National Cancer Institute

U.S. DEPARTMENT OF HEALTH AND HUMAN SERVICES
National Institutes of Health

Digital Phantoms for Developing Protocols in Particle Therapy

AAPM 2015

Anaheim, CA

Choonsik Lee

History

Evolution of Computational Human Phantoms

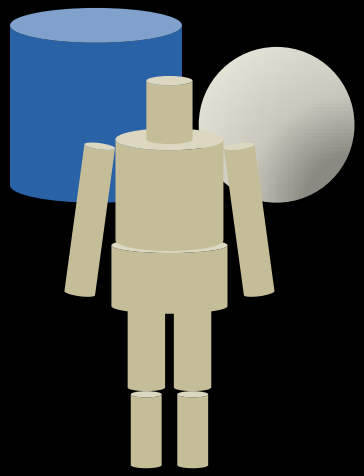
More accurate anatomy

1950s
Simple phantoms

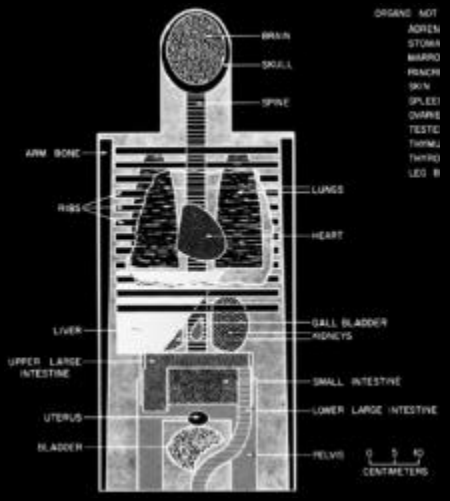
1960s
Stylized phantoms

1980s
Voxel phantoms

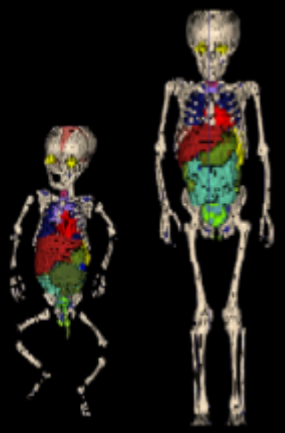
2000s
Hybrid phantoms



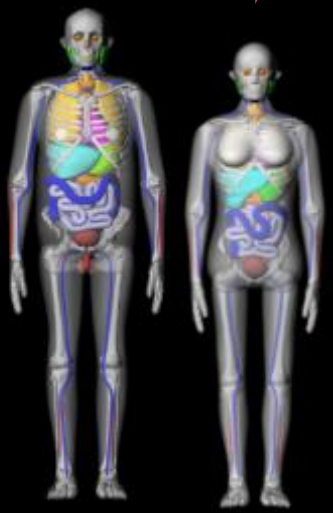
BOMAB phantom



ORNL adult phantom

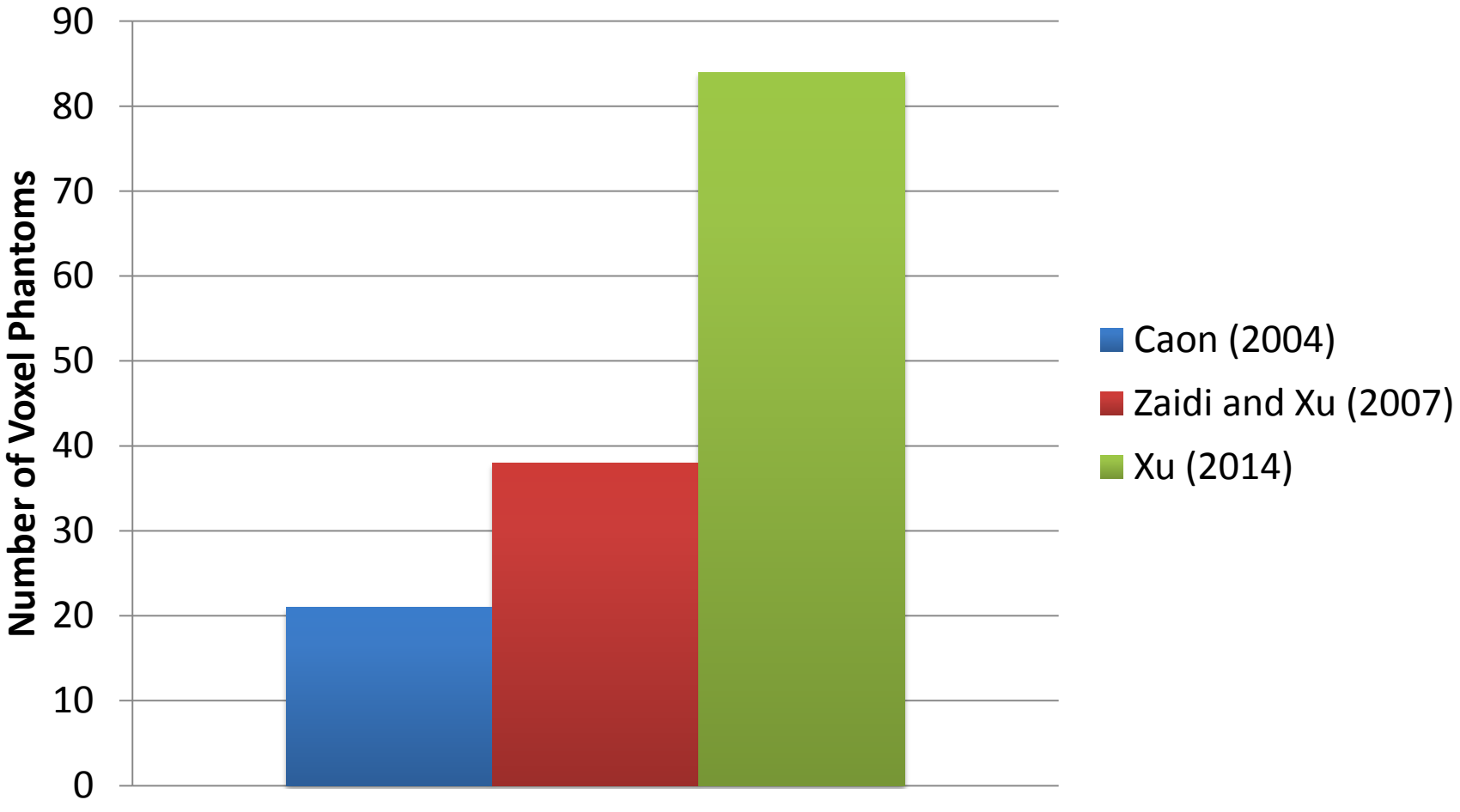


GSF BABY and CHILD
voxel phantoms



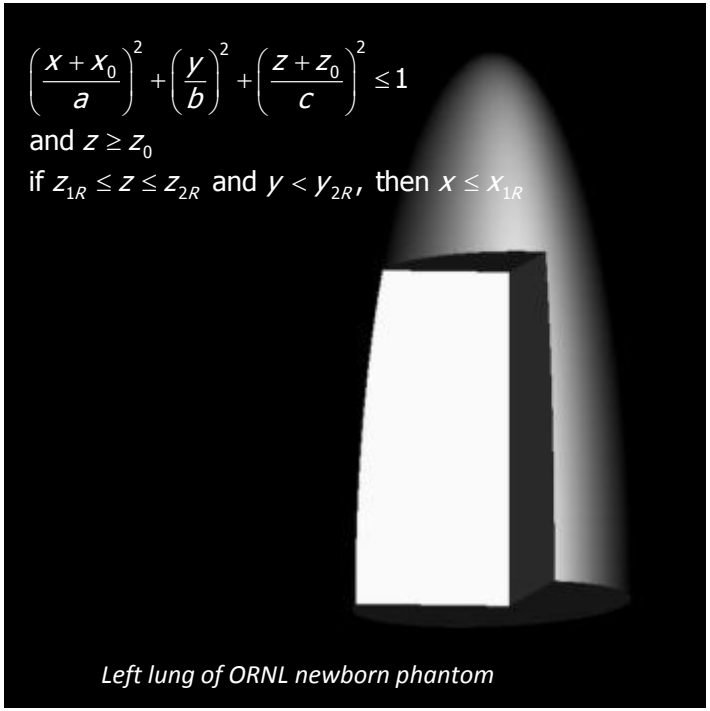
UF/NCI
Hybrid phantoms

Status of Voxel Phantom Development

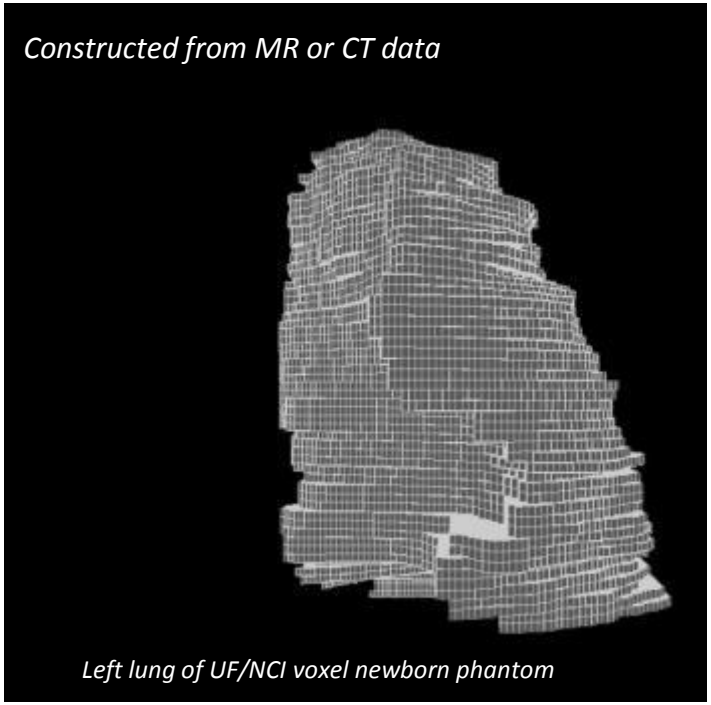


