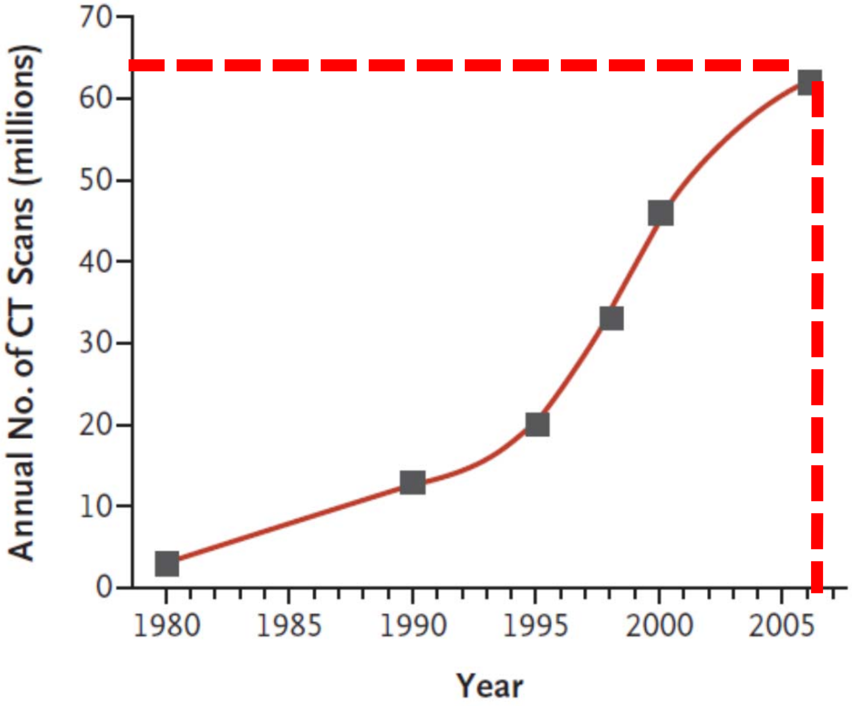
Troy, NY USA

http://RRMDG.rpi.edu

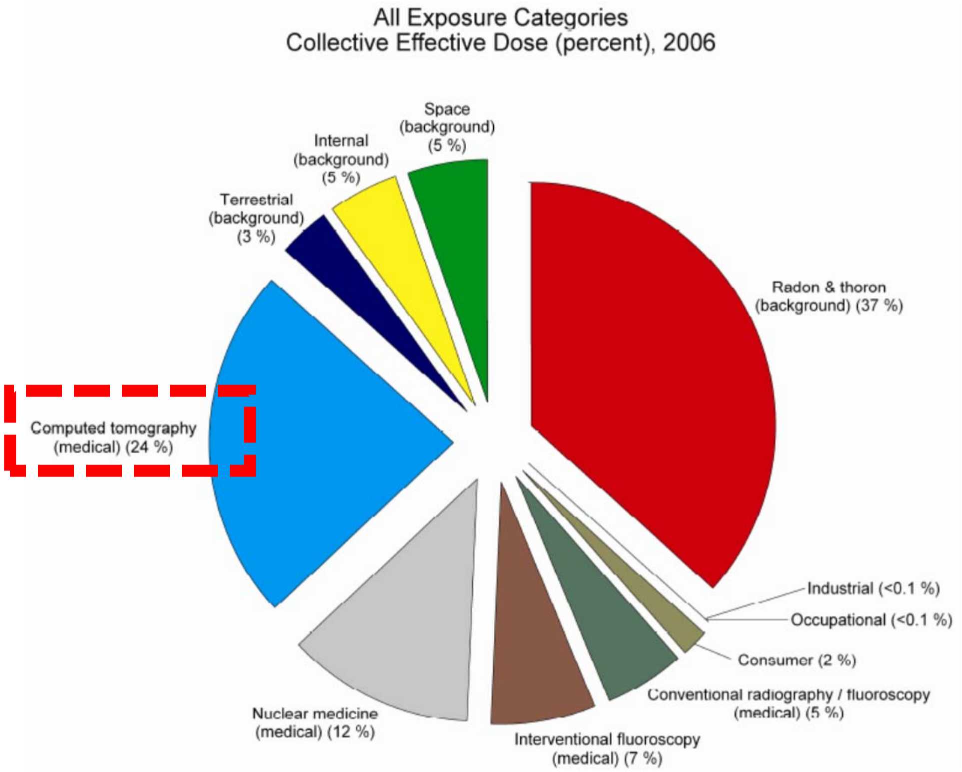
Acknowledgements

- NIH/NIBIB (1R42EB010404) and NIH/NLM (R01LM009362) funding supports
- Dr Bob Liu at Massachusetts General Hospital
- Dr Wesley Bolch and Mr. Danny Long at University of Florida

