New Mesh-type Phantoms and Their Dosimetry Applications Including Emergencies

ICRP-ERPW Symposium

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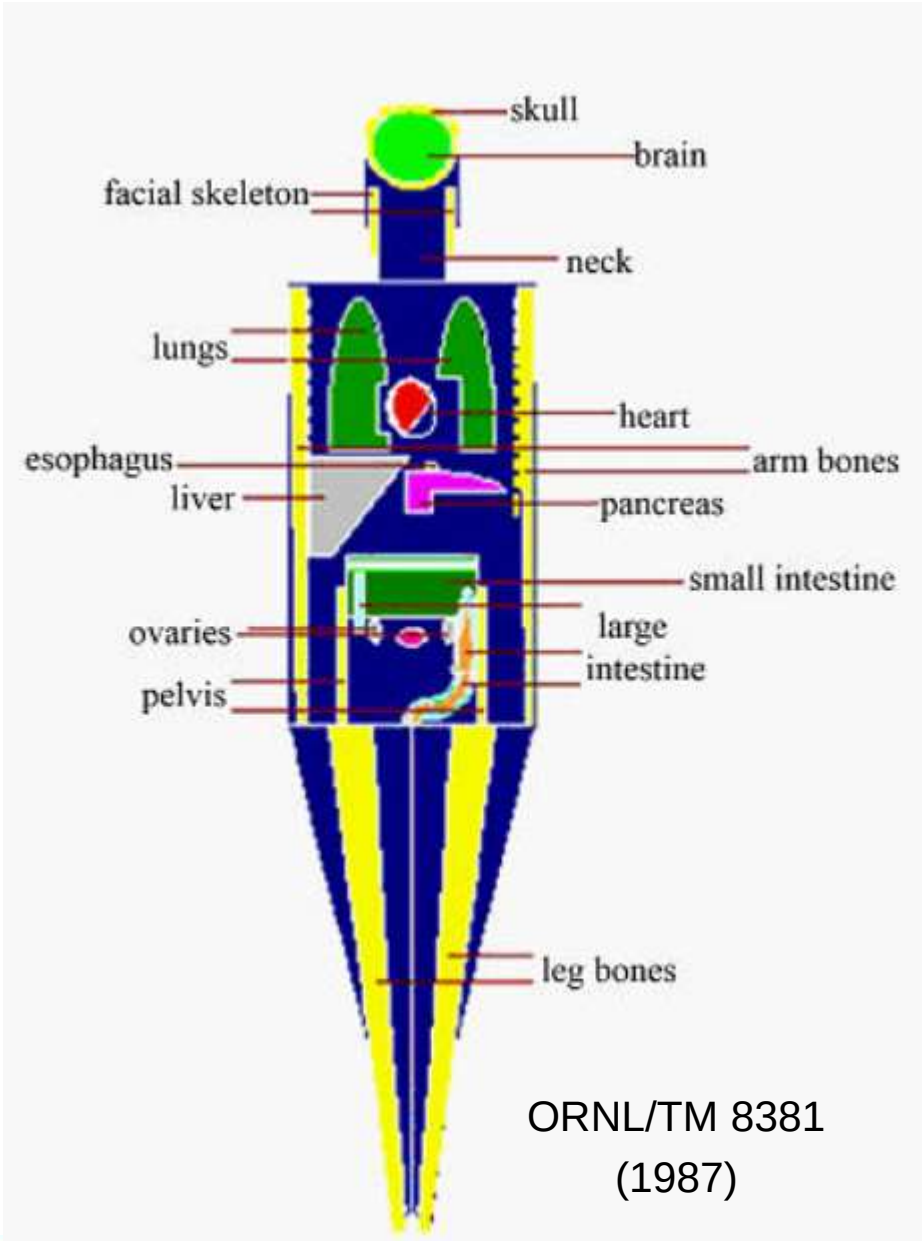
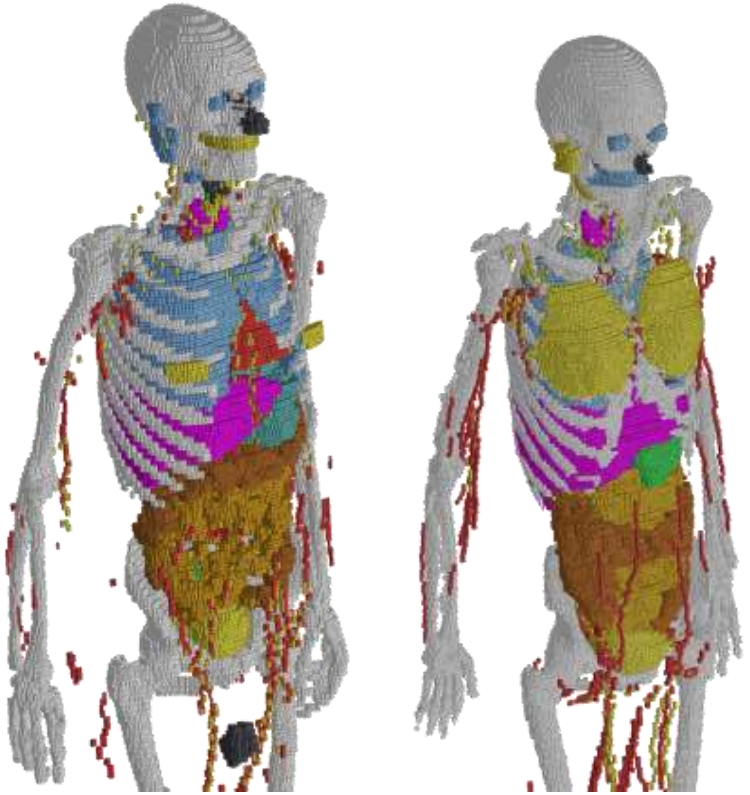
Computational Phantoms



ORNL/TM 8381
(1987)

"VRCPs"

Voxel-type Reference
Computational Phantoms



ICRP Publication 110
(2009)

ICRP Task Group 103 (2016)

- Main Commission
- Scientific Secretariat
- Committee 1 Radiation Effects
- Committee 2 Doses from Radiation Exposure
- Committee 3 Protection in Medicine
- Committee 4 Application of the Commission권 Recommendations
- Committee 5 Protection of the Environment
- Emeritus Members
- Full ICRP Membership List
- ICRP and Fukushima
- Formal Relations with other Organisations
- ICRP Funding

Task Group 103
Mesh-type Reference Computational Phantoms (MRCP)

The mandate for this Task Group - Mesh-type Reference Computational Phantoms (MRCP) - will be focused on converting the current voxel-type reference computational phantoms into a high-quality mesh format to address the limitations of the voxel-type phantoms in some dose coefficient calculations.
Specific work will include:

1. development of mesh-type ICRP reference computational phantoms which have all source and target tissues including the details of the eyes and skin and the thin target tissues (10-300 micron) of the alimentary and respiratory tract organs,
2. use of these mesh-type phantoms to calculate external and internal dose coefficients to estimate the uncertainties of the current reference dose coefficients, especially for the dose coefficients calculated with stylized phantoms (eye lenses, skin, and alimentary and respiratory tract organs) for weekly penetrating radiations, and
3. demonstration of phantom posture change and related dose coefficient calculations.