Current Trends

First vs. Second generation phantoms



Stylized (mathematical) phantom
Since 1960s

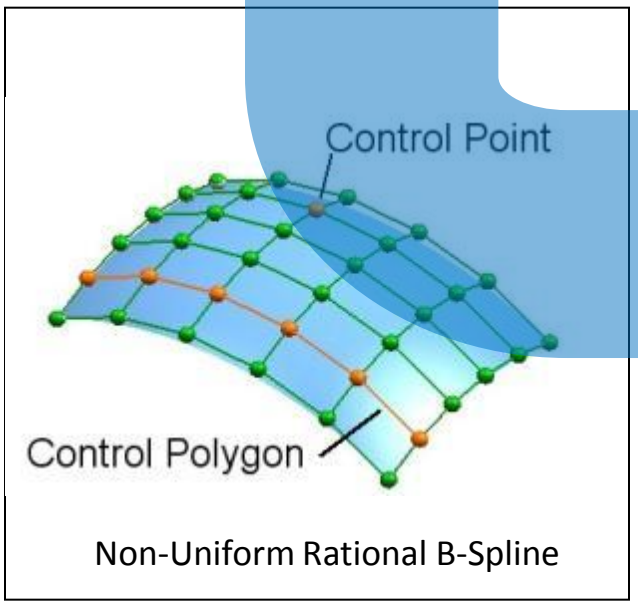


Voxel (tomographic) phantom
Since 1980s

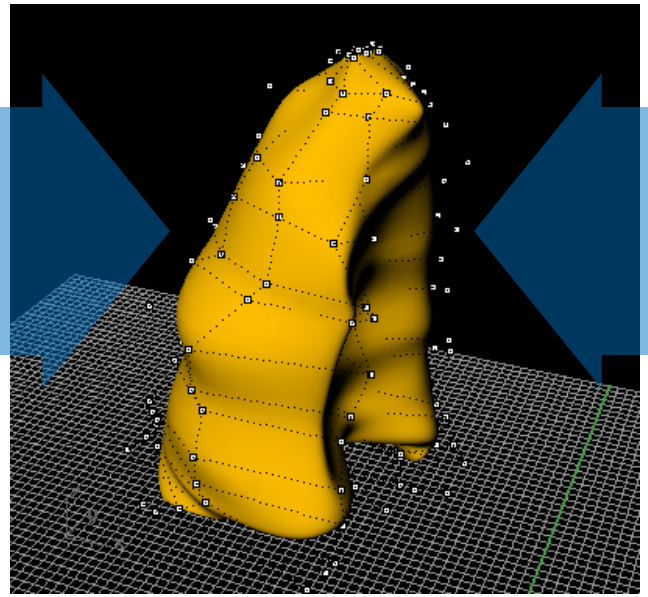
Third generation phantoms: Hybrid approach*

Stylized phantom

Mathematical Flexibility
(NURBS surface)

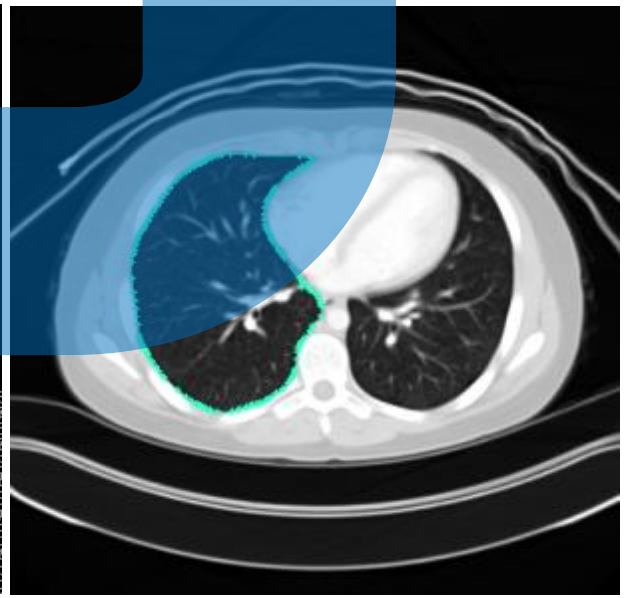


Hybrid**



Voxel phantom

Anatomical Realism
(CT images of patient)

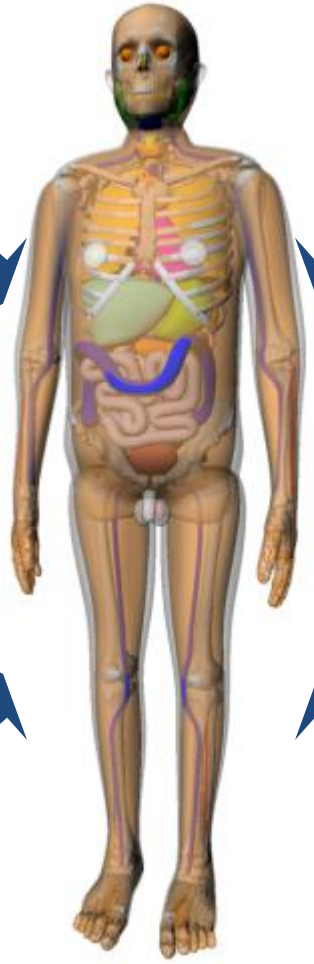


*Segars et al. Nuclear Science 2001, Lee et al. Radiation Protection Dosimetry 2007
**Also known as Boundary Representation (BREP)

Reference data incorporated

Reference organ volume (ICRP Publication 89)

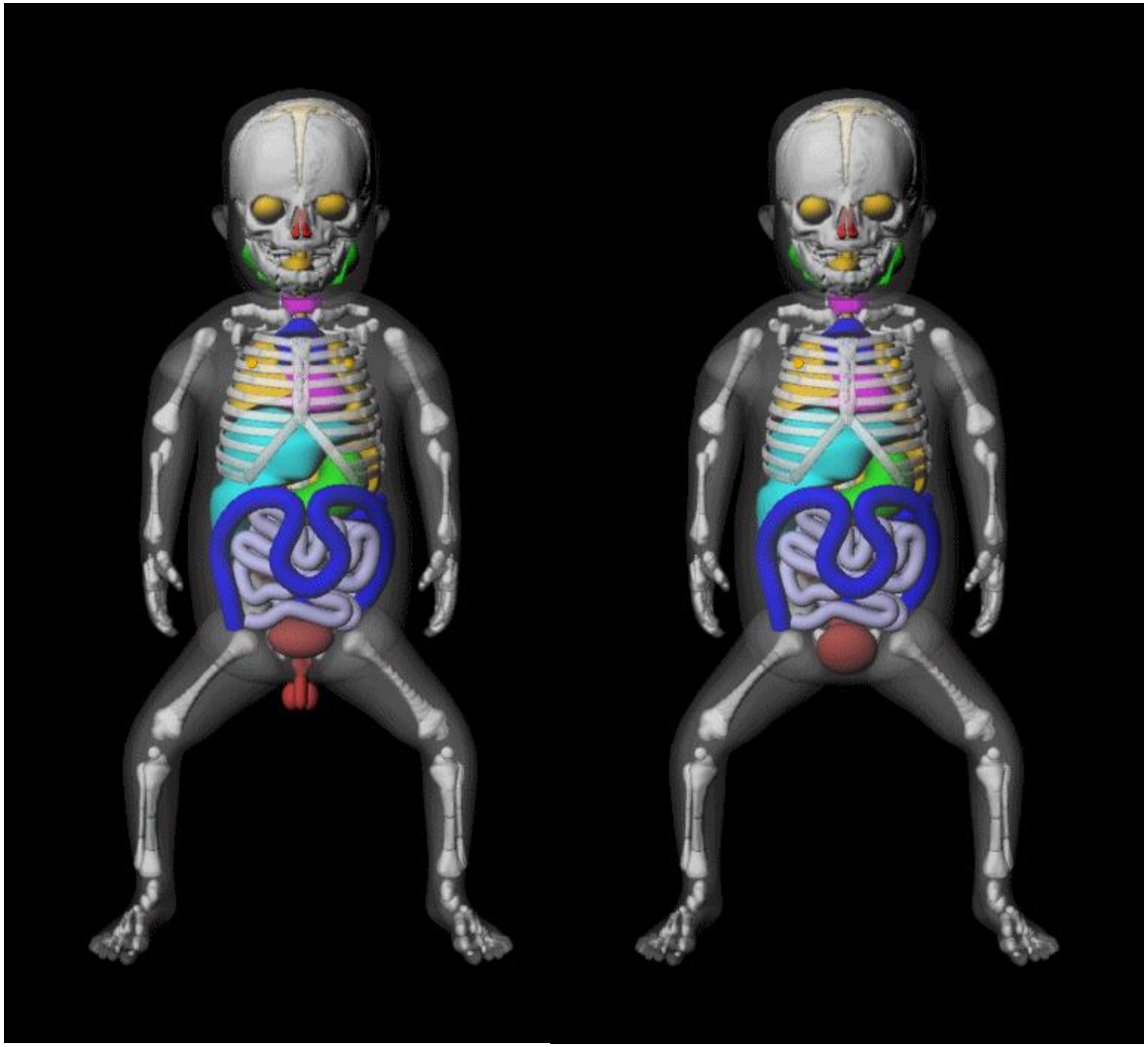
Reference organ composition (ICRU Report 46 & ICRP Publication 89)