Concern About CT Dose at The Highest Level Today



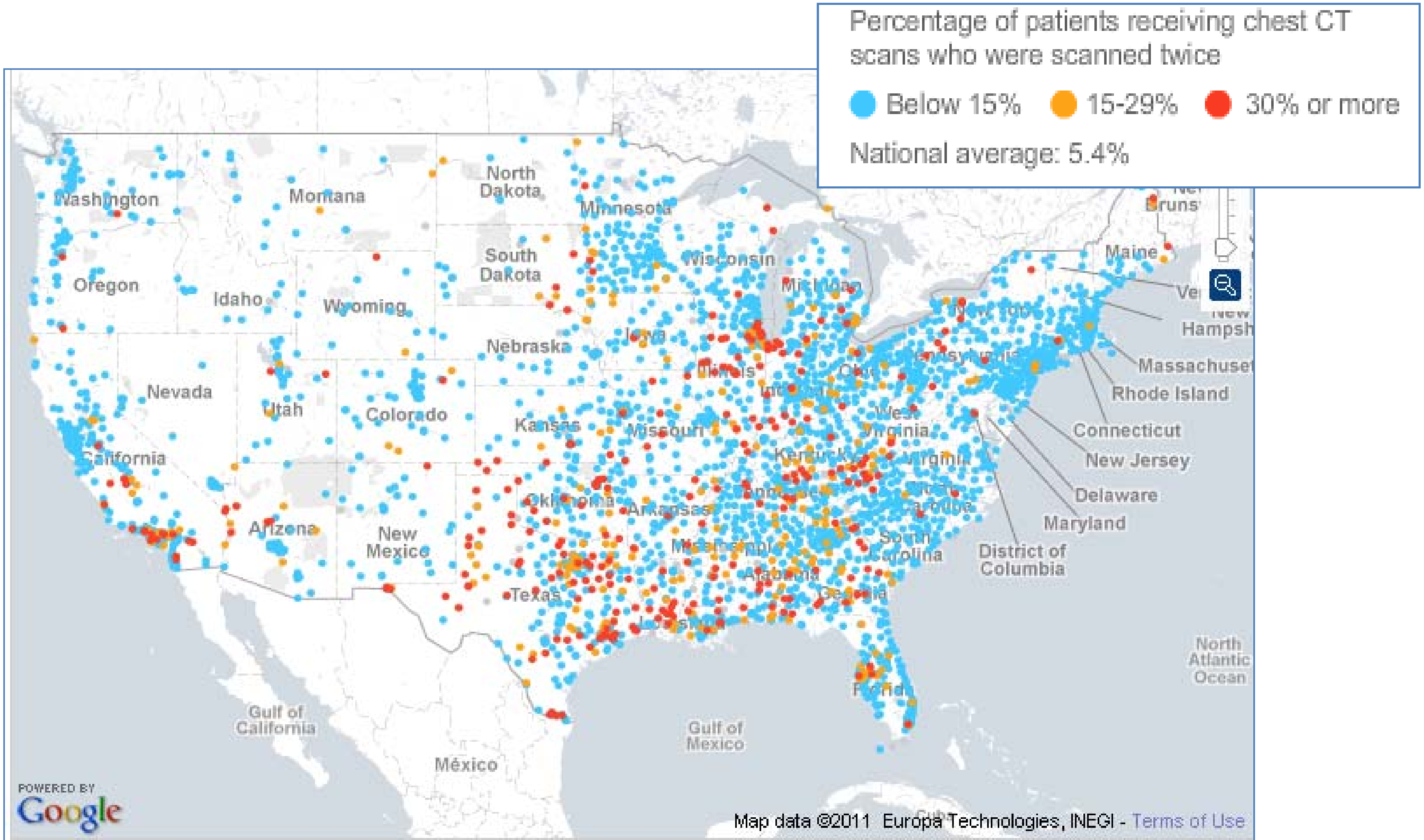
Brenner and Hall, N Engl J Med. 2007



NCRP. Report No. 160, Ionizing Radiation Exposure of the Population of the United States. 2008.

Overuse for CT Scanning

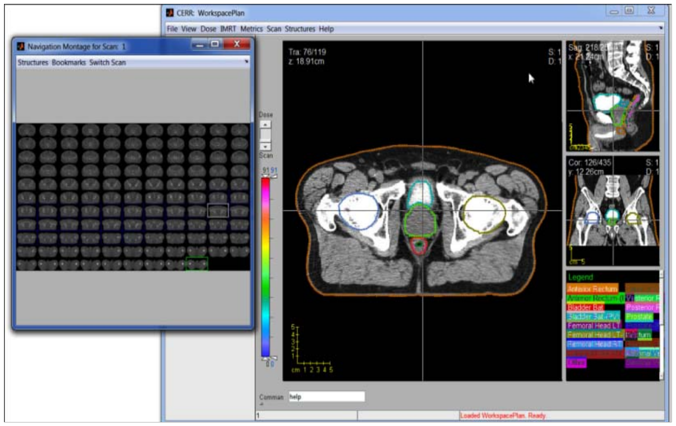
A single chest CT scan ≈ 350 standard chest X-rays

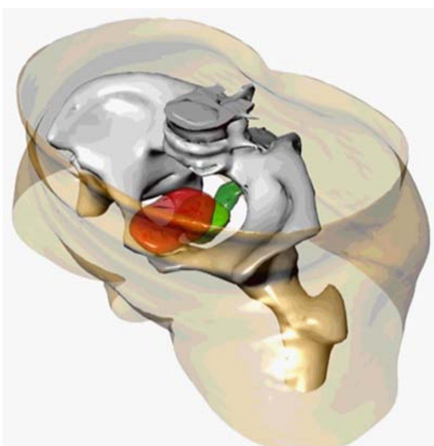


http://www.nytimes.com/2011/06/18/health/18radiation.html?pagewanted=all

CT Dose Not That Small

— 45 CT scans are used for Image-Guided Radiation Therapy (IGRT)





Organ	CT dose (Gy)
Rectum	0.8
Prostate	0.6
Bladder	0.8
Left Femoral Head	1.82

Imaging doses (a total of 45 scans) from MDCT at 250 mAs /scan

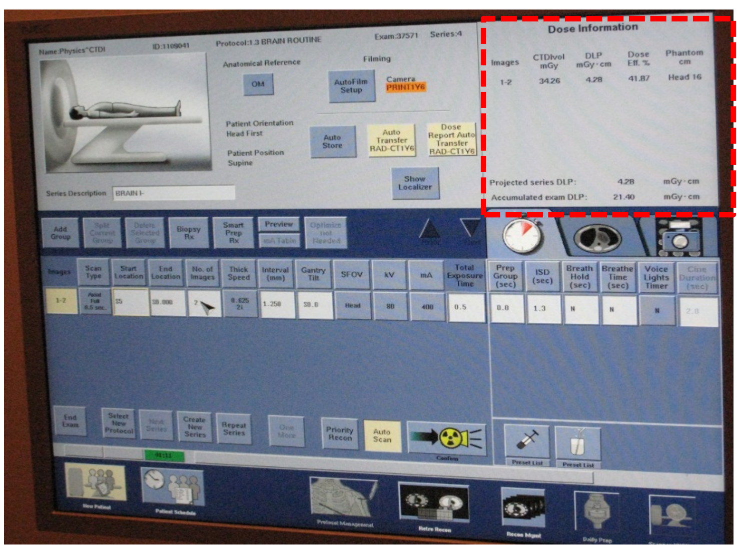
A P Ding , J W Gu, X G Xu, Trofimov AV. Monte Carlo calculation of imaging doses from diagnostic multi-detector CT and kilovoltage cone beam CT as part of prostate cancer treatment plans. Med Phys. 37(12): 6199-6204, 2010

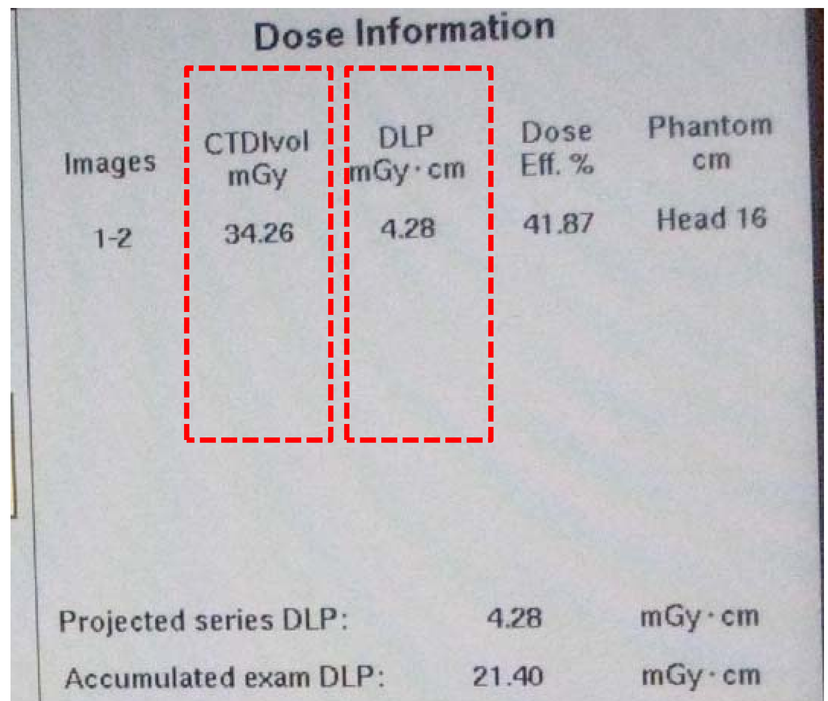
General Methodologies for CT Dose Estimation