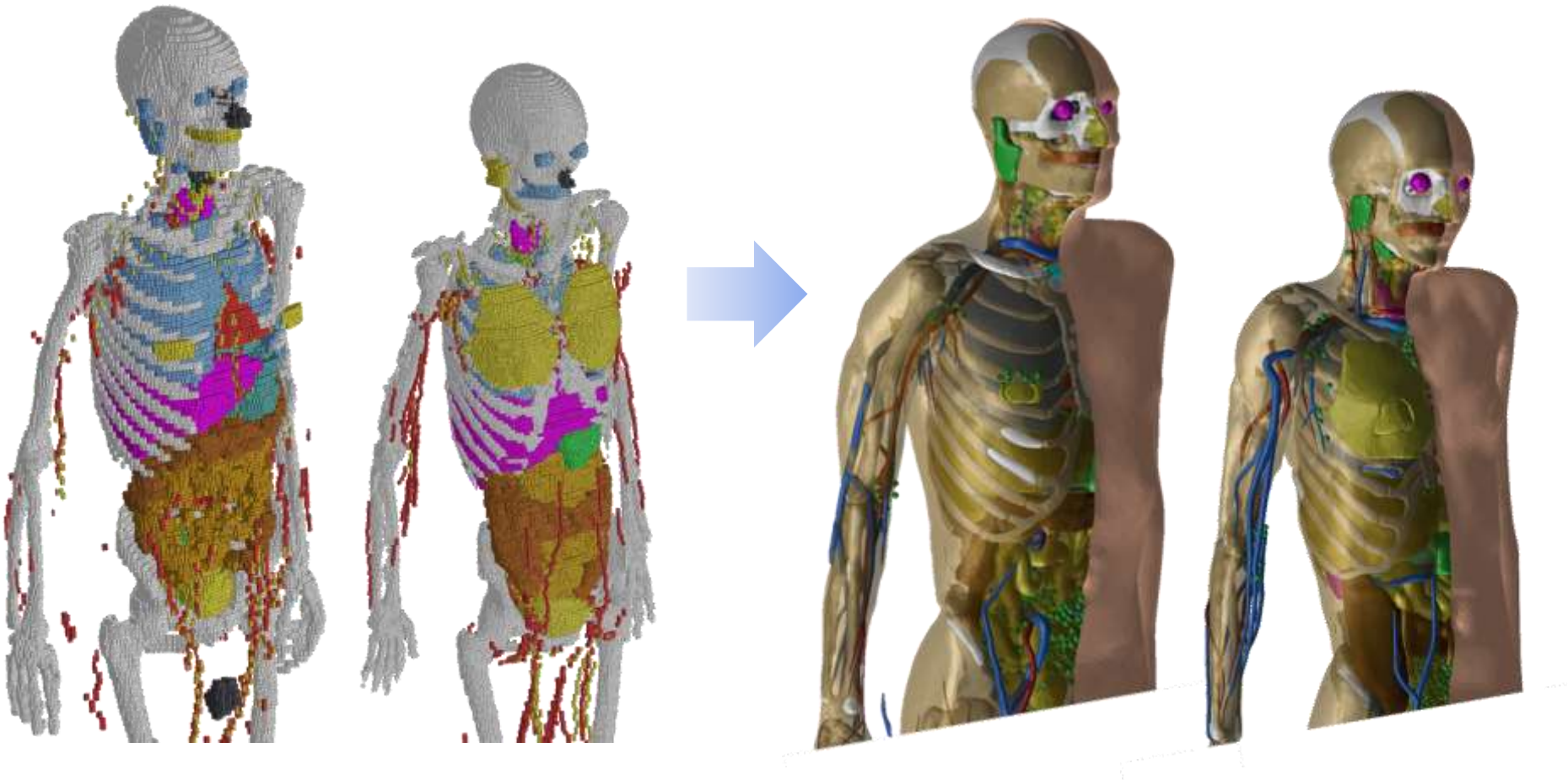
Chair

Prof Chan Hyeong Kim

TG 103 Members

- Full members
  - Chan Hyeong Kim (Hanyang Univ., Korea, ICRP C2) - Chair
  - Yeon Soo Yeom (Hanyang Univ., Korea)
  - Maria Zankl (HMGU, Germany)
  - Nina Petoussi-Henss (HMGU, Germany, ICRP C2)
  - Wesley Bolch (Univ. of Florid, U.S.A, ICRP C2)
  - Choonsik Lee (NCI, U.S.A)
- Corresponding members
  - Keith Eckerman (ORNL, U.S.A)
  - Riu Qiu (Tsinghua University, China)
  - Bum Sun Chung (Ajou Univ., Korea) – M.D./anatomist
  - Chansoo Choi (Hanyang Univ., Korea)
  - Min Cheol Han (INFN, Italy)
  - Han Sung Kim (KIRAMS, Korea)
  - Tat Thang Nguyen (Honoi Institute of Technology, Vietnam)

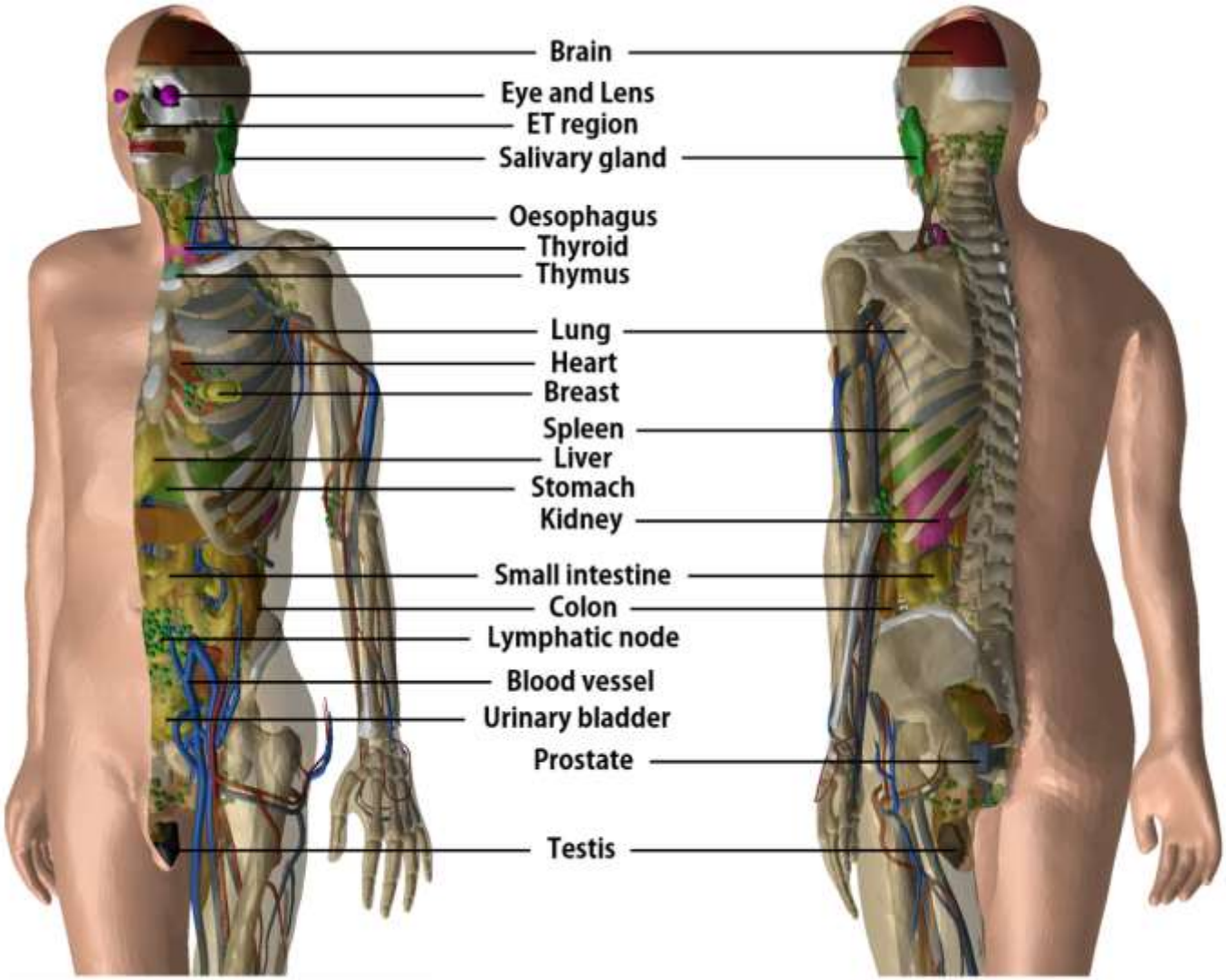
MRCPs (Mesh-type Reference Computational Phantoms)



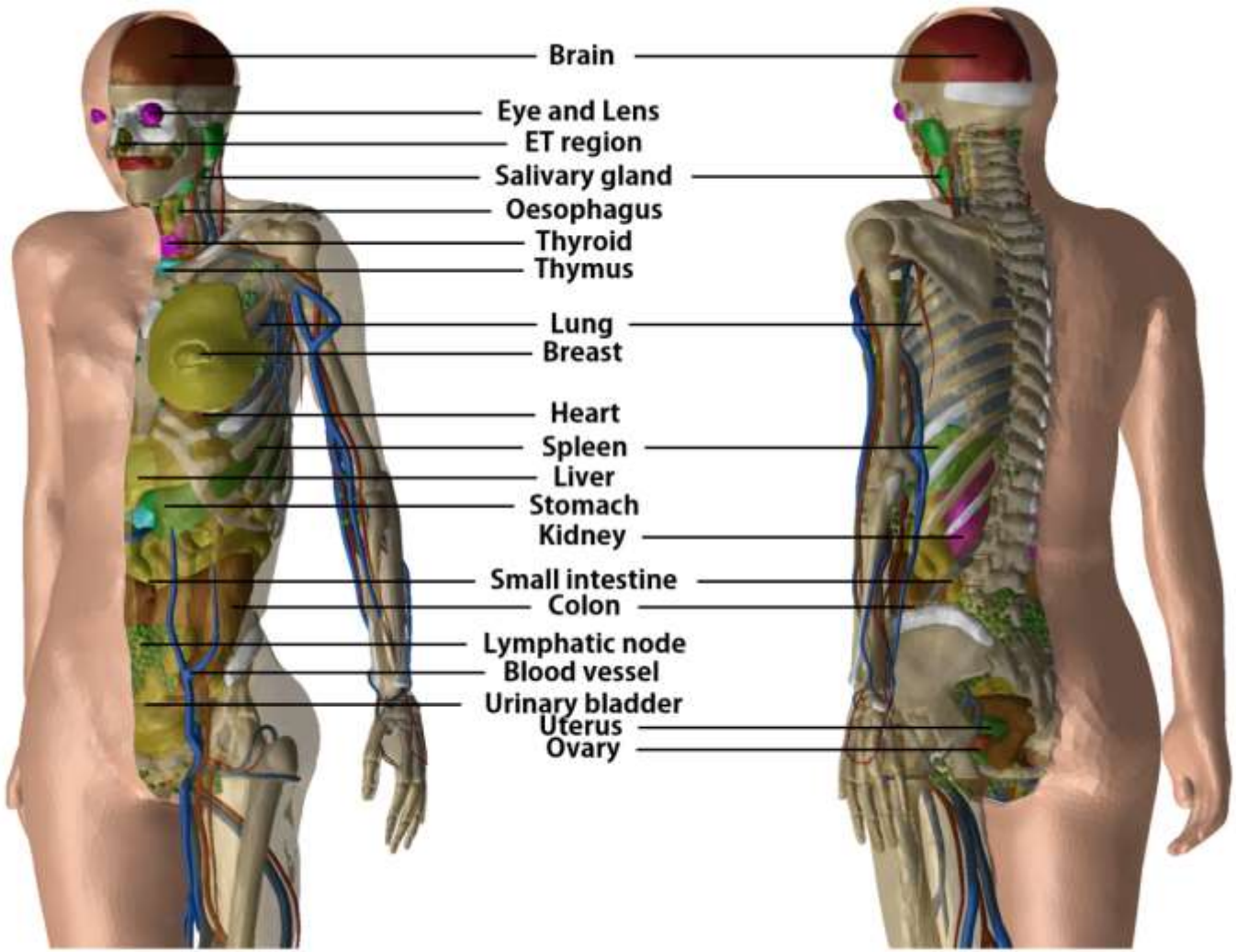
VRCPs
(ICRP Publication 110)

MRCPs
(Mesh-type Reference Computational Phantoms)