Reference gastro-intestine (ICRP Publication 100)

Reference anthropometry (CDC NHANES data)

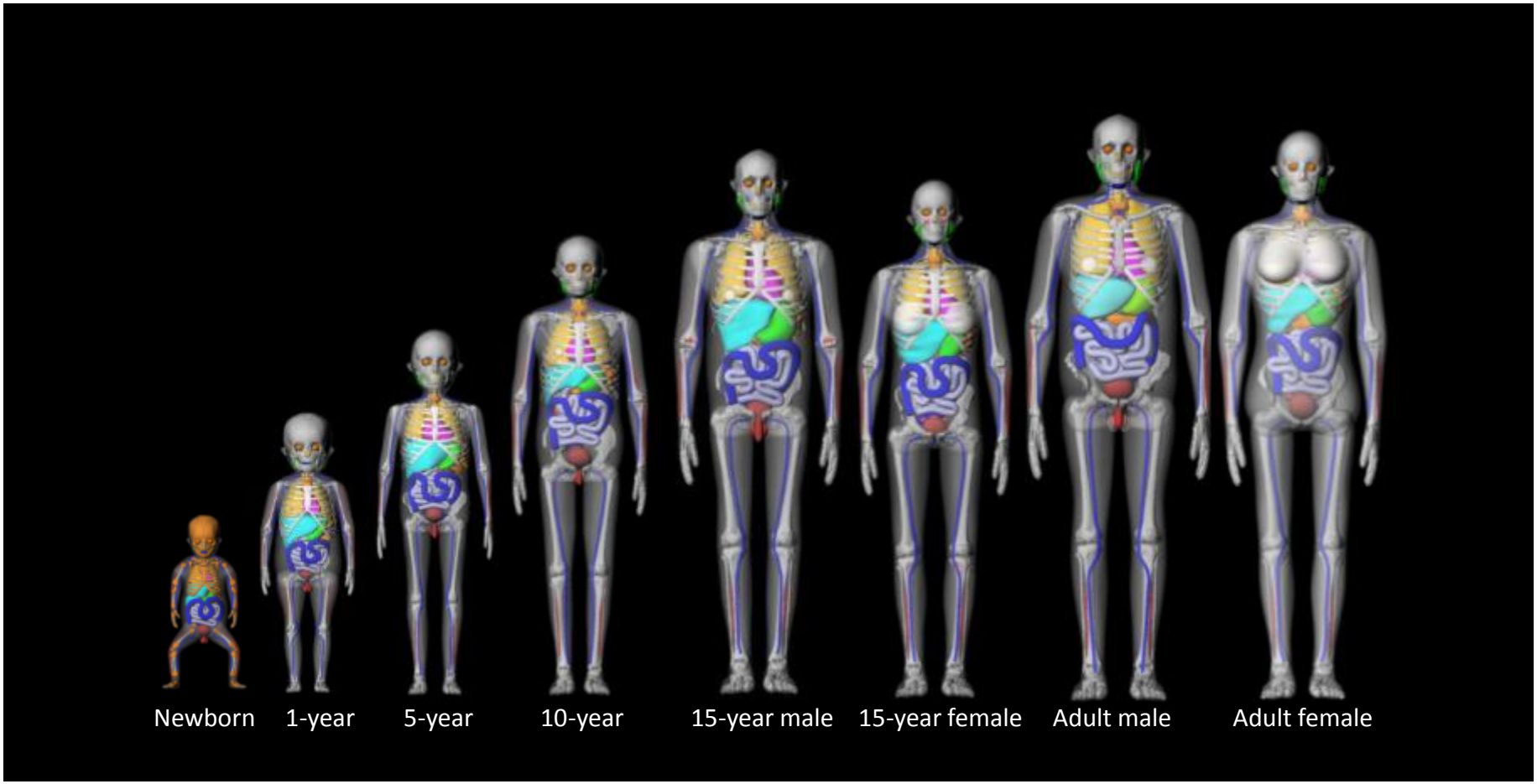
World-first newborn hybrid phantom*



UF/NCI hybrid male (left) and female (right) newborn phantoms

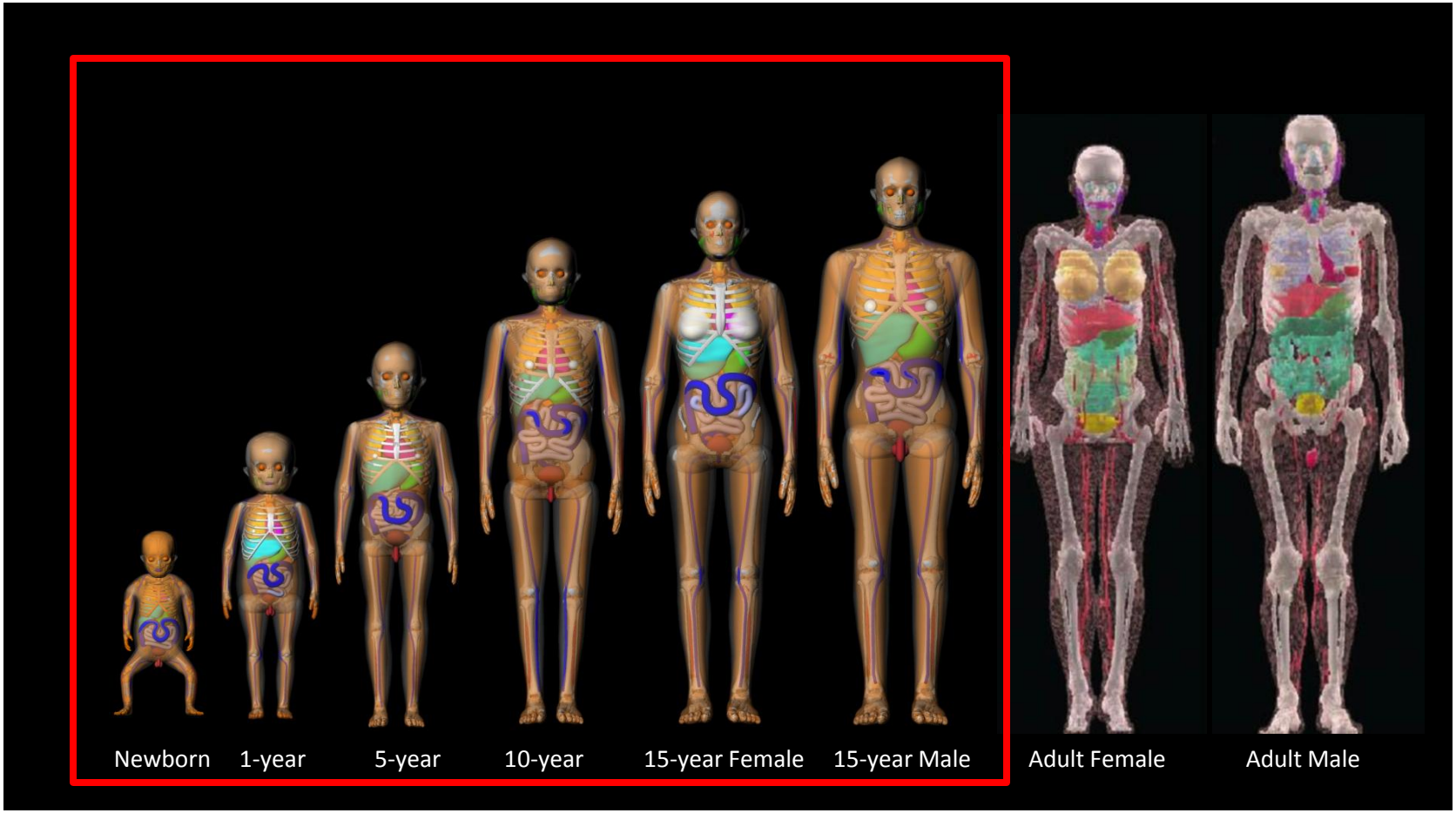
*Lee et al. PMB 2007

A series of Hybrid Phantoms (2006-2013)