- Using CTDI and DLP
- Physical Measurements Using Physical Phantoms
- Using Patient Models and Monte Carlo Simulations

Dosimetry Metrics on Current Commercial CT Scanners

- CT dose index (CTDI) and Dose Length Product (DLP)
- Patient gender/size specific dose information not available





CTDI/DLP and Patient Dose – Not the Same Thing

- CTDI and DLP:
  - Standardized measures of the radiation output of a CT system
  - ***Not*** patient dose
  - No organ doses available
- It's better to use patient phantoms

Ways of Determining CT Organ Doses

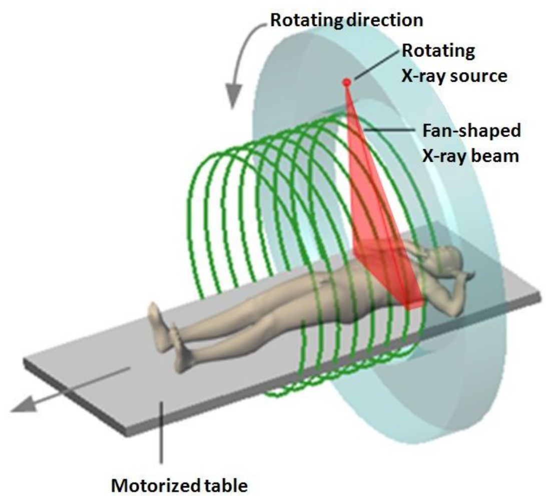
Physical measurement

- ✓ Dosimeter
- ✓ Physical phantom of patient
- ✓ CT modality

CT dose measurement

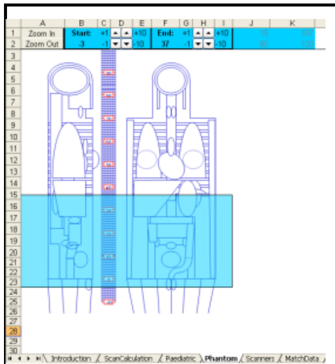
Computational simulation

- ✓ Simulation tool (Monte Carlo)
- ✓ Computational model
- ✓ CT scanner model



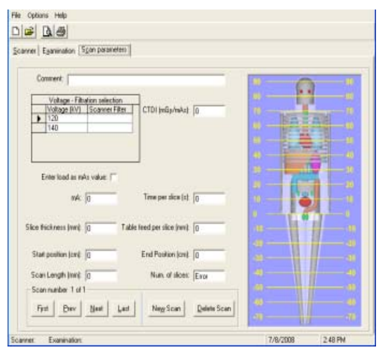
CT dose simulation

Existing Software Packages Do not Meet the Needs



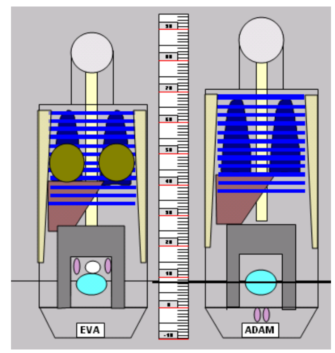
ImPACT

1



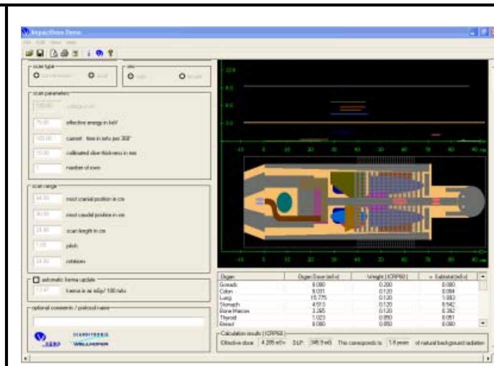
CT Dose

2



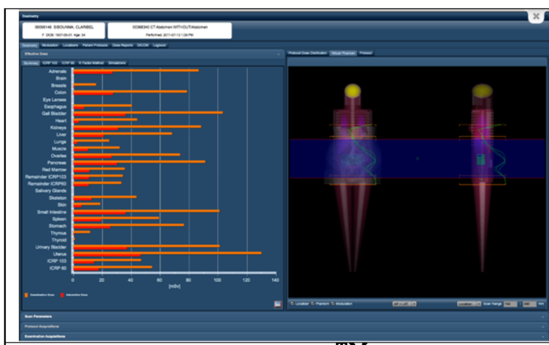
CT-Expo

3



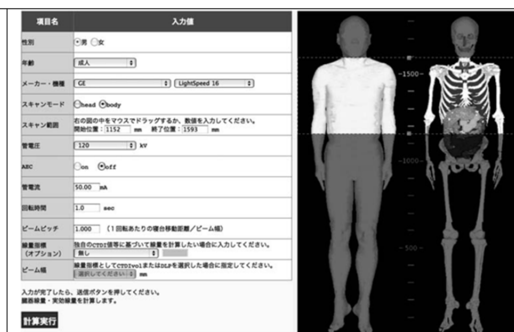
ImpactDose

4



eXposure™

5



WAZA-ARI

6

Rensselaer
why not change the world?℠

Motivation

- Increasing CT exposure becomes a national problem
- Accurate dosimetry tool needed
- Existing software outdated and crude
- CT dose-reporting mandatory (e. g., California)
- FDA public hearing recently on CT dose
- Our "virtual patient" technology, Monte Carlo modeling, and software engineering bring many opportunities

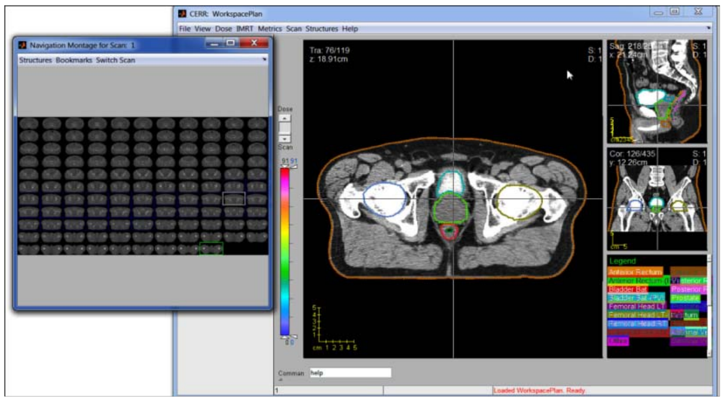
Methods: To Calculate Organ Doses from CT Exams