Male MRCP


Brain
Eye and Lens
ET region
Salivary gland
Oesophagus
Thyroid
Thymus
Lung
Heart
Breast
Spleen
Liver
Stomach
Kidney
Small intestine
Colon
Lymphatic node
Blood vessel
Urinary bladder
Prostate
Testis

Female MRCP


Brain
Eye and Lens
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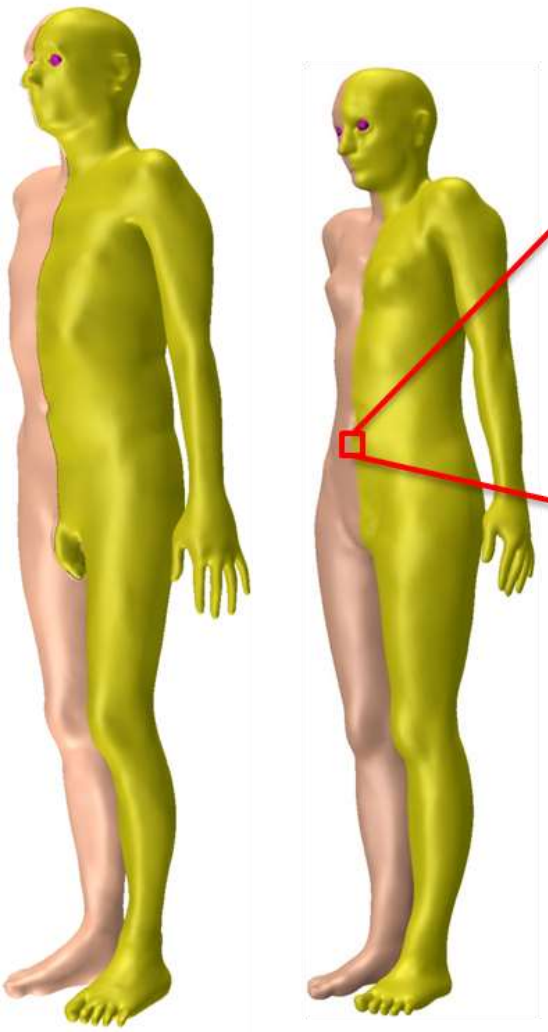
Oesophagus
Thyroid
Thymus
Lung
Breast
Heart
Spleen
Liver
Stomach
Kidney
Small intestine
Colon
Lymphatic node
Blood vessel
Urinary bladder
Uterus
Ovary

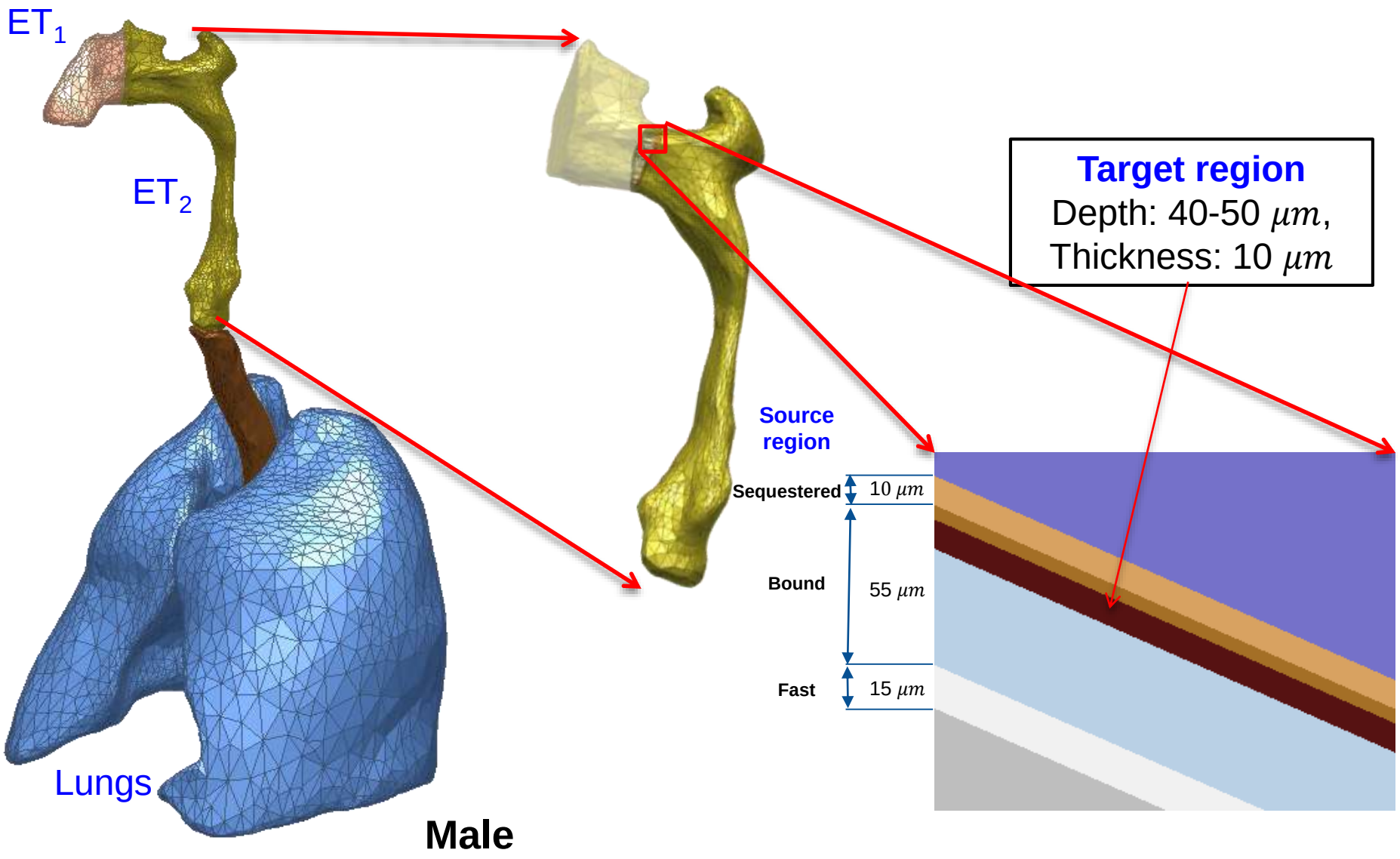
Skin



Male *Female*

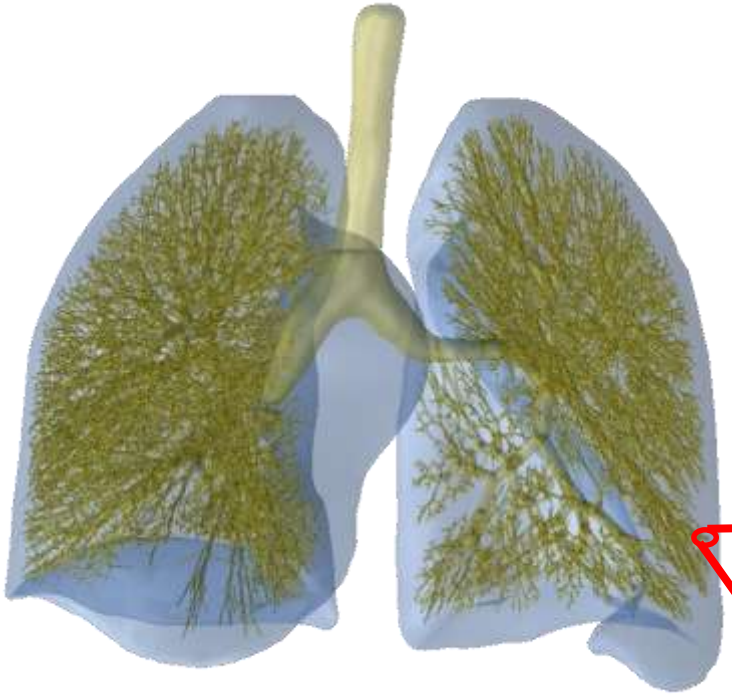
Target layer
Depth: 50-100 μm
Thickness: 50 μm