* Lee et al, PMB 2007, MP 2008, PMB 2010

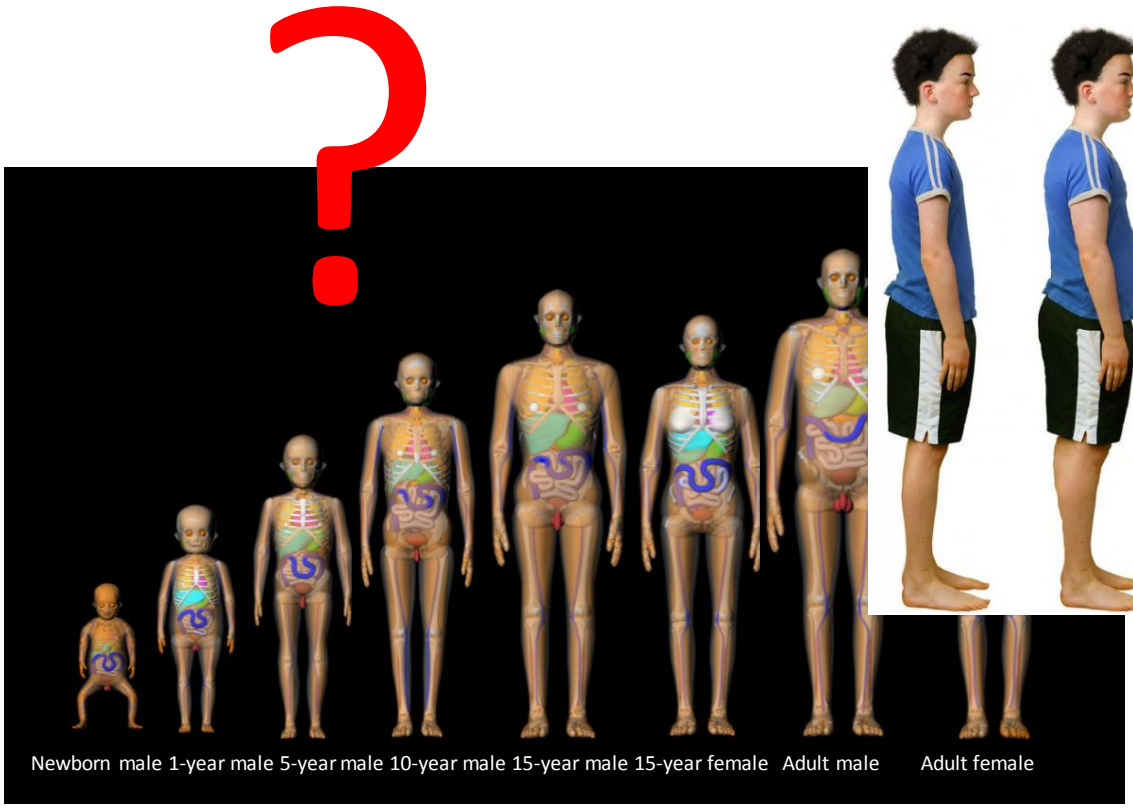
ICRP Reference Pediatric* and Adult** Phantoms

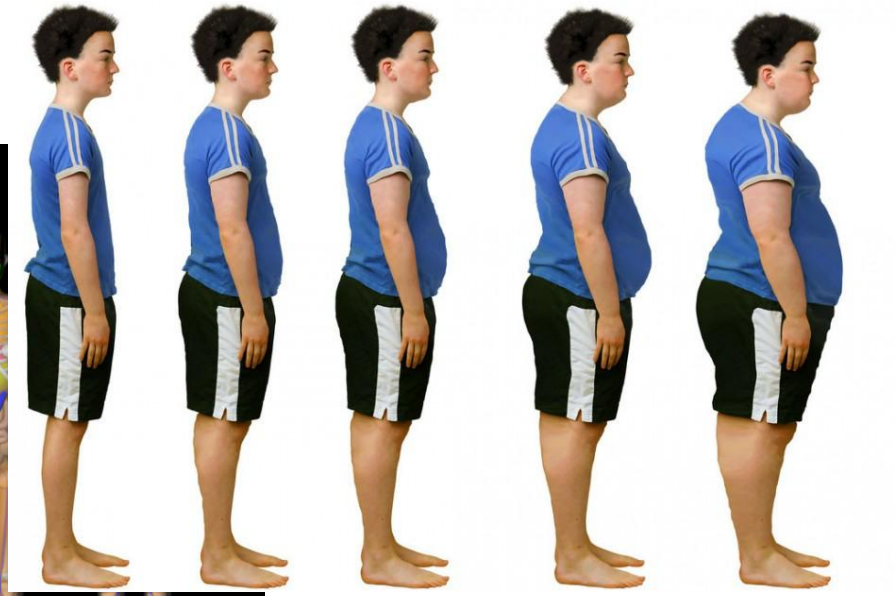


*ICRP Publication (in preparation)
**ICRP Publication 110 (2009)

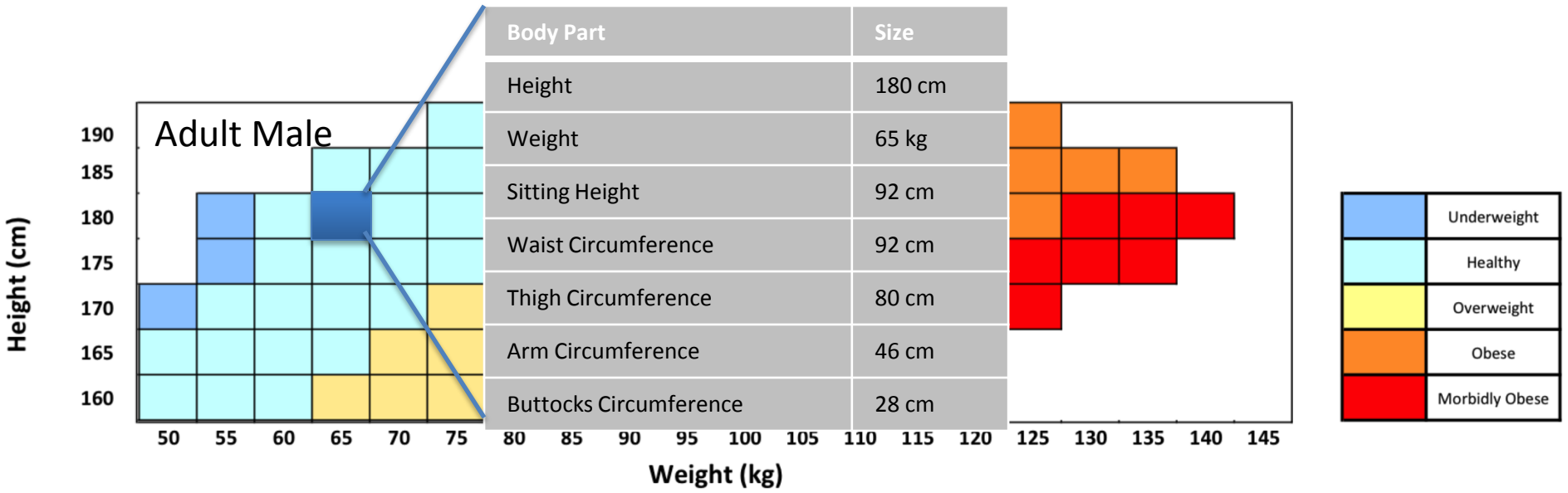
Body size-specific phantoms

- Body size significantly varies among patients at the same age
- Radiation dose depends on body size