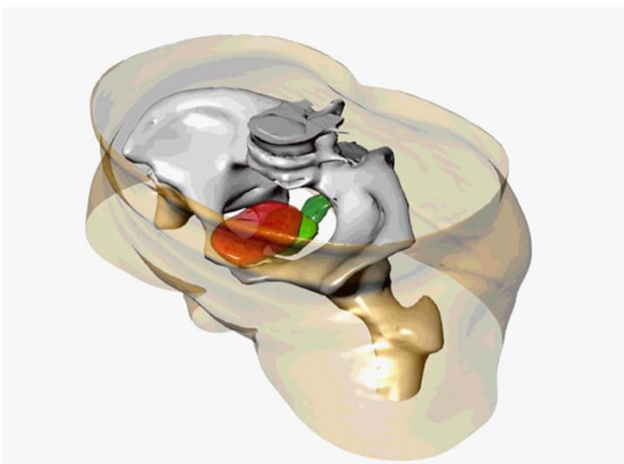
- Model patients or parts of patients
- Model CT scanner in detail
- Monte Carlo Methods/codes
- Simulate CT scans
- Calculate organ doses

Rensselaer

Partial and Whole-Body Computational Patient Phantoms

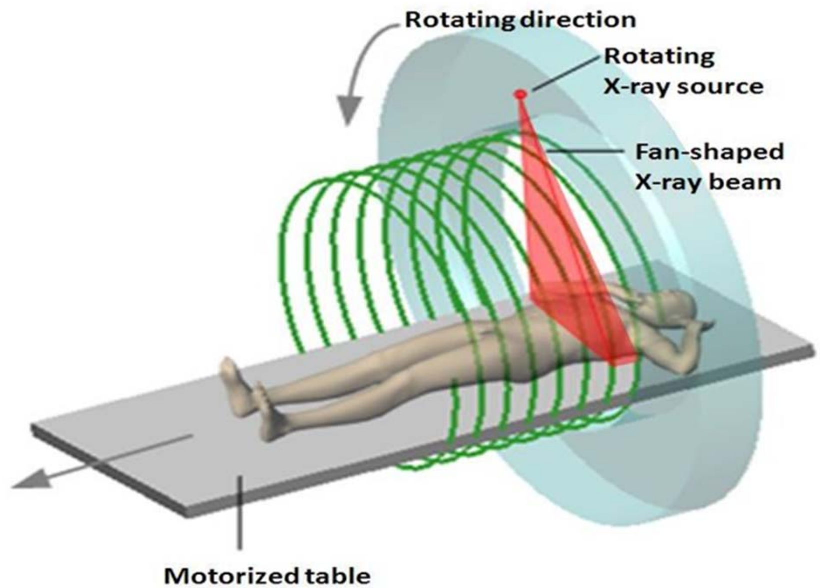
Partial patient model created from CT images





In-field organ doses *only*

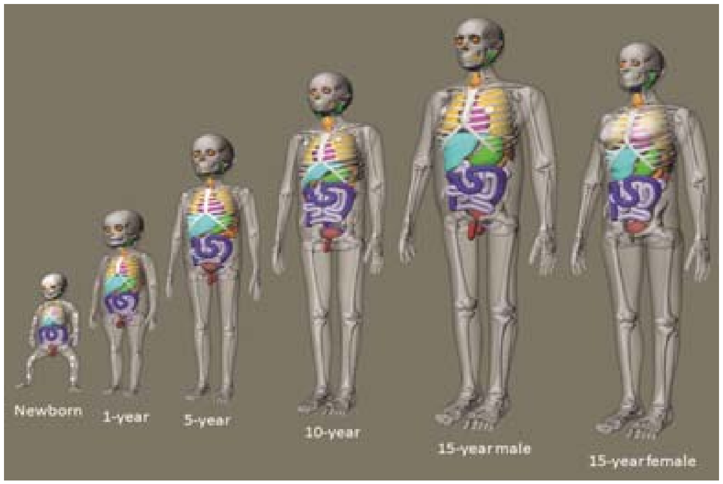
Whole-body patient phantoms



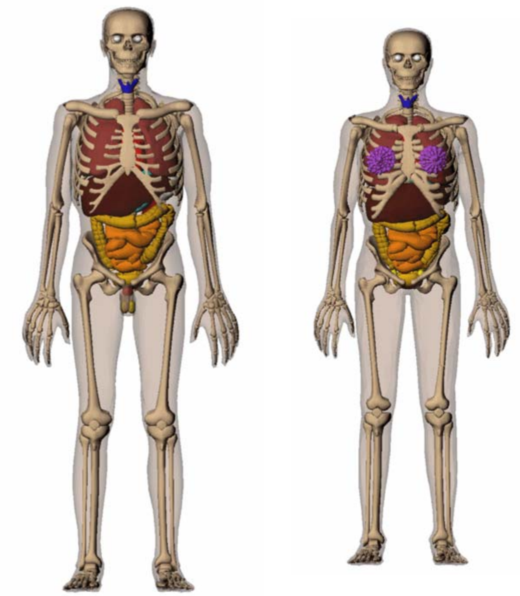
- **In-field organ doses**
- **Out-of-field organ doses**
- **Partial organ doses**
- **Averaged organ doses**

Methods: Virtual Patients

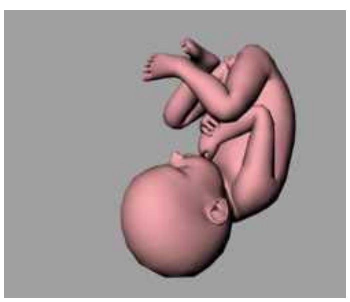
—Average Population

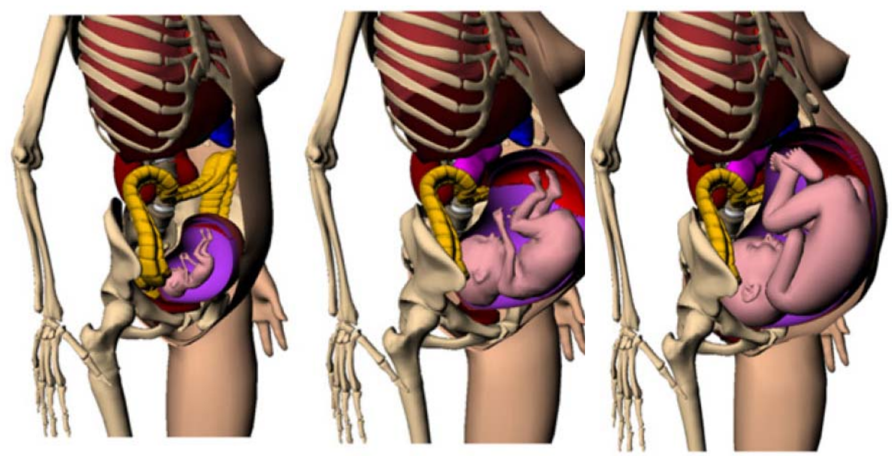


UF pediatric phantoms
- Lee (2010) (Lee, et al., Phys. Med. Biol, 2010)