Respiratory Tract Organs

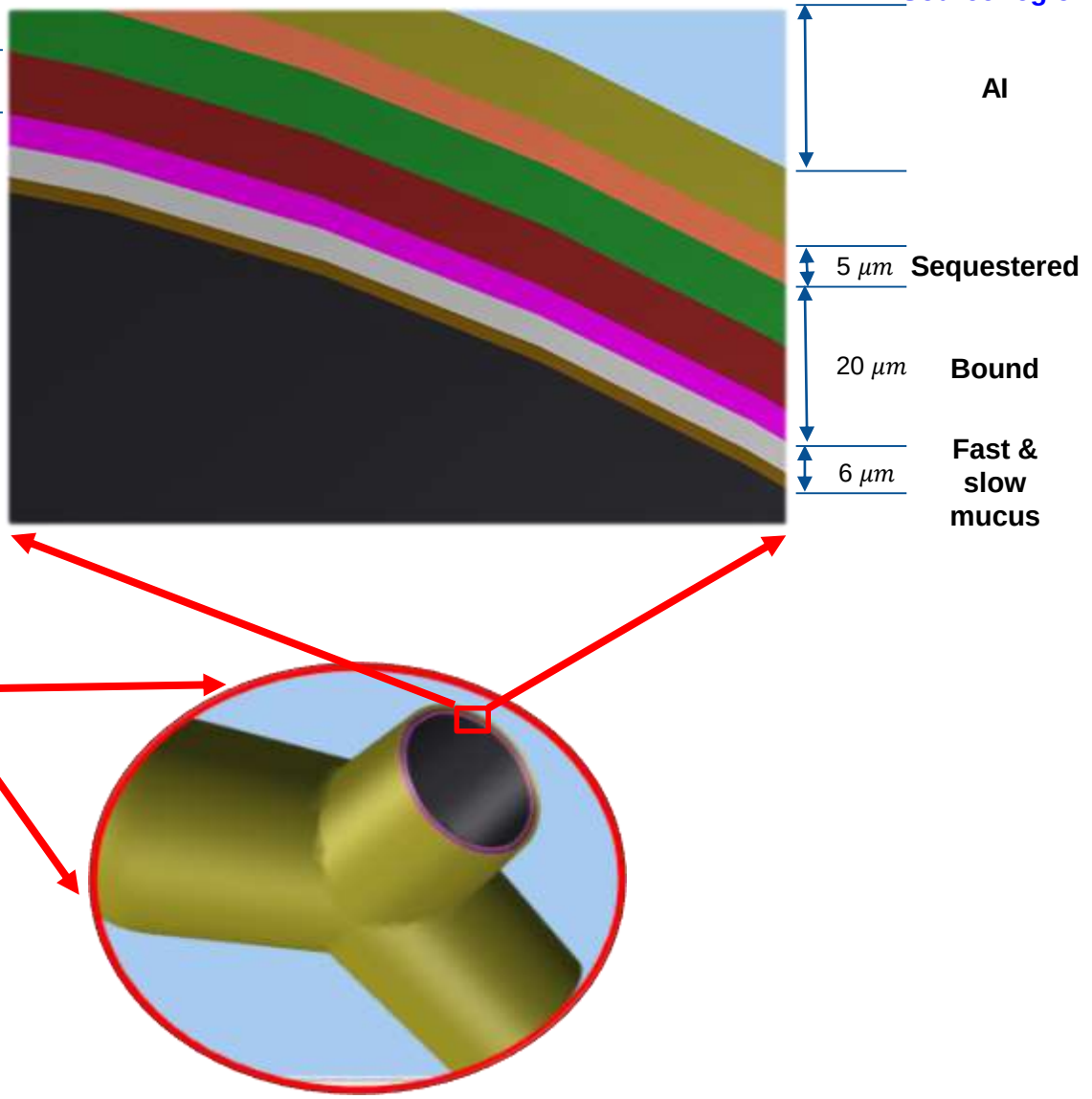


Lungs

Male



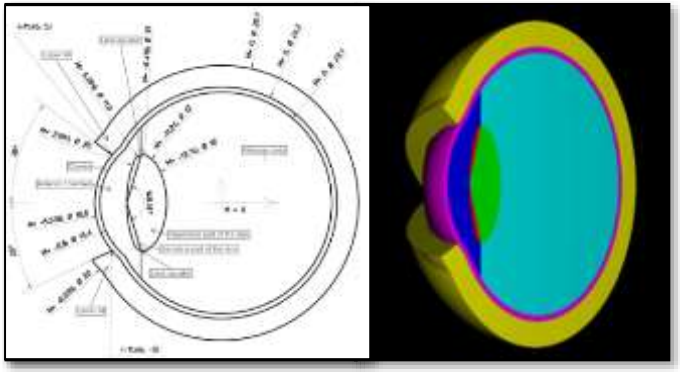
“Turn ON/OFF”



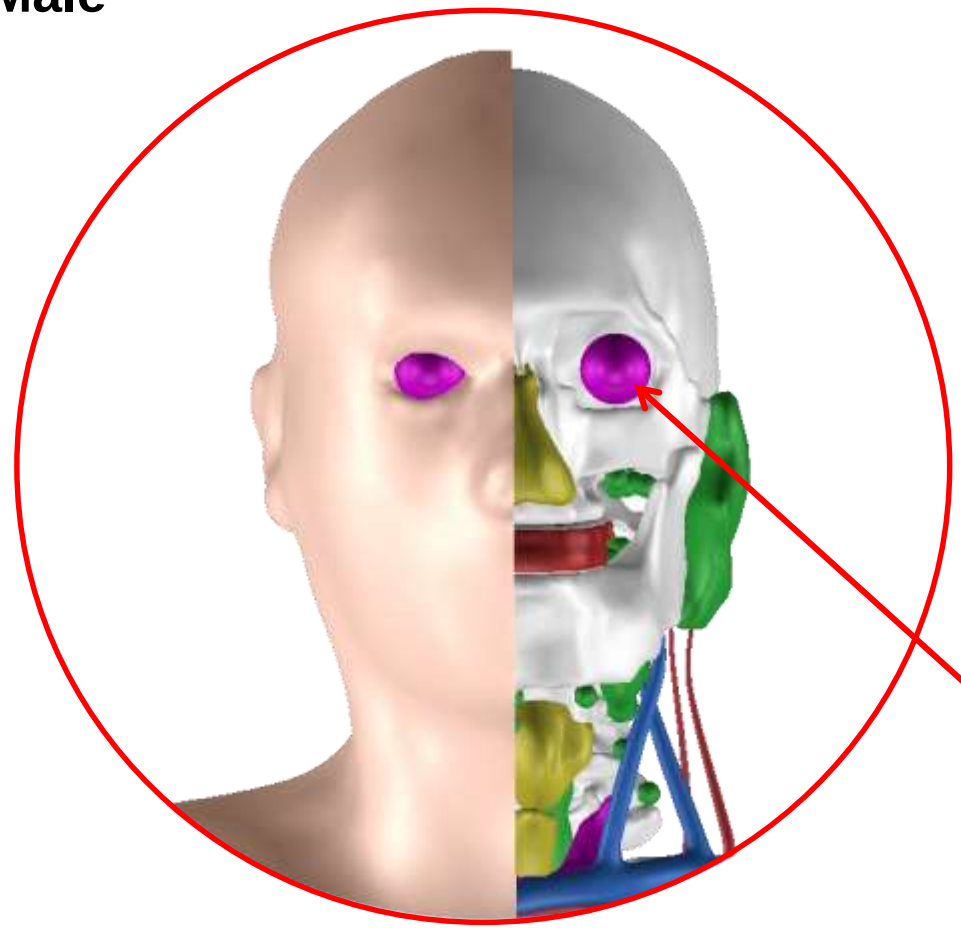
Bronchiolar (bb)

Eyeballs

Behrens' eye model (2009)

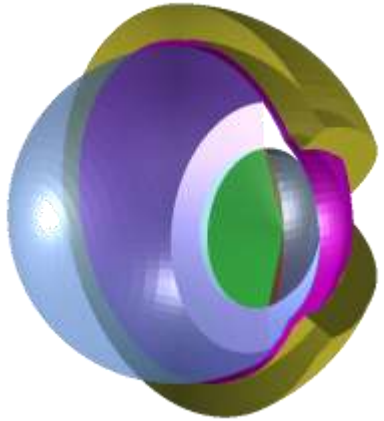


Male



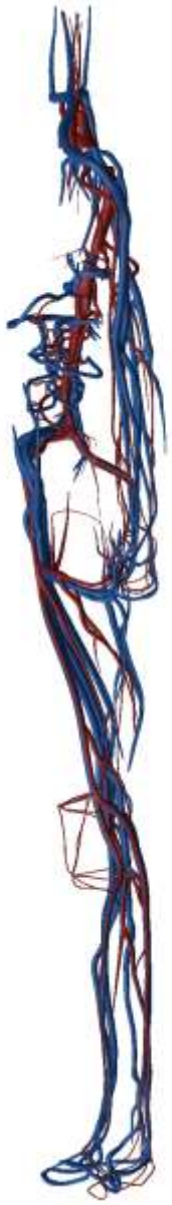
Installed

Converted to mesh format



Blood in Large Arteries and Veins

Male



Female

Muscle

Male

Female

Lymphatic Nodes

Male

Female

MRCPs – Complete

Male

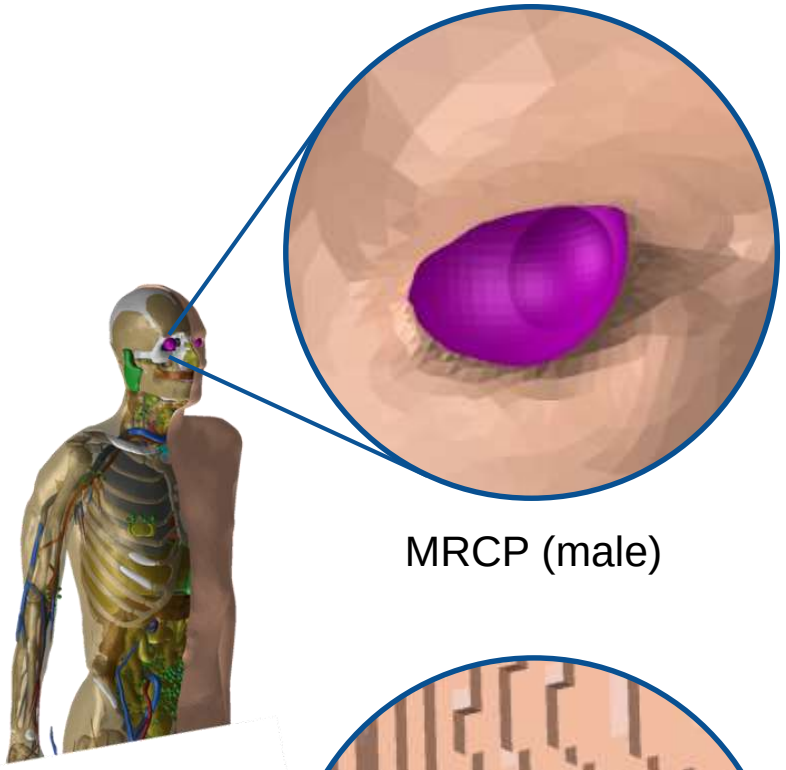
Female

List of Topics

- Compatibility with MC codes
- Dosimetry impact
- DCs for Industrial Radiography Sources

Compatibility with MC Codes

MRCP (Male) and Voxel Phantoms



MRCP (male)

Voxelized phantom
(0.6 x 0.6 x 0.6 mm^3)

Voxelized phantom
(1 x 1 x 1 mm^3)

Voxelized phantom
(2 x 2 x 2 mm^3)

Voxelized phantom
(4 x 4 x 4 mm^3)