UF/NCI Phantom Library*

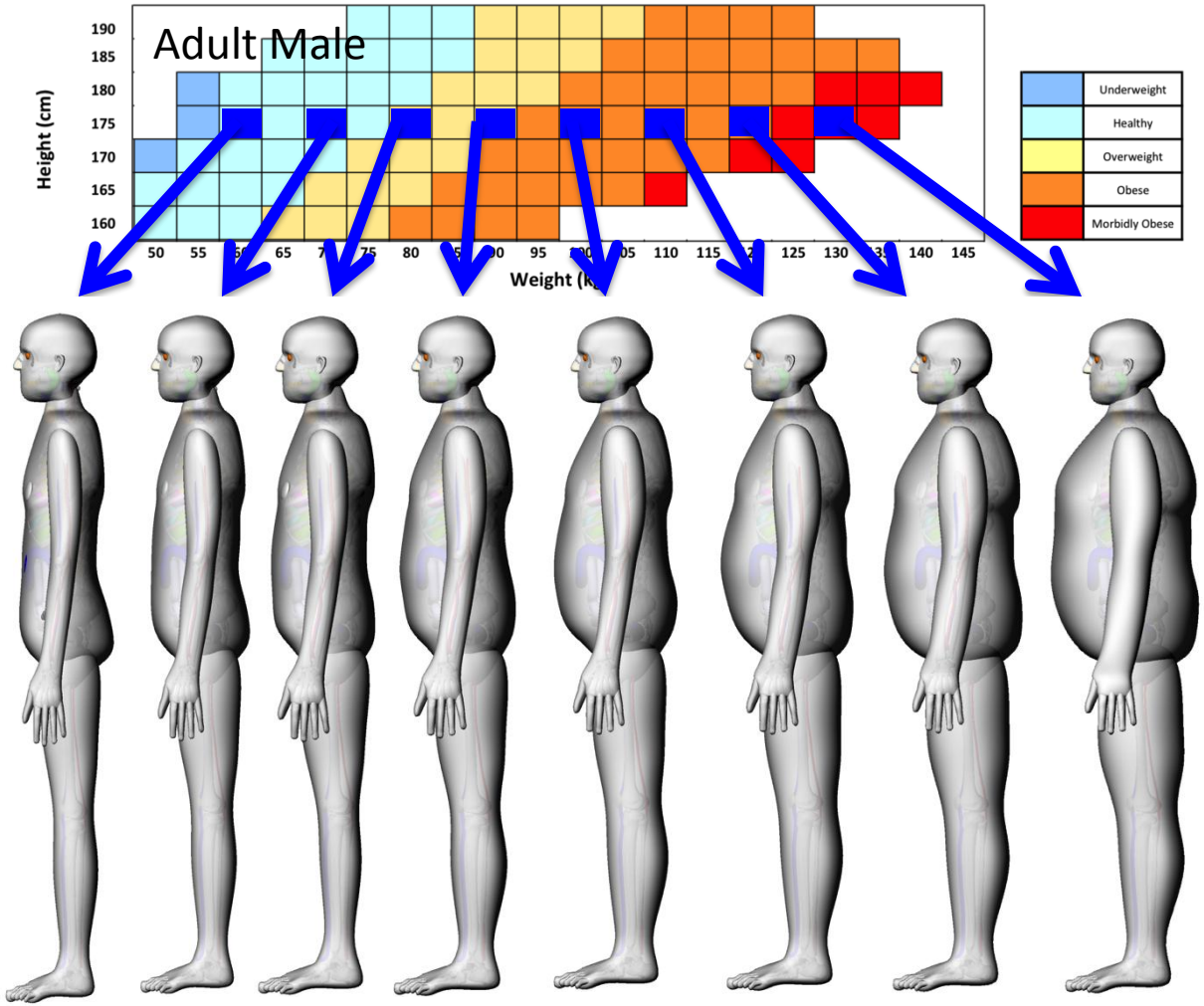


Body Part	Size
Height	180 cm
Weight	65 kg
Sitting Height	92 cm
Waist Circumference	92 cm
Thigh Circumference	80 cm
Arm Circumference	46 cm
Buttocks Circumference	28 cm

- BMI distribution grid developed from US CDC survey data
- Seven different body dimensions assigned to each cell
- Body size-dependent phantoms developed by deforming the reference phantoms

*Geyer et al. PMB 2014

UF/NCI Phantom Library*

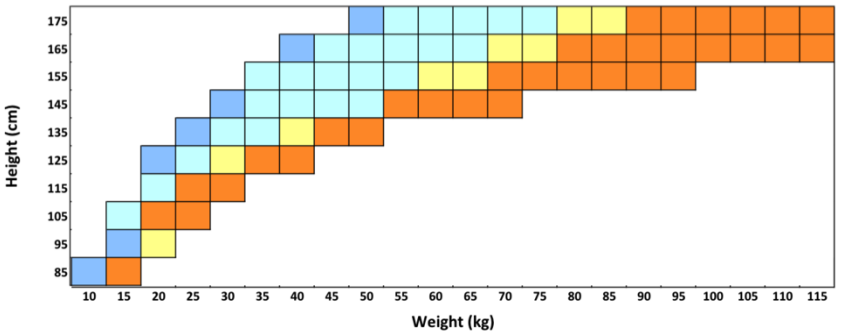


A series of the adult male phantoms at 175 cm high and different weights, 60 – 130 kg