RPI adult male and female phantoms
- Zhang (2009) (Zhang, et al., Phys. Med. Biol, 2009)

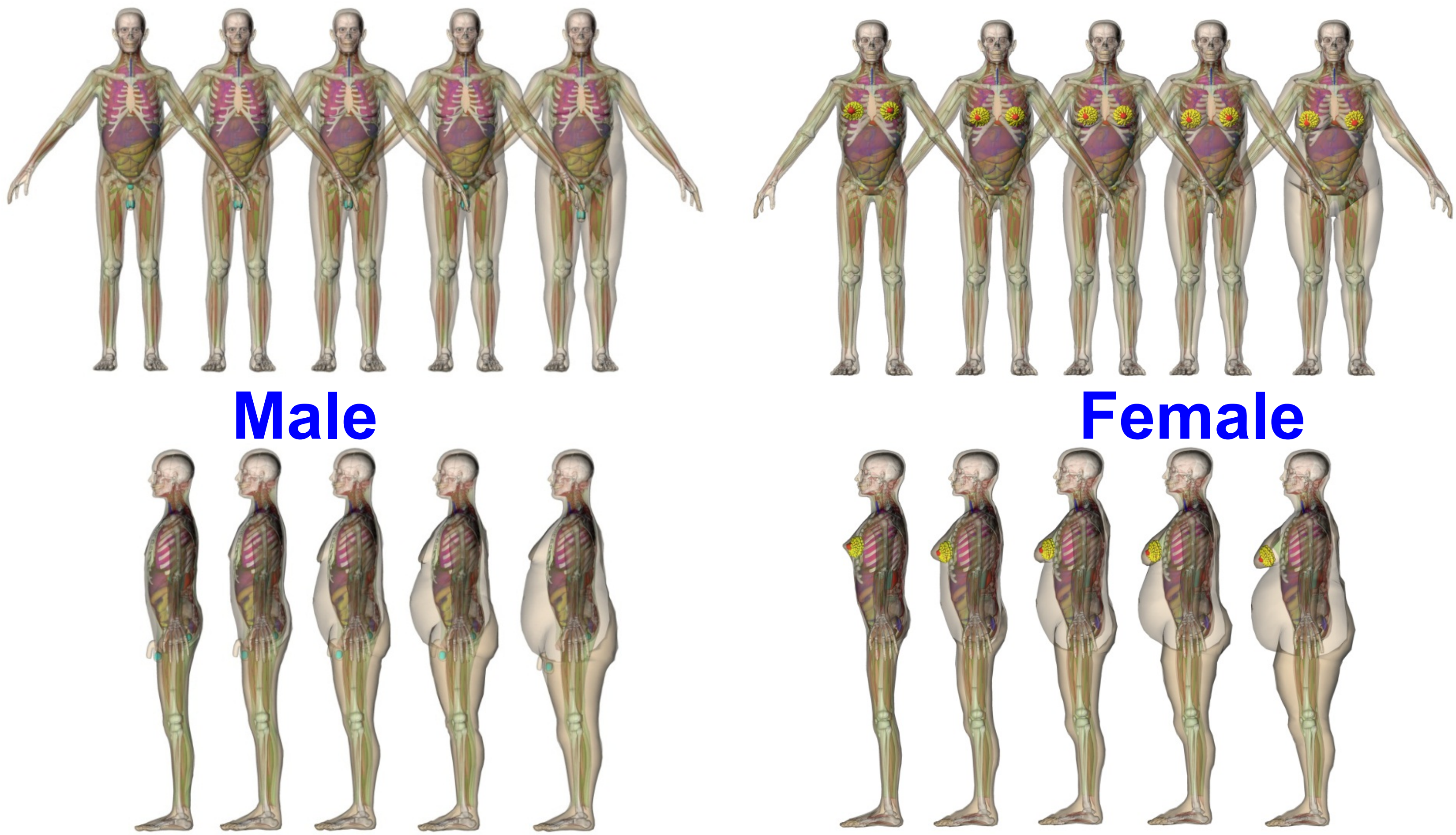




RPI P3, P6 and P9 phantoms with gestation of 3, 6 and 9 months, respectively
- Xu (2007) (Xu, et al., Phys. Med. Biol, 2007)

A New Set of Obese Phantoms

Ding A, Mille M, Liu T, Caracappa PF, Xu XG. Extension of RPI-adult male and female computational phantoms to obese patients and a Monte Carlo study of the effect on CT imaging dose. Phys. Med. Biol. 57(9): 2441-2459, 2012 (*FEATURE ARTICLE*).

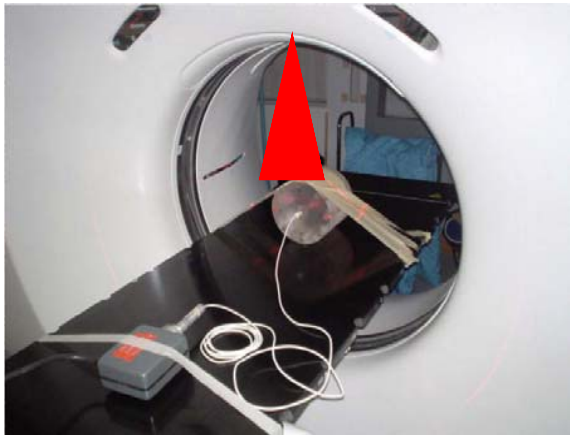


Normal Weight **OverWight** **Obese I** **Obese II** **Morbidly Obese**

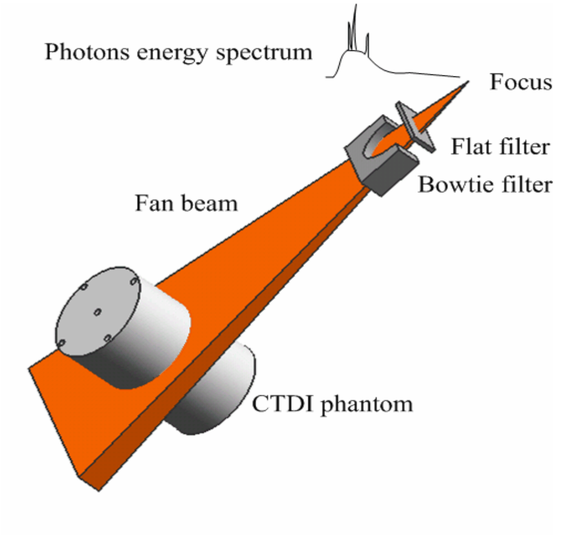
Methods: CT Scanner Modeling

- Detailed GE LightSpeed Pro 16 MDCT x-ray source and scan protocols modeled in MC codes
- Tube kVp, mAs, pitch, and collimation
- "Adjustment Factor" used for different scanners