VRCP (male)
(2.137 x 2.137 x 8 mm^3)

Memory Requirement

Unit: GB

Phantom		PHITS	Geant4	MCNP
MRCP (male)		1.2	10.6	13.7
Voxelized phantom	0.6 mm	44.7	1.8	5.5
	1.0 mm	9.7	0.8	1.6
	2.0 mm	1.3	0.6	0.6
	4.0 mm	0.3	0.6	0.5
VRCP (male)		0.3	0.5	0.5

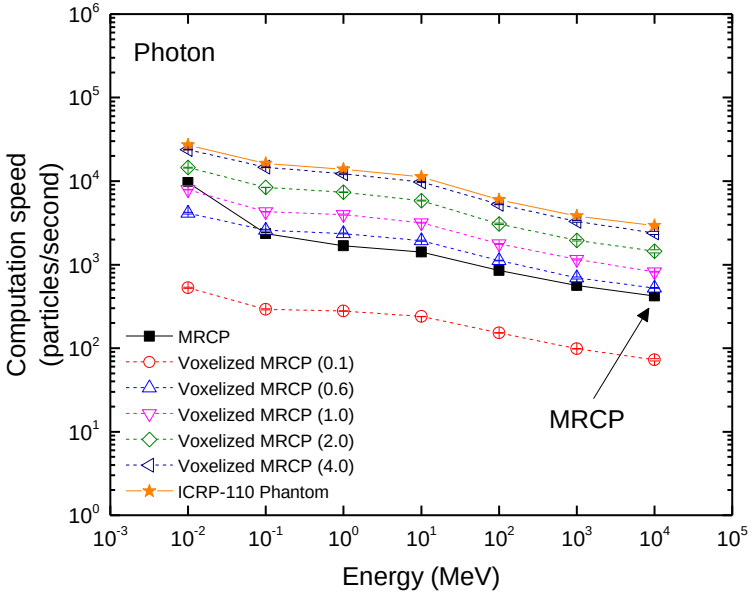
* Typical PC memory size (e.g. Dell XPS):16 GB, 32 GB, and 64 GB.

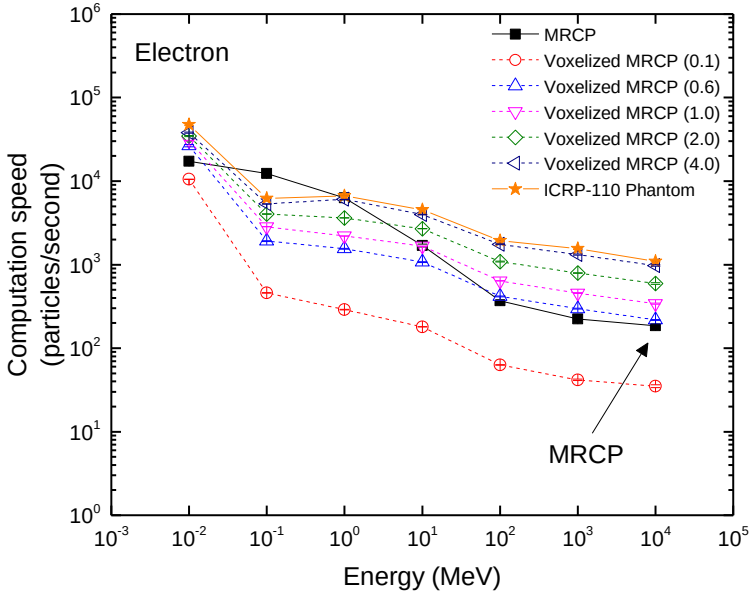
Initialization Time

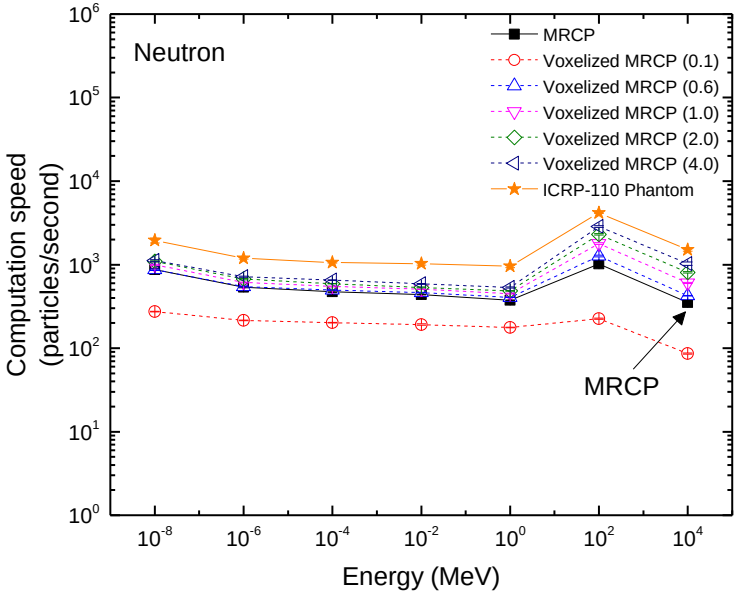
Unit: minutes

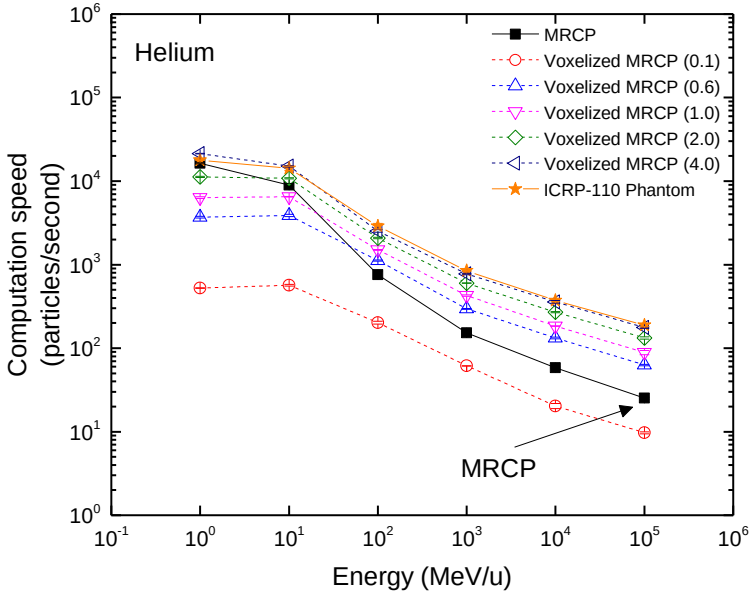
Phantom		PHITS	Geant4	MCNP
MRCP (male)		0.2	3.3	2.3
Voxelized phantom	0.6 mm	15.1	0.8	19.5
	1.0 mm	3.5	0.6	5.5
	2.0 mm	0.5	0.5	1.7
	4.0 mm	0.2	0.5	1.1
VRCP (male)		0.2	0.4	1.0