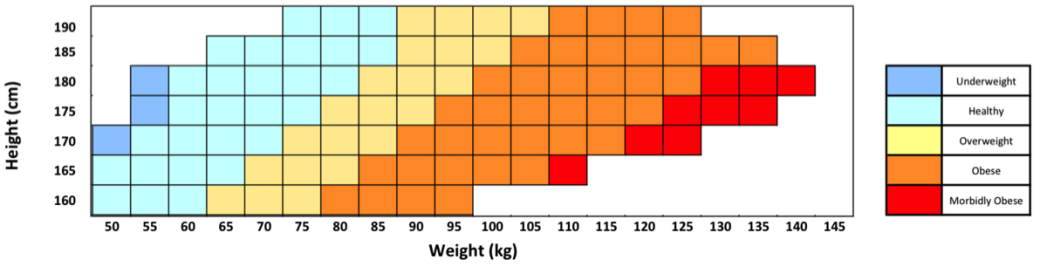
*Geyer et al. PMB 2014

UF/NCI Phantom Library*

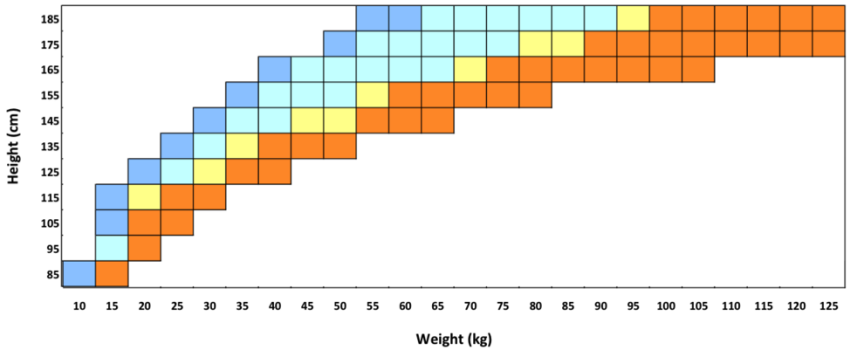
Pediatric Female



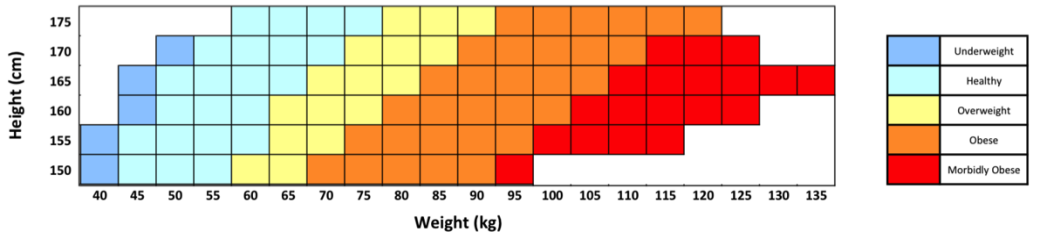
Adult Female



Pediatric Male

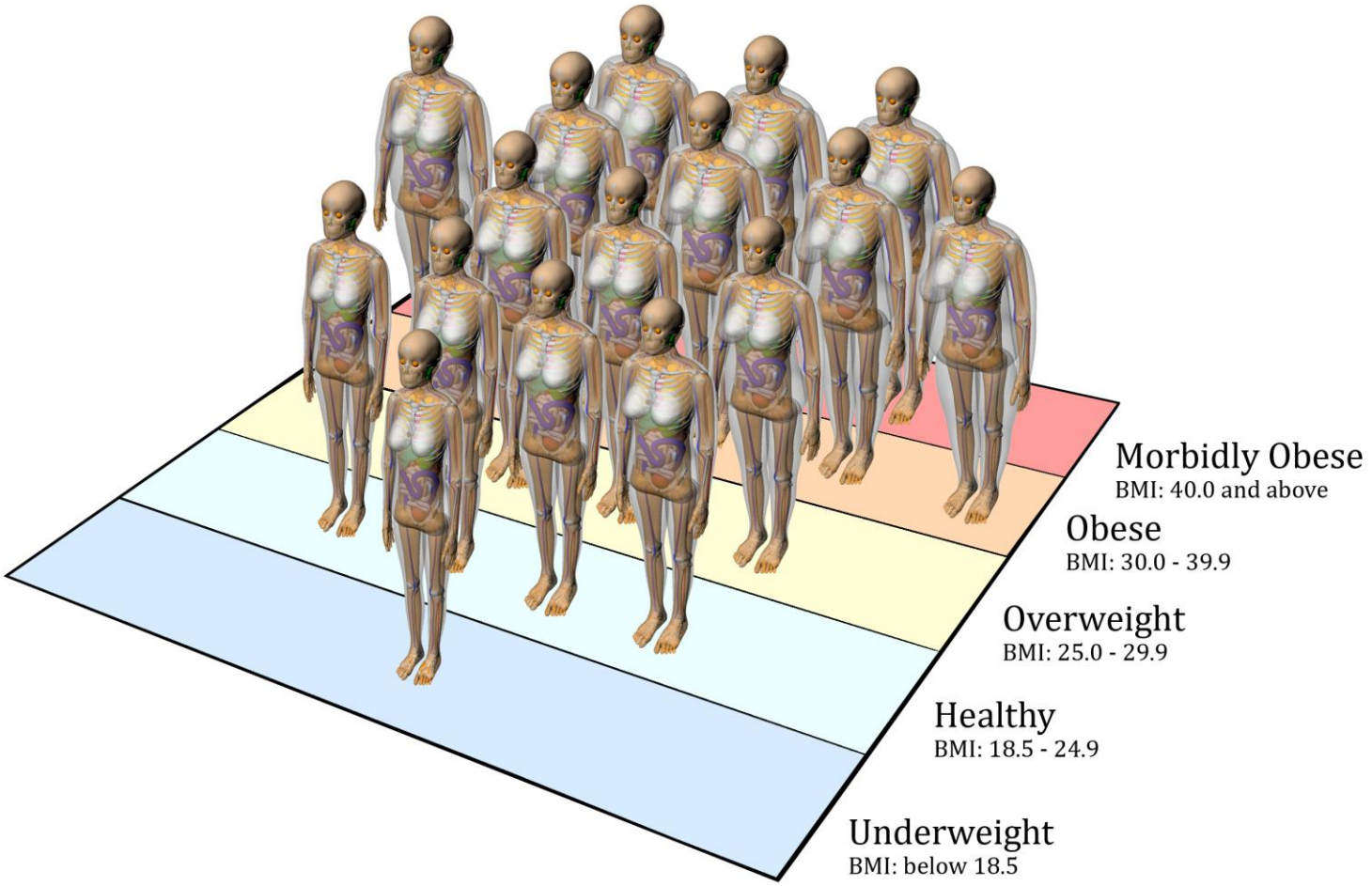


Adult Male



*Geyer et al. PMB 2014

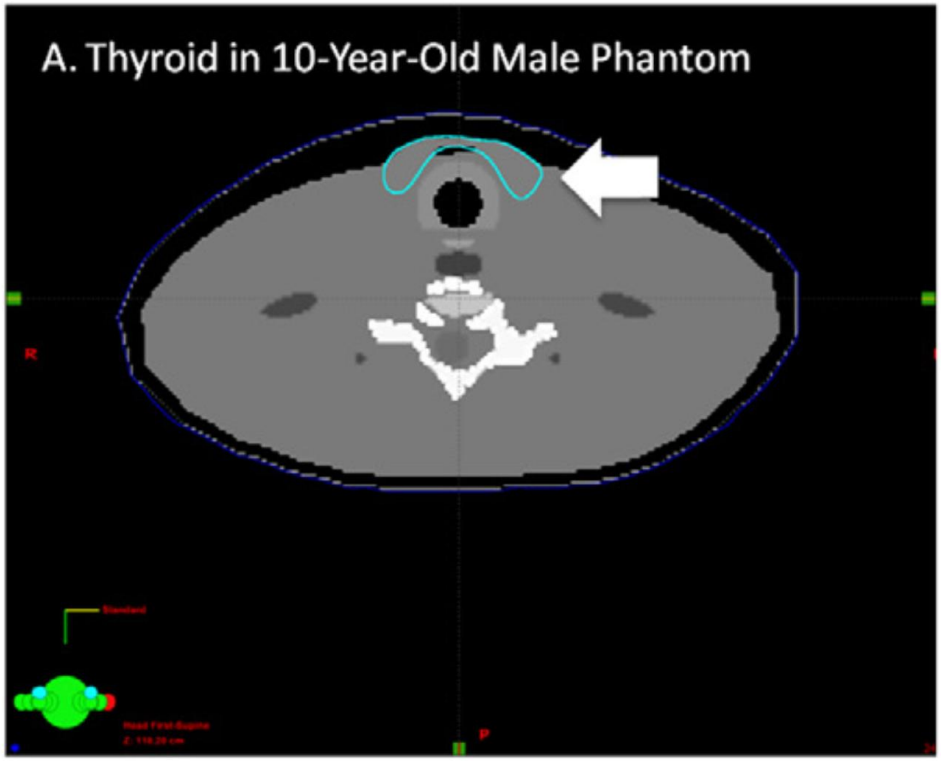
UF/NCI Phantom Library: 351 phantoms

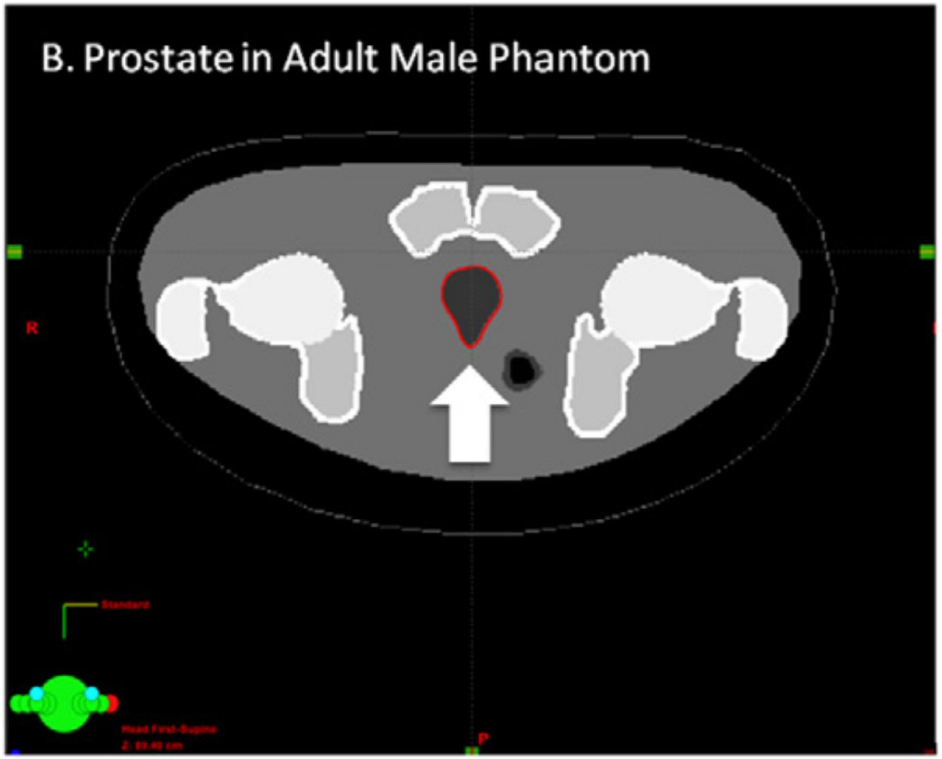


*Geyer et al. PMB 2014

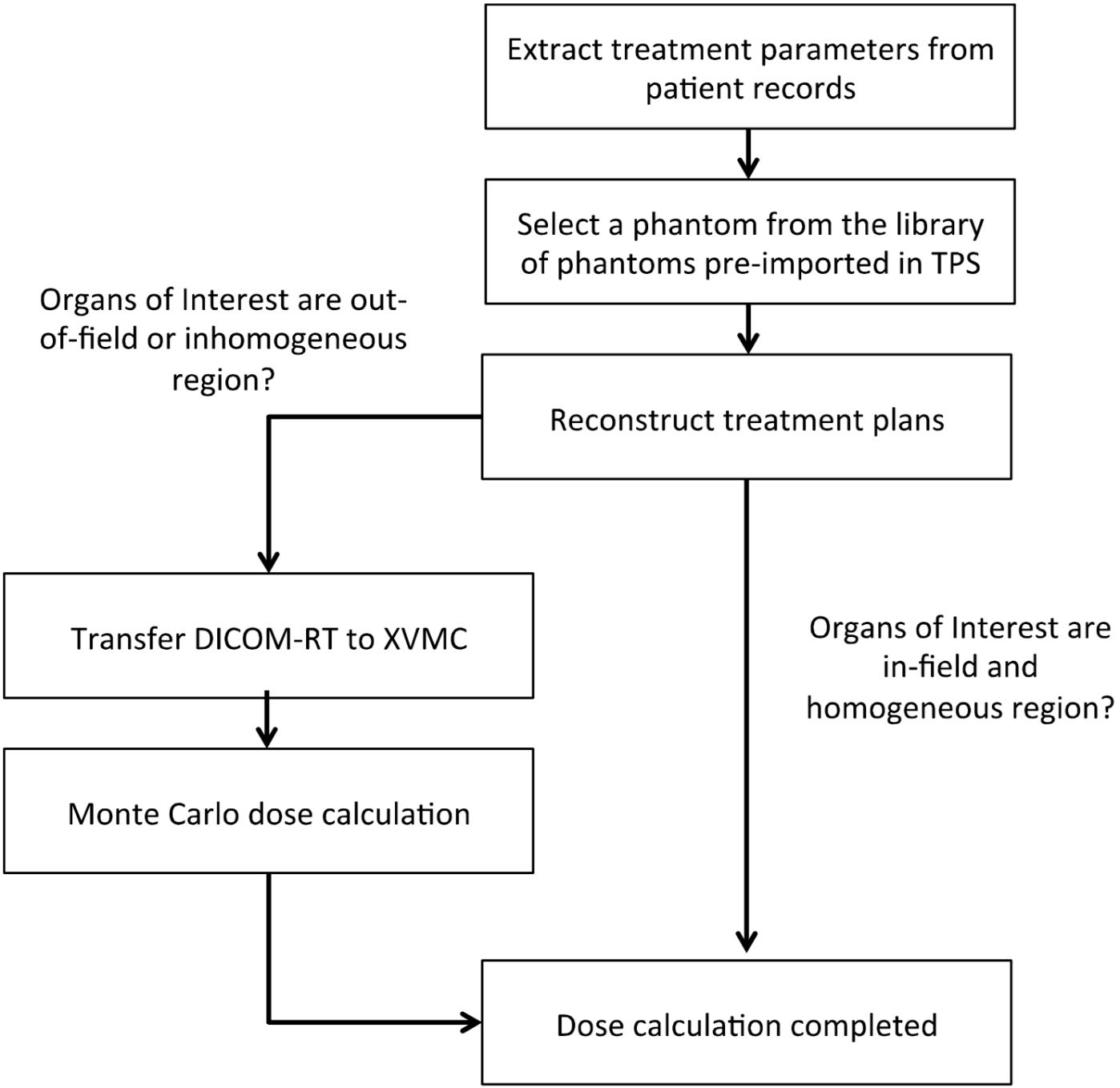
Applications to Normal Tissue Dose Calculations in Radiotherapy Patients

Convert the UF/NCI phantoms into DICOM-RT*





* Pyakuryal et al (in preparation)