  (Caracappa et.al, AAPM 2010)
- TCM protocols included



CT setup with CTDI phantom



(Gu et.al, Phys. Med. Biol. 2009)

Methods: Monte Carlo code

MCNPX (version 2.6.0)

- Monte Carlo N-Particle Extended (MCNPX) code
- "Repeated structures" format used for patient phantoms description
- "Cookie-cutter" function used for defining fan beam
- F6 tally card to score deposited energy

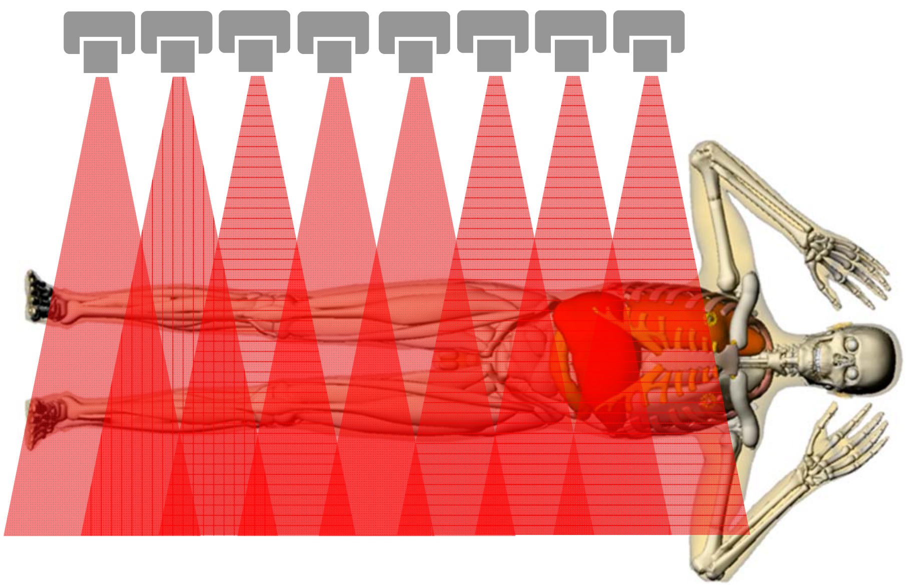
Methods: A Comprehensive Slice-by-slice Organ Dose Database

- **Axial scan simulations in MCNPX**
- **Contiguous scans from the top to the bottom of 27 phantoms**
- CT technical parameters

  -4 different tube voltages: 80, 100, 120, and 140 kVp

  -4 different beam collimations: 1.25 mm, 5 mm , 10 mm and 20 mm

  -Using both the head and body bowtie filters



Rensselaer
why not change the world?℠

Methods: Effective Dose Calculations

- Effective Dose takes into account
  - Absorbed Dose to specific organs
  - Radio-sensitivity of each organ
  - ICRP-103 and ICRP-60

$$E = \sum_{T} w_T H_T = \sum_{T} w_T \sum_{R} w_R D_{T,R}$$

w_T= tissue weighting factor
w_R= radiation weighting coefficient (1 for photons)
$D_{T,R}$= average absorbed dose to tissue T

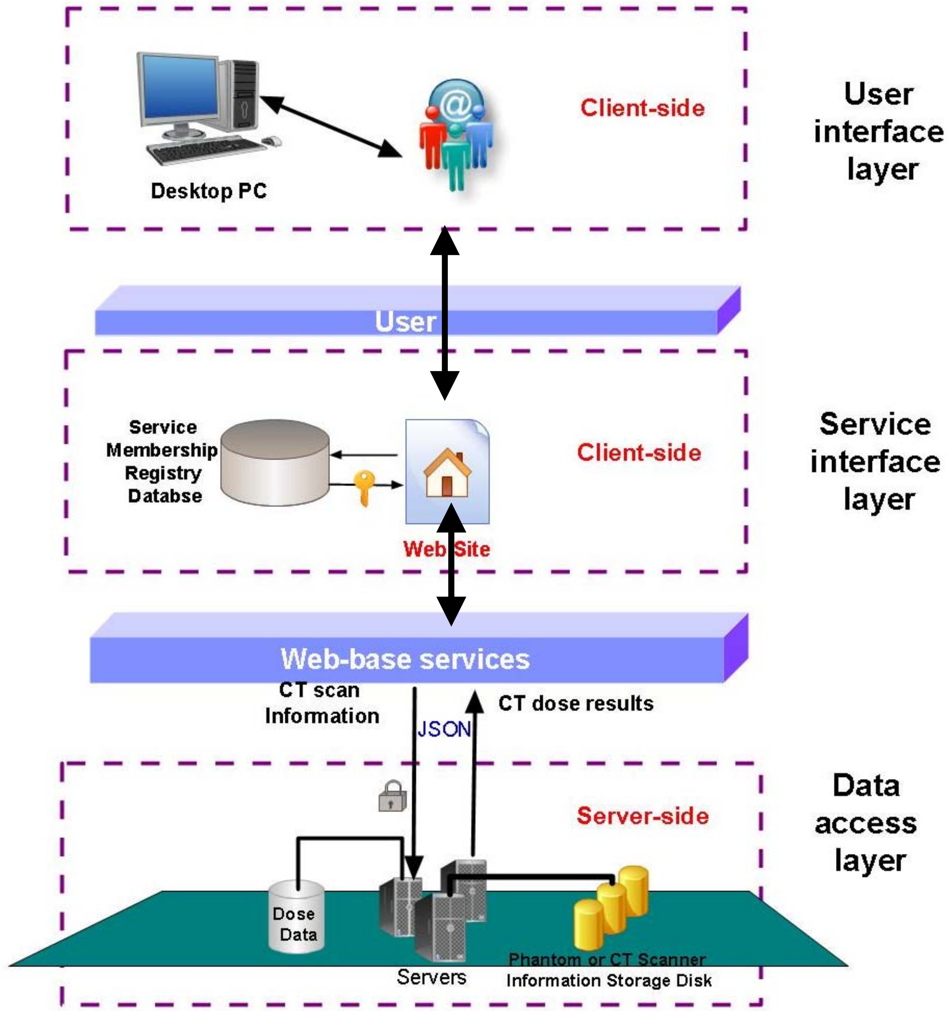
Rensselaer
why not change the world?℠

Methods: Software as a Service (SaaS)

- Web-based software as a service
- Not require setup CDs
- No needs for downloads, client-side configuration
- No other tedious deployment steps
- Suitable to develop a cross-platform application

Methods: Service-Orientated Architecture (SOA)

- A new software design architecture
- Essentially a collection of functions
- Flexible to manage
- Easy to upgrade /update frequently
- JSON (JavaScript Object Notation) interpret and response user request