Computation Speed – Geant4

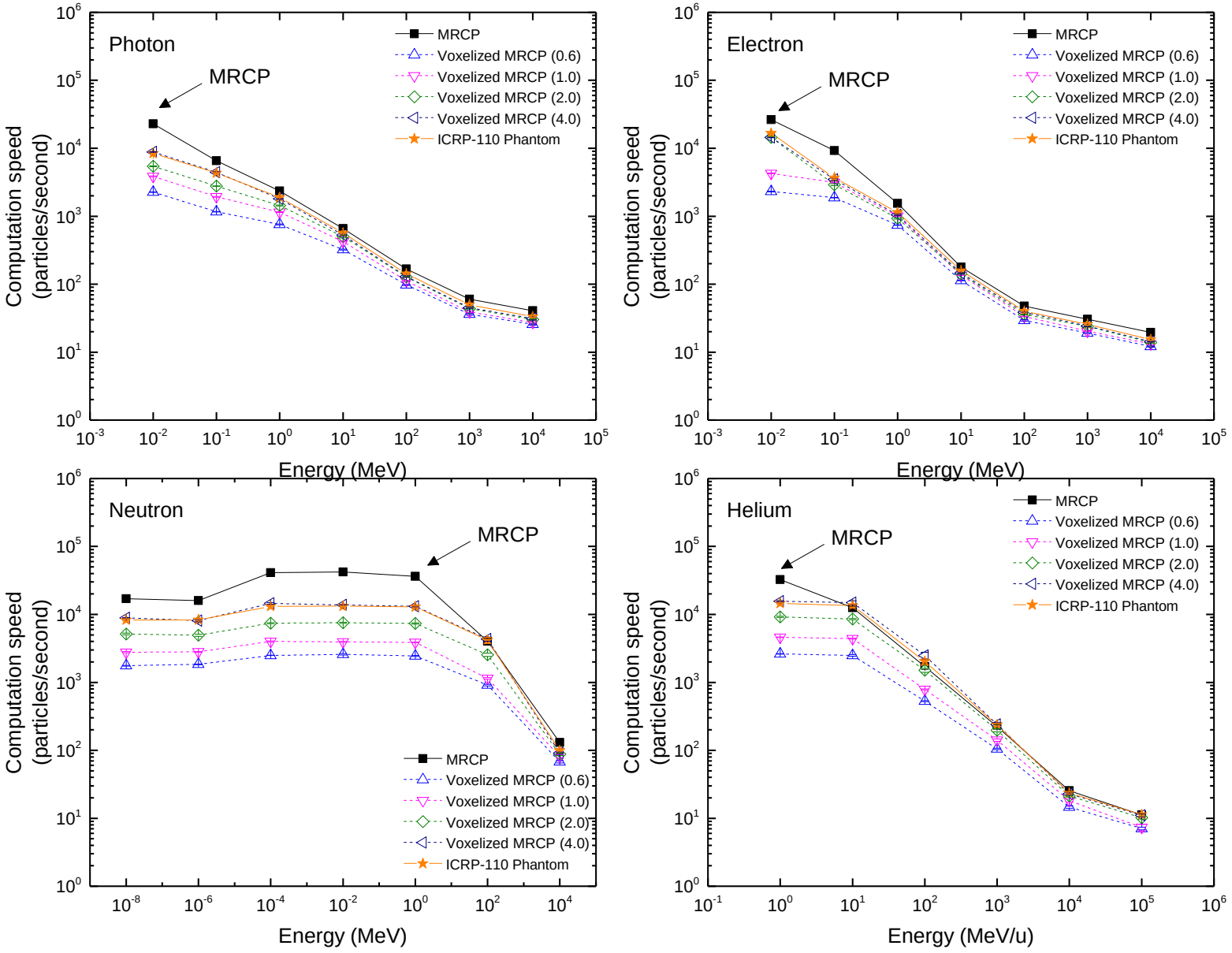




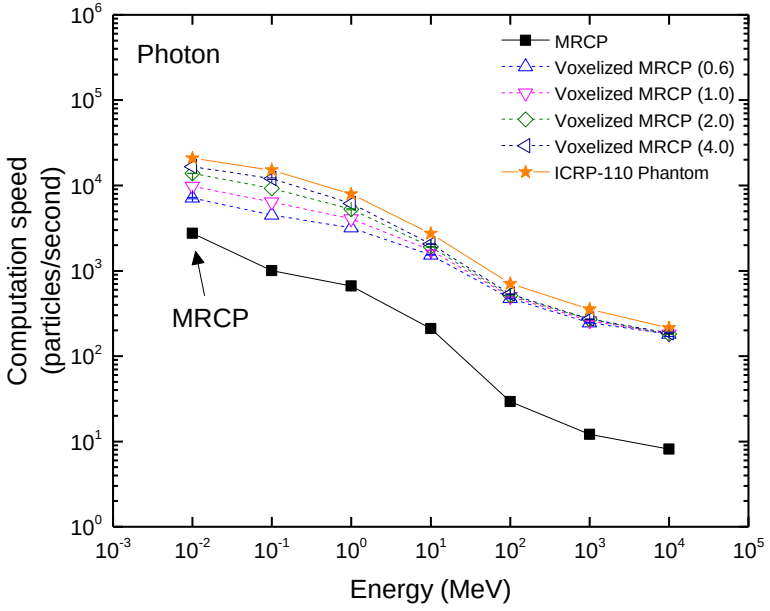


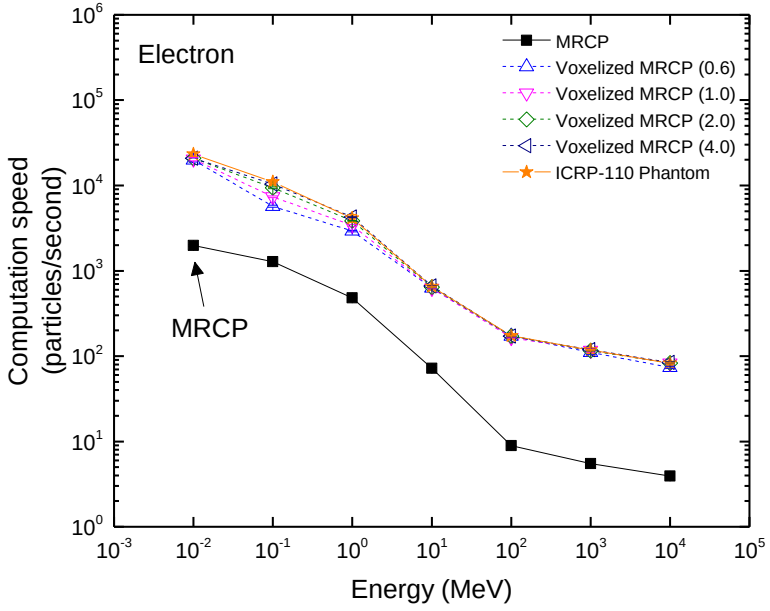


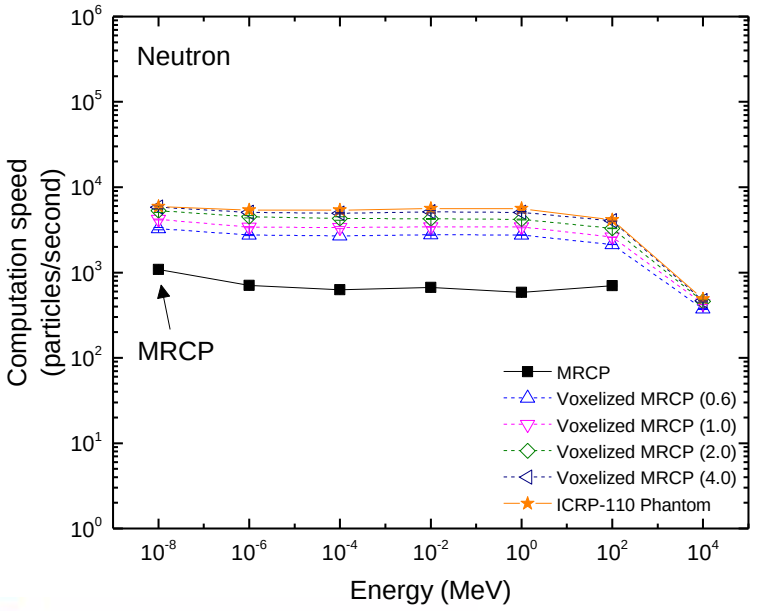
Computation Speed - PHITS

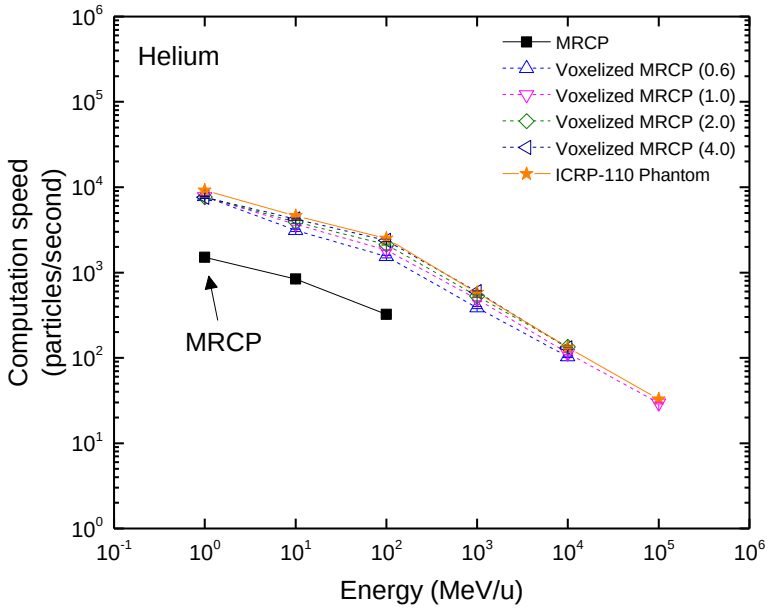


Computation Speed – MCNP6



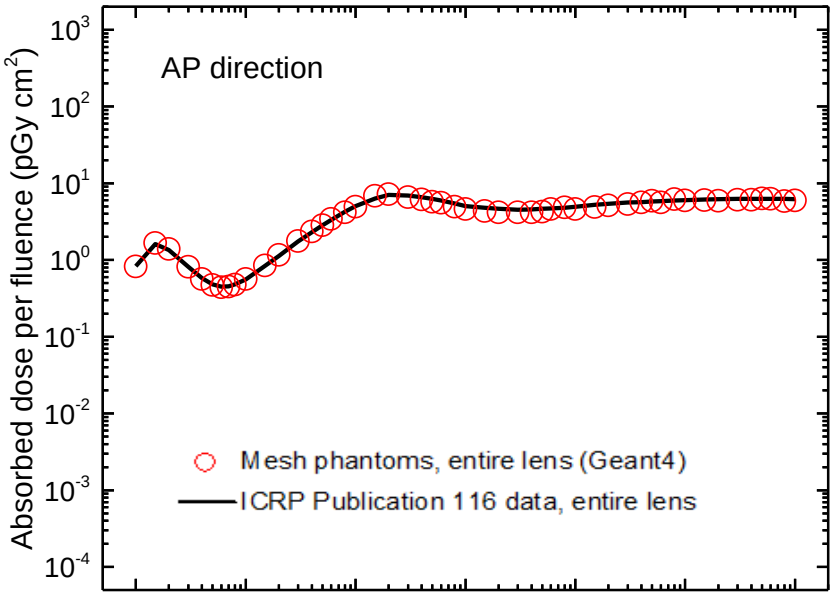