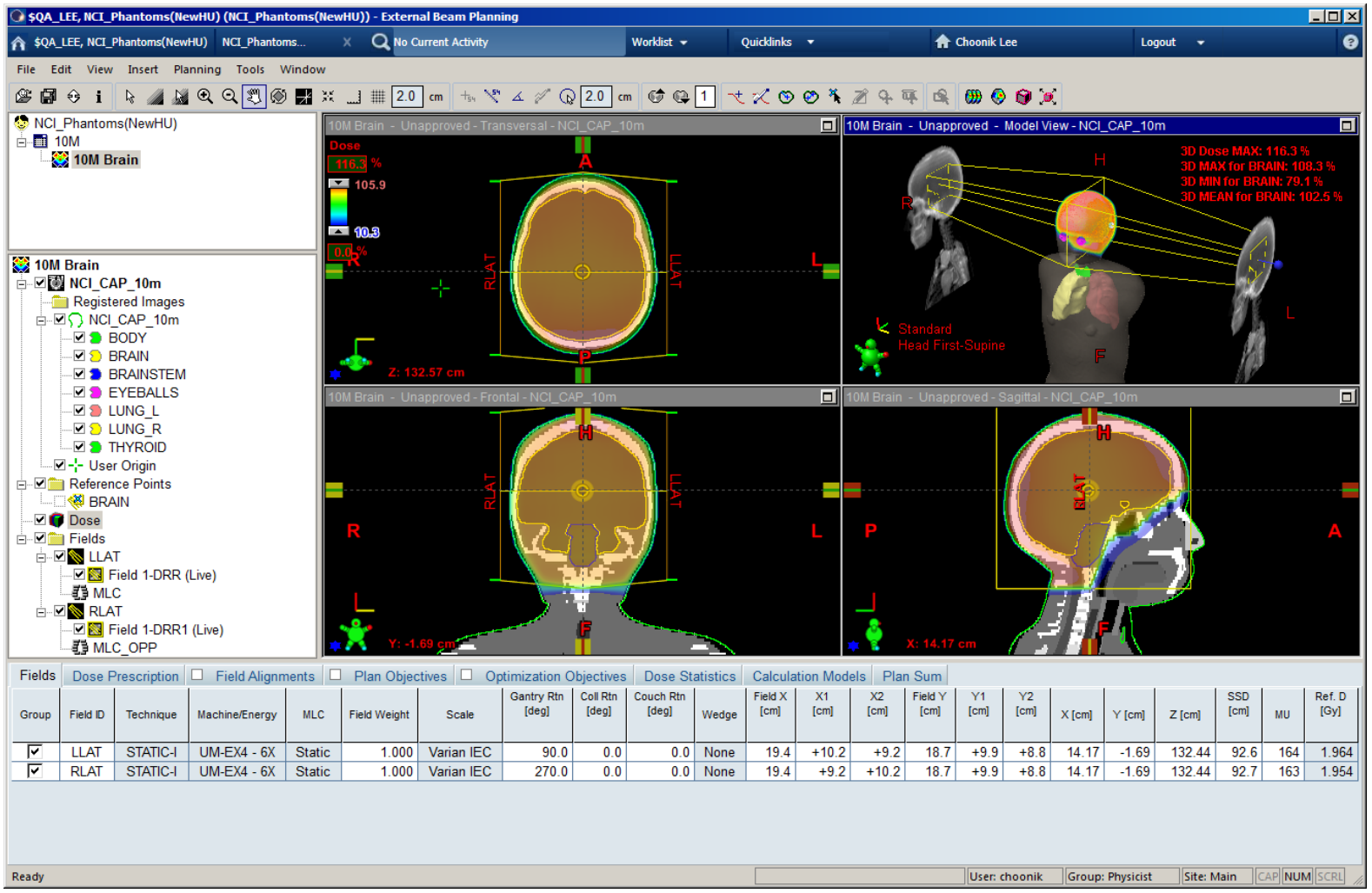

Extract treatment parameters from patient records
Select a phantom from the library of phantoms pre-imported in TPS
Reconstruct treatment plans
Organs of Interest are out-of-field or inhomogeneous region?
Transfer DICOM-RT to XVMC
Monte Carlo dose calculation
Organs of Interest are in-field and homogeneous region?
Dose calculation completed

Illustrative organ dose calculations

- Two cases of cancer treatment
  - Brain cancer in 10-year-old phantom
  - Prostate cancer in adult male phantom

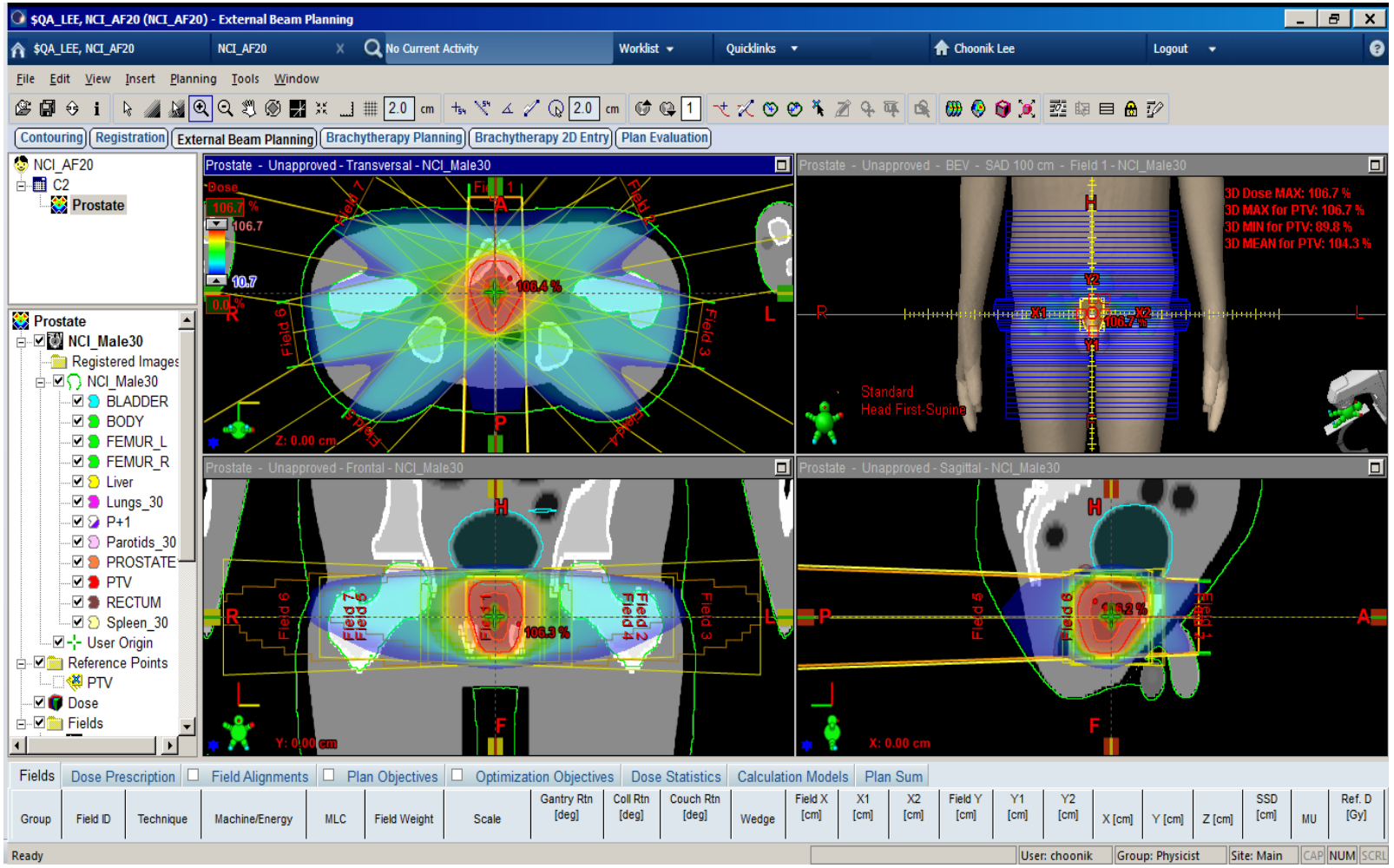
- Steps
  - Convert 10-year-old male and adult male Hybrid Phantoms
  - Treatment planning and generate DICOM-RT
  - Monte Carlo calculation using DICOM-RT