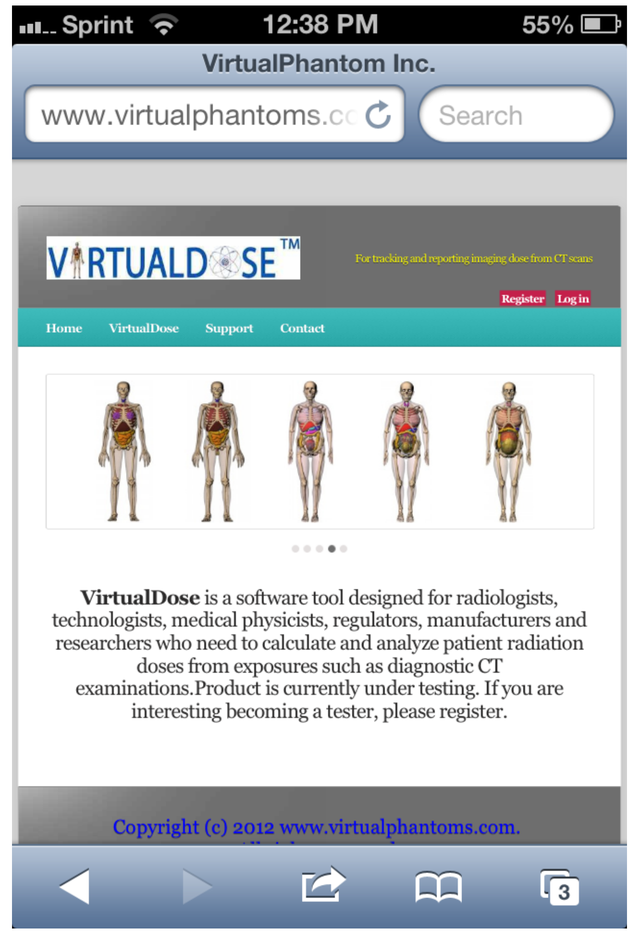
Methods: Programming Languages and Tools

- **Microsoft .NET Framework**
- **Programming Languages**
  - HTML (Hypertext Markup Language)
  - JavaScript
  - JQuery
  - C#
- **Microsoft Visual Studio 2010**
- **Microsoft SQL Server 2008**