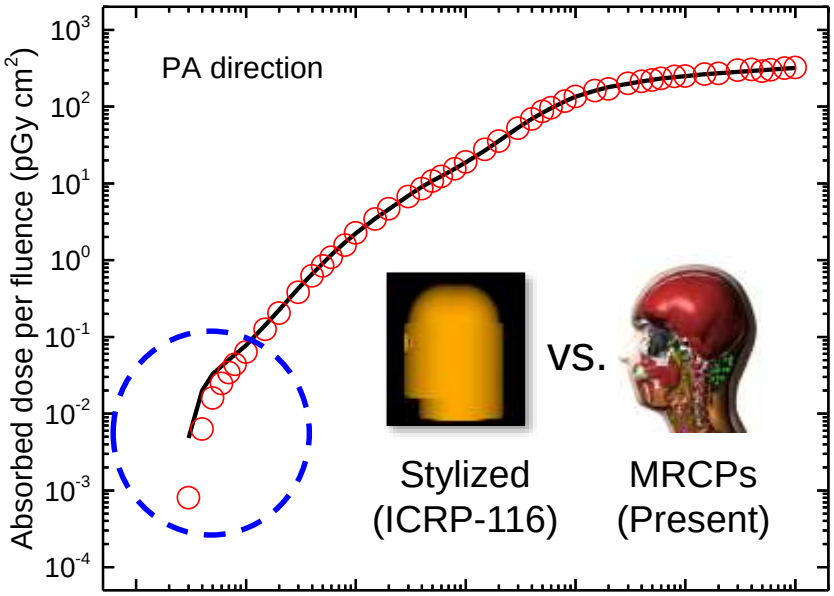


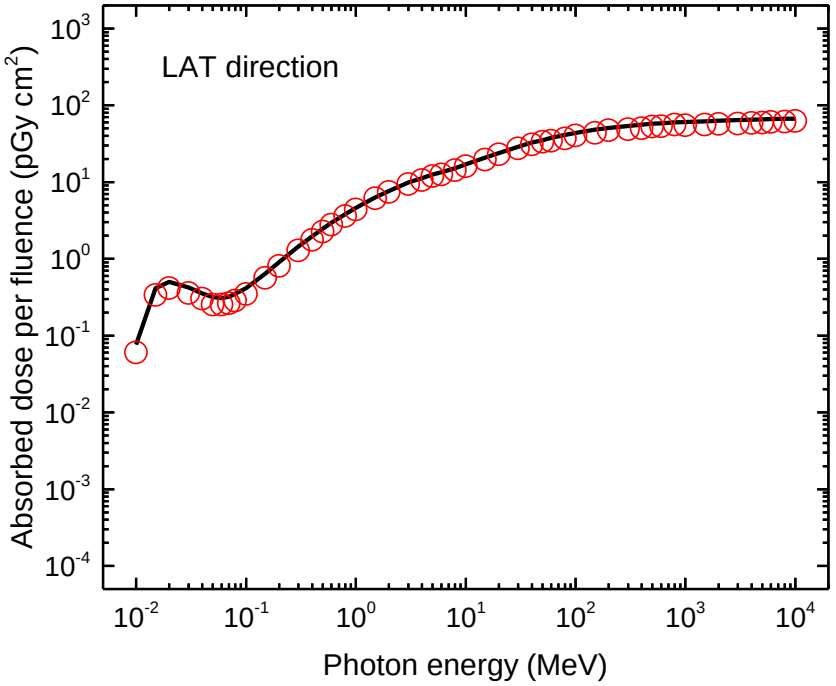


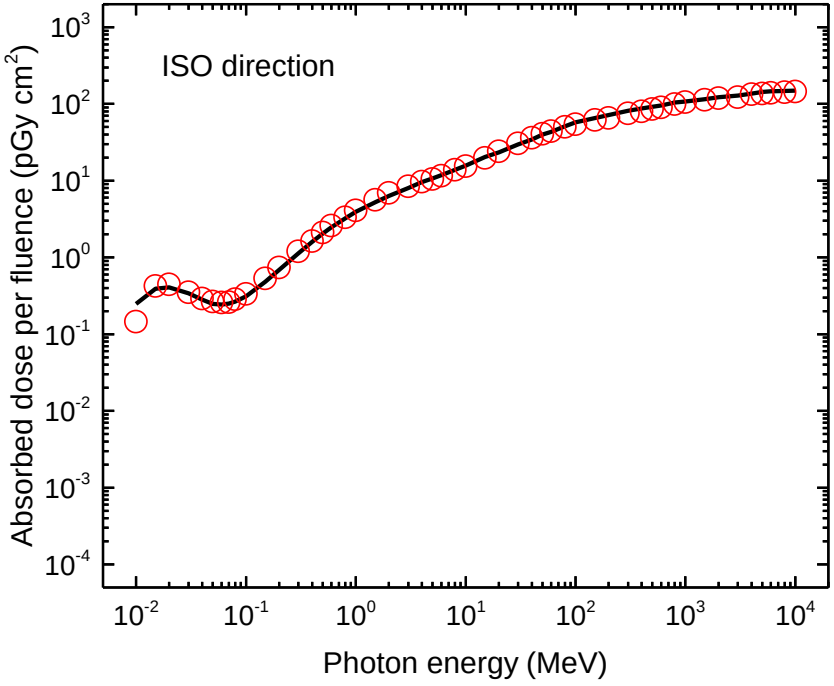
Dosimetry Impact

Lens Dose Coefficient – Photon

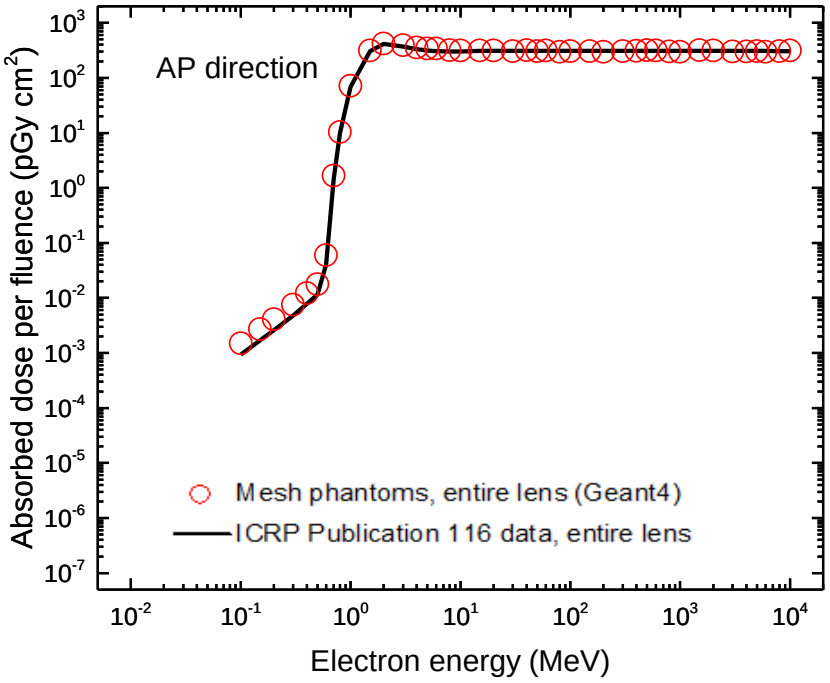




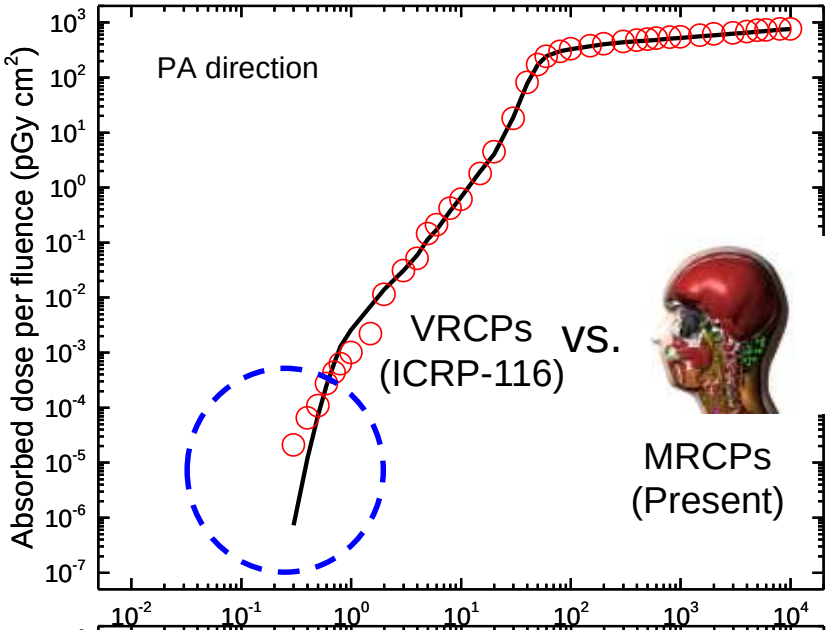


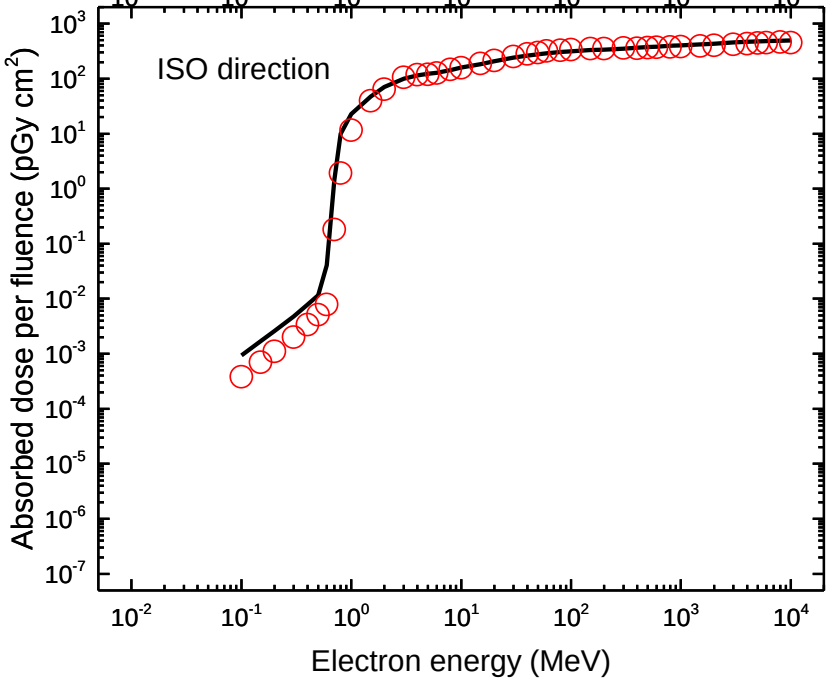


Lens Dose Coefficient – Electron

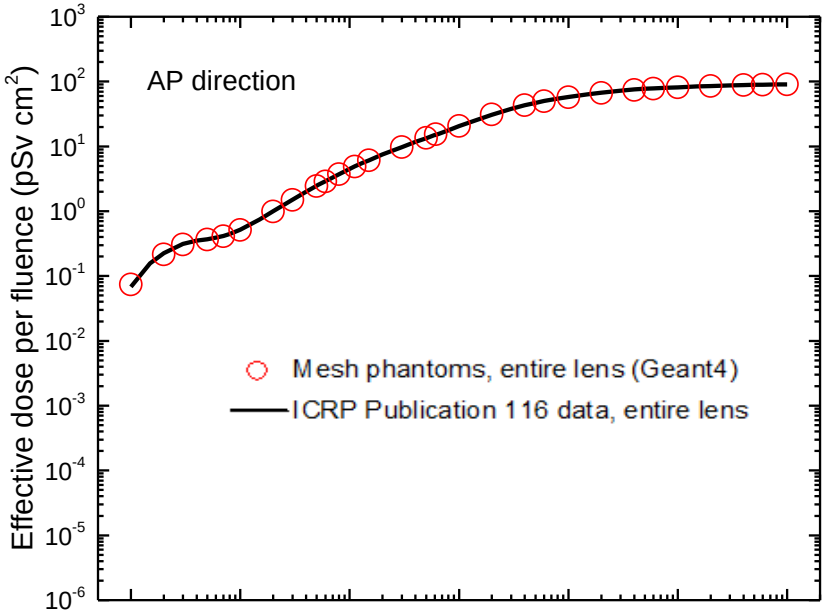


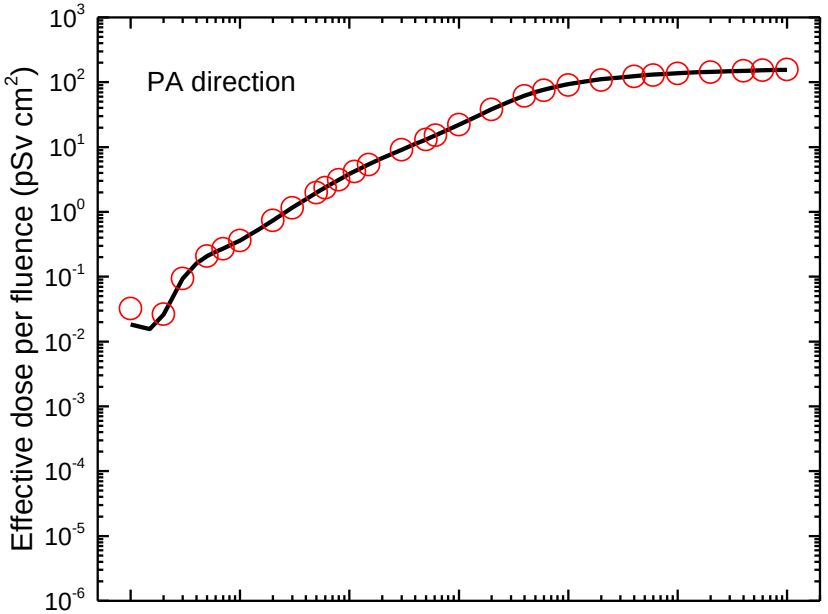
LAT (not given in ICRP-116)

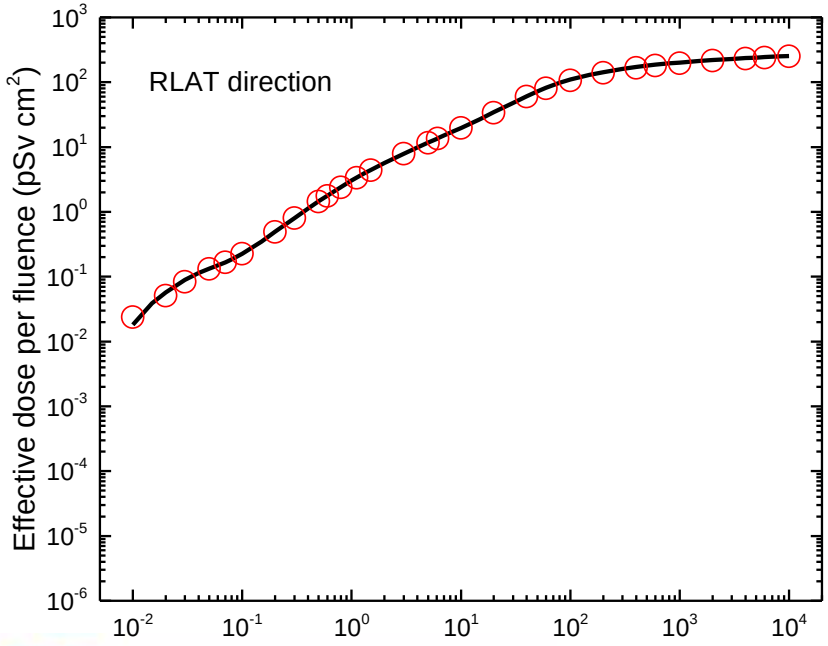


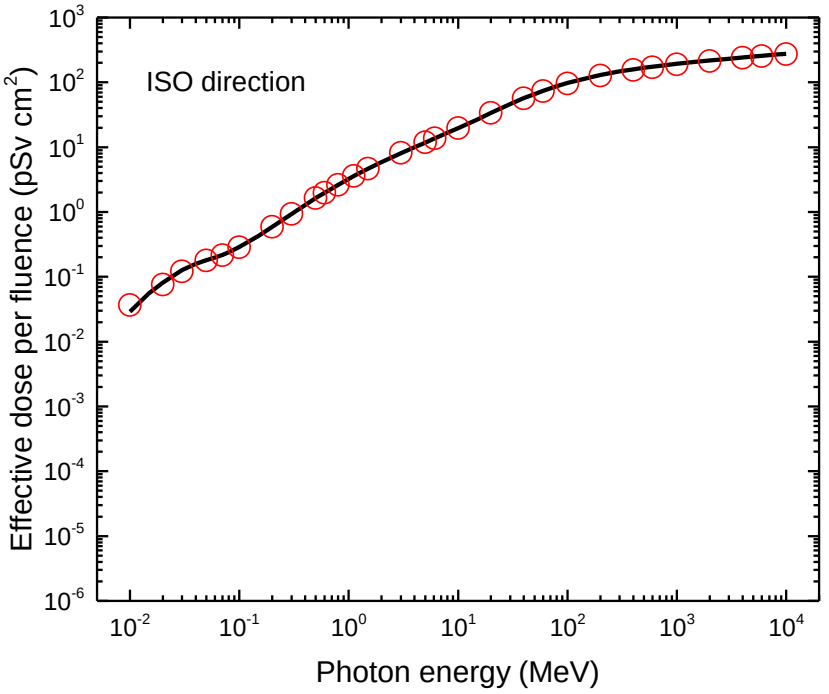


Effective Dose Coefficient – Photon

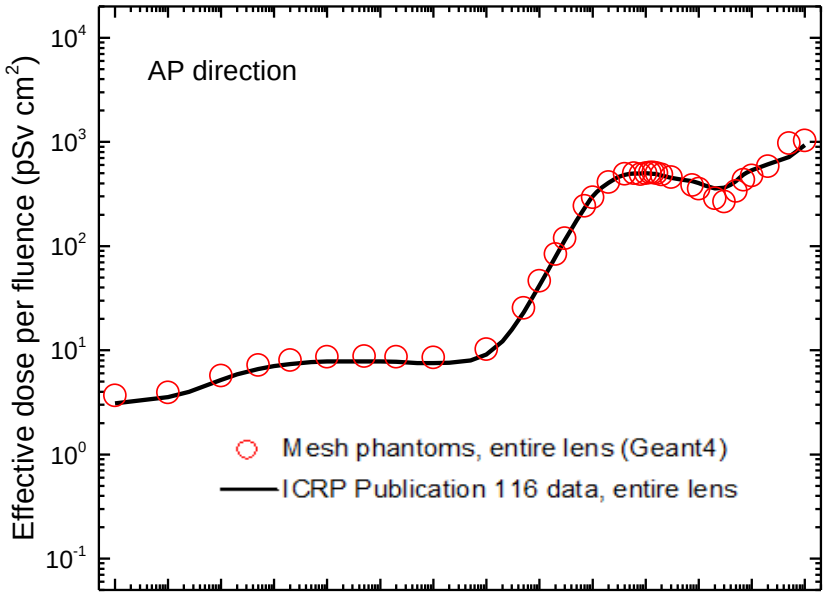


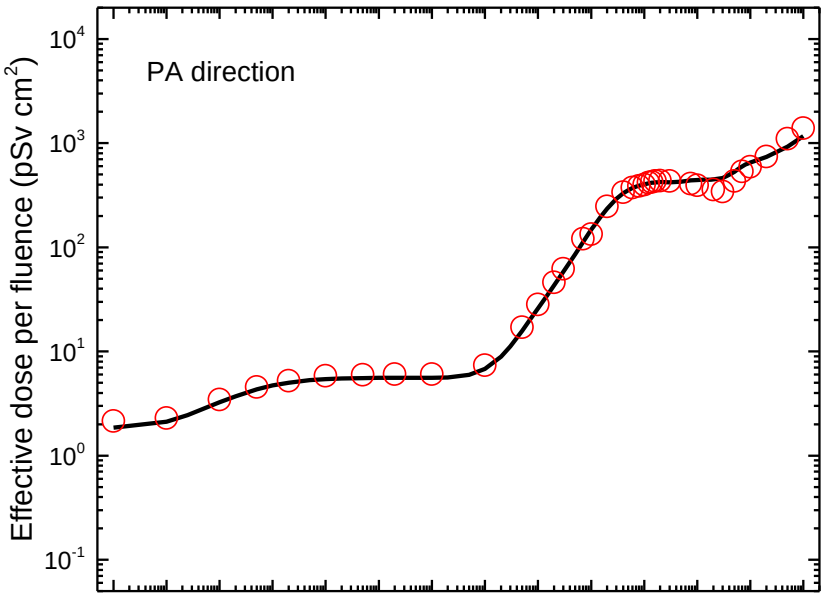