Treatment plan: 10-year-old brain tumor

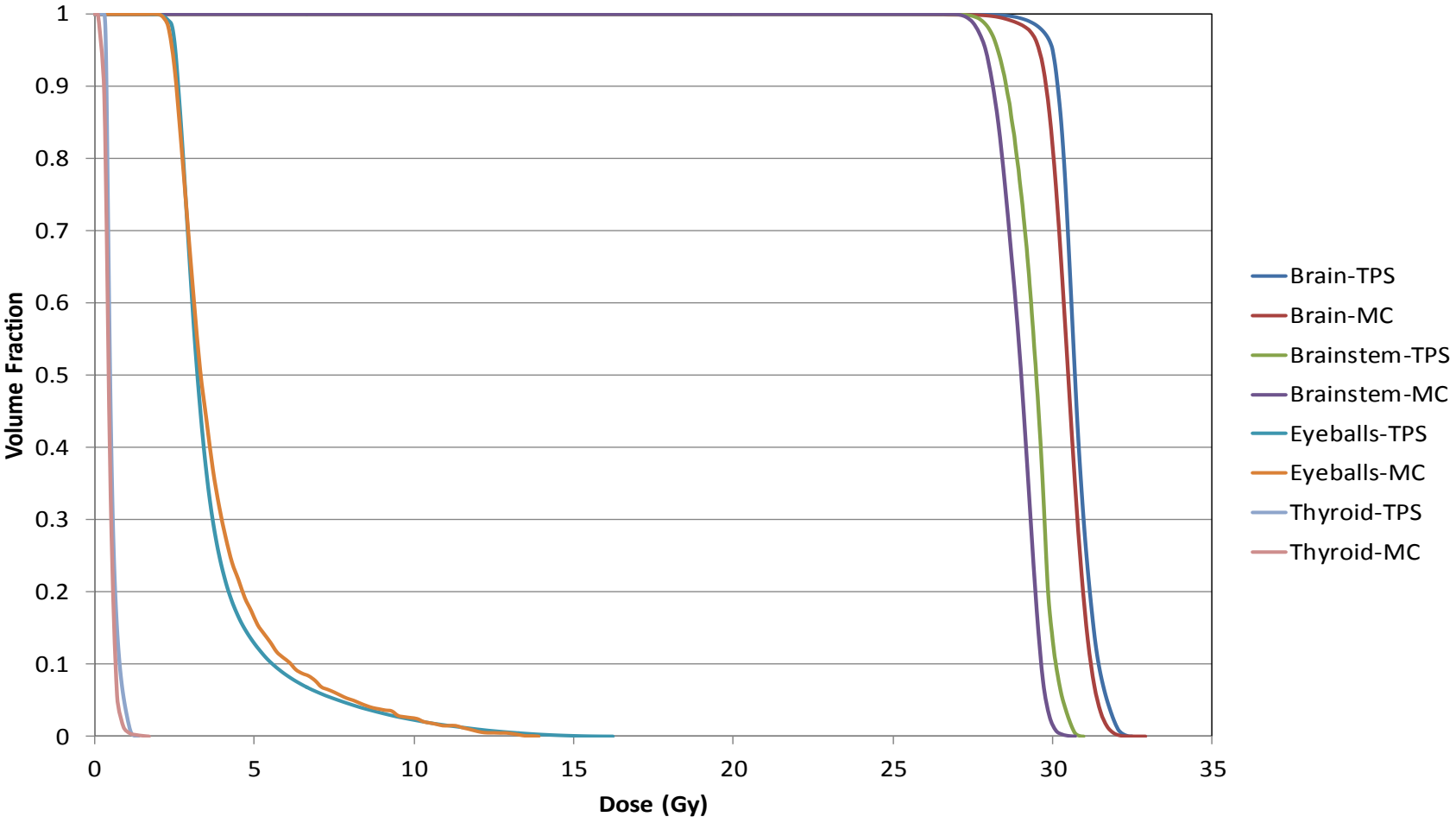


Group	Field ID	Technique	Machine/Energy	MLC	Field Weight	Scale	Gantry Rtn [deg]	Coll Rtn [deg]	Couch Rtn [deg]	Wedge	Field X [cm]	X1 [cm]	X2 [cm]	Field Y [cm]	Y1 [cm]	Y2 [cm]	X [cm]	Y [cm]	Z [cm]	SSD [cm]	MU	Ref. D [Gy]
☑	LLAT	STATIC-I	UM-EX4 - 6X	Static	1.000	Varian IEC	90.0	0.0	0.0	None	19.4	+10.2	+9.2	18.7	+9.9	+8.8	14.17	-1.69	132.44	92.6	164	1.964
☑	RLAT	STATIC-I	UM-EX4 - 6X	Static	1.000	Varian IEC	270.0	0.0	0.0	None	19.4	+9.2	+10.2	18.7	+9.9	+8.8	14.17	-1.69	132.44	92.7	163	1.954

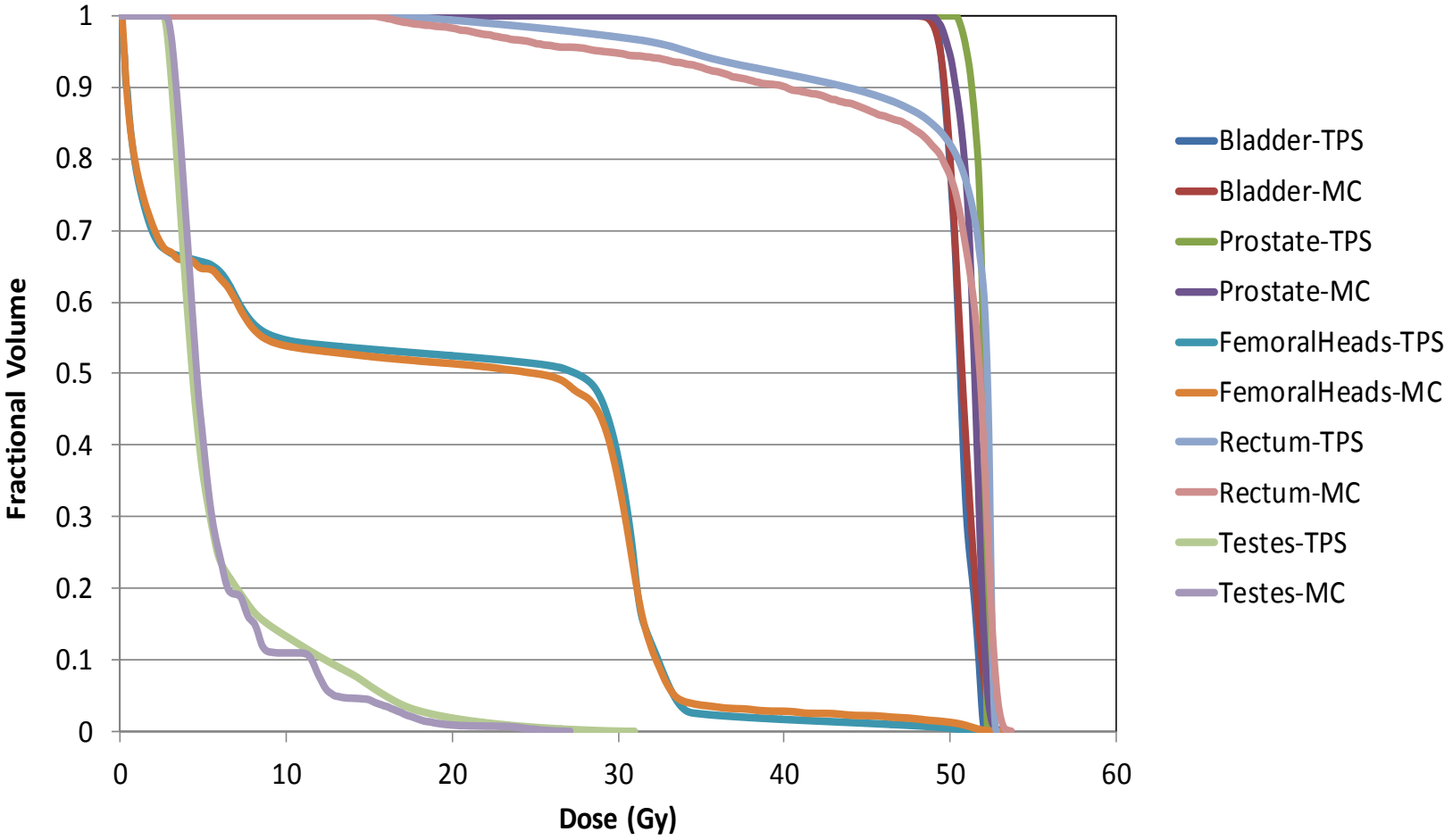
Treatment plan: Adult male prostate tumor



DVH for 10-year-old brain tumor treatment



DVH for adult male prostate tumor treatment



Summary

- Computational phantoms have evolved from simplified to realistic format.
- Recent developments focus on: body size-specific phantoms, posture-specific phantoms.
- ICRP is working on pediatric reference phantoms after the adult reference phantoms.
- Computational phantoms can be used for reference anatomy in radiotherapy dosimetry studies.

Which reference data was not incorporated into the Reference adult phantoms of the International Commission on Radiological Protection (ICRP)?

5%	1. Reference organ mass
2%	2. Reference material density
3%	3. Reference body dimension
80%	4. Reference organ location
10%	5. Reference gastro-intestinal dimension

Answer: 4. Reference organ location

Reference: ICRP, “Adult Reference Computational Phantoms,” ICRP Publication 110, Ann. ICRP **39**(2), 1–166 (2009).

Which of the followings is the advantage of using computational phantoms in developing clinical treatment planning protocols?

1%	1. Pre-contoured organs and tissues
1%	2. DICOM-RT format available
1%	3. Represent reference anatomy data
3%	4. Cover whole body anatomy
94%	5. All of the above

Answer: 5. All of the above

Reference: C. Lee, J.W. Jung, C. Pelletier, A. Pyakuryal, S. Lamart, J.O. Kim, and C. Lee, “Reconstruction of organ dose for external radiotherapy patients in retrospective epidemiologic studies,” Physics in medicine and biology **60**(6), 2309–2324 (2015)