Results: VirtuaDose^{TM} Graphical User Interface

Computer

Smartphone

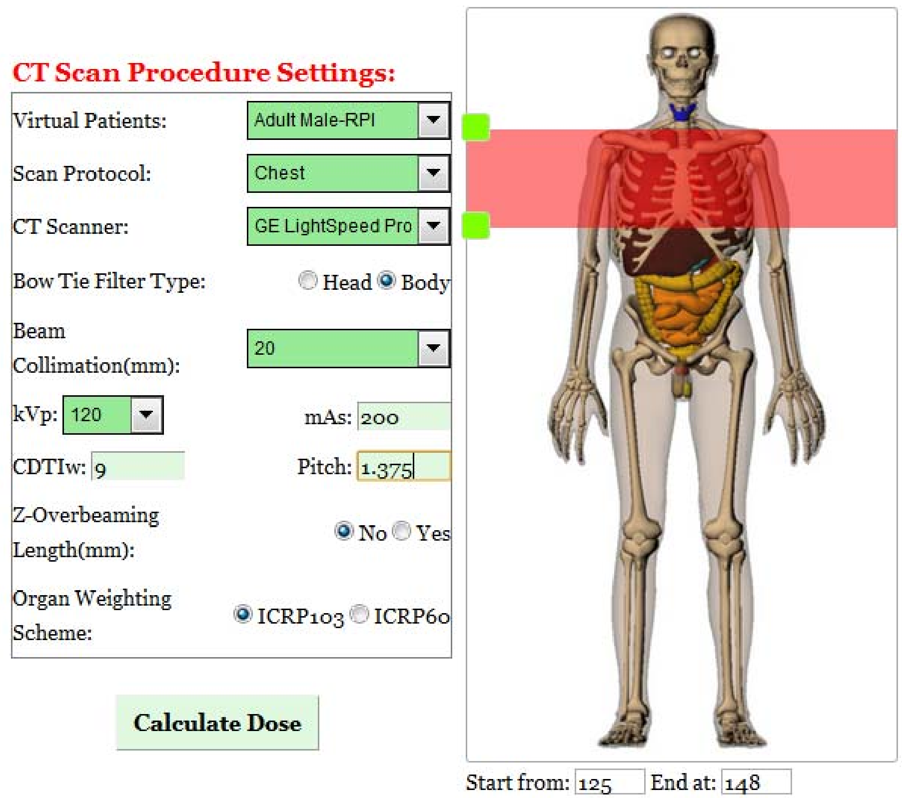


http://www.virtualphantoms.com

Results: VirtualDose^{TM} Interactive Graphical User Interface

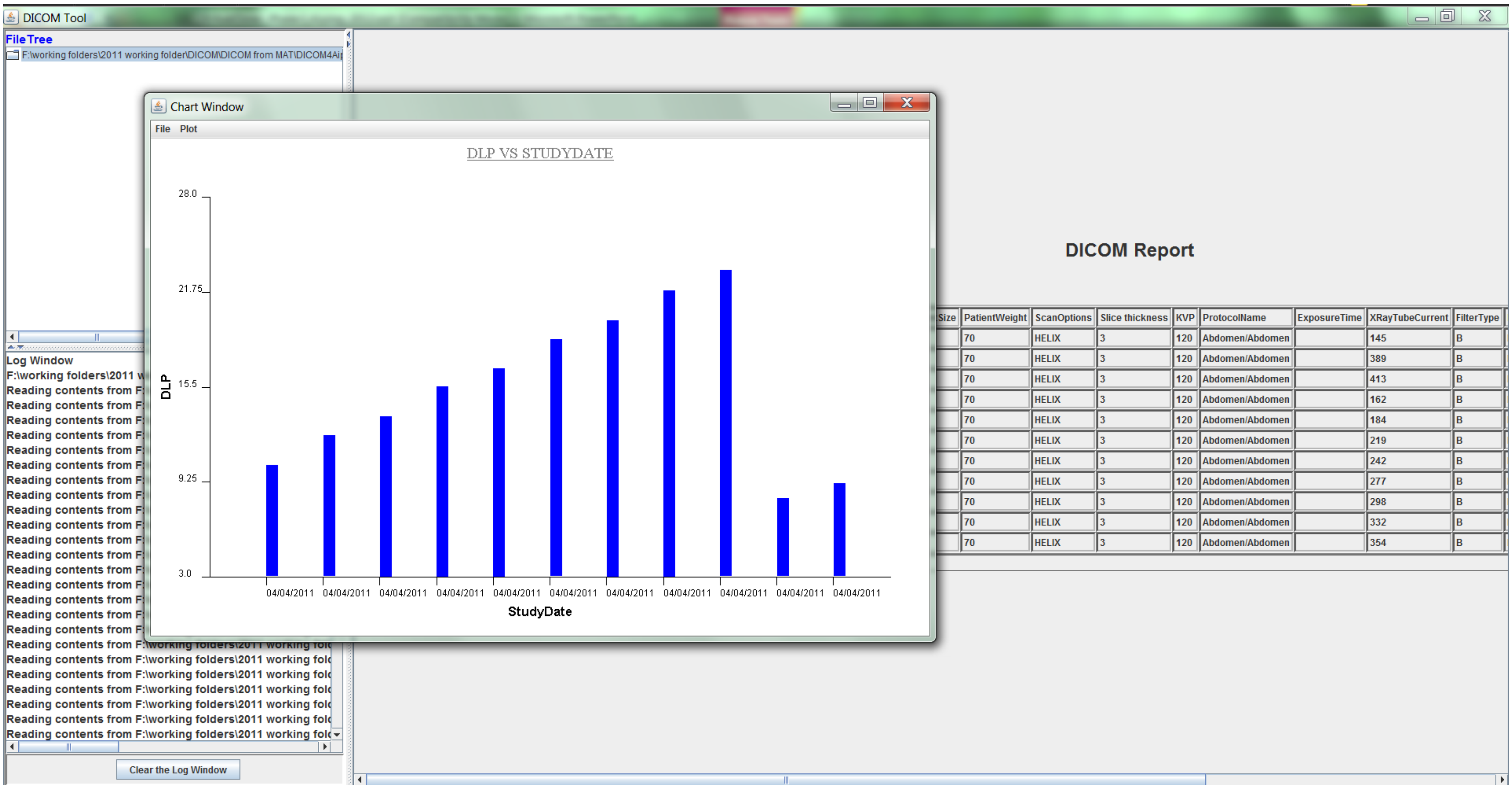
User input parameters

- Patient Phantom type
- Standard scan protocols from a drop-down Combo box
- Type of scanner
- BTF type
- Collimation for the scanner
- Z-overscanning
- kVp for the scanner
- mAs
- Pitch
- CTDI$_w$



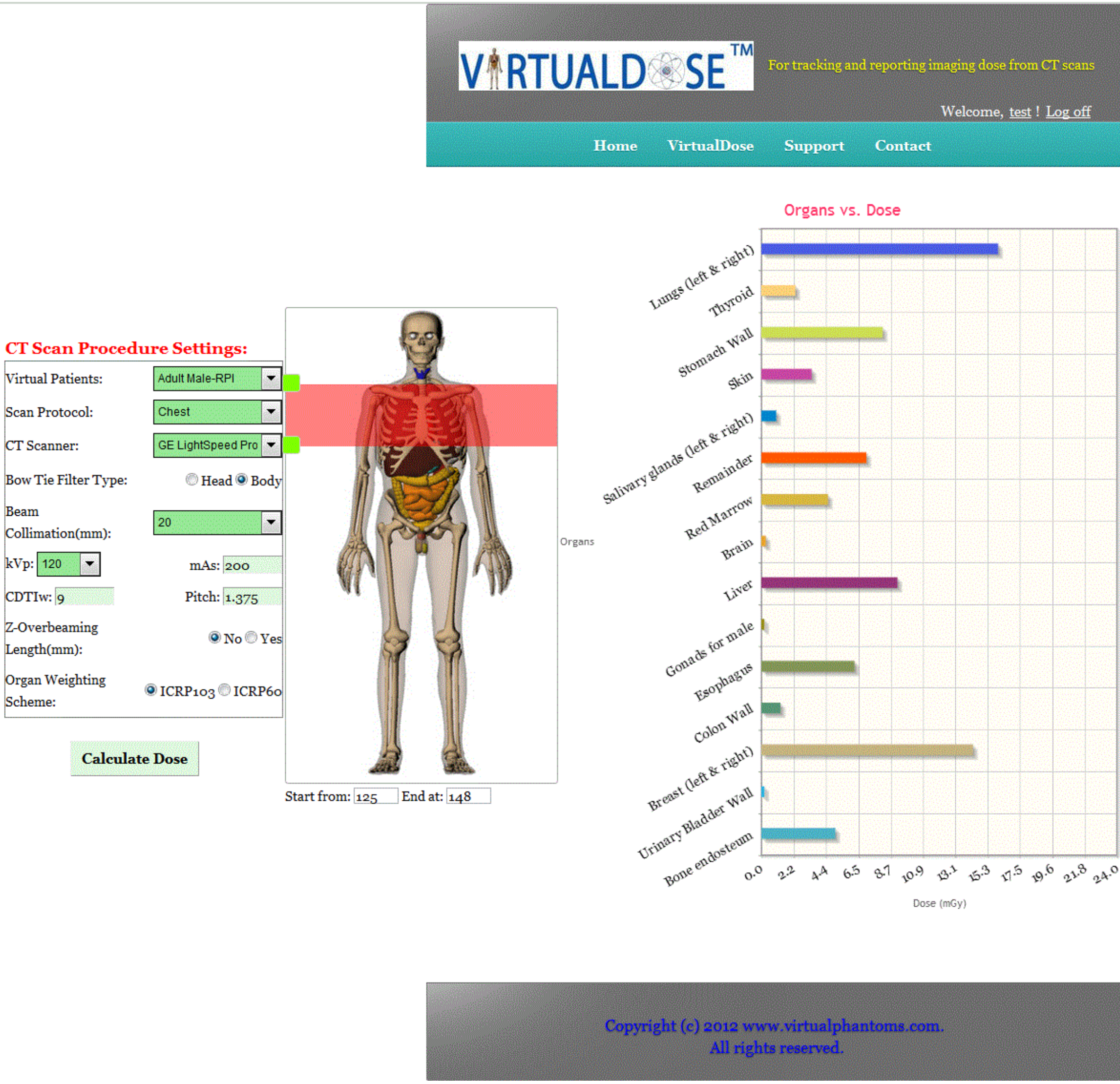
Results: DICOM Processing Capability in VirtualDose^{TM}

Retrieve scan information in DICOM locally for patient CT dose reporting



![Rensselaer — why not change the world?]

Results: VirtualDose^{TM} Rapid Archiving and Reporting Features



Organ Dose	
Organs/Tissues Name	**Doses (mGy)**
Bone endosteum	5.0
Brain	0.3
Breast (left & right)	14.3
Colon Wall	1.3
Esophagus	6.3
Gonads for male	0.2
Liver	9.2
Lungs (left & right)	16.0
Red Marrow	4.5
Remainder	7.1
Salivary glands (left & right)	1.0
Skin	3.4
Stomach Wall	8.2
Thyroid	2.3
Urinary Bladder Wall	0.2
Total Effective Dose (mSv): 7.0	

New $2.6 Million Grant from NIBIB to support GPU-based Monte Carlo Code Development

- **Fast MC calculation speed**
- **Real-time CT dose calculation**
- **Less than 10 seconds**

http://news.rpi.edu/update.do?artcenterkey=3083

Conclusions

- Existing software fail to meet current and future needs for accurate and state-of-the-art CT dose reporting
- Our work shows several improvements
  - Anatomically realistic children, adult, pregnant female, and obese patients
  - Accurate CT source modeling
  - DICOM process capability
  - User-friendly GUI design
  - Web-based service
- Clinical testing undergoing at MGH

VIRTUALDOSE™

http://www.virtualphantoms.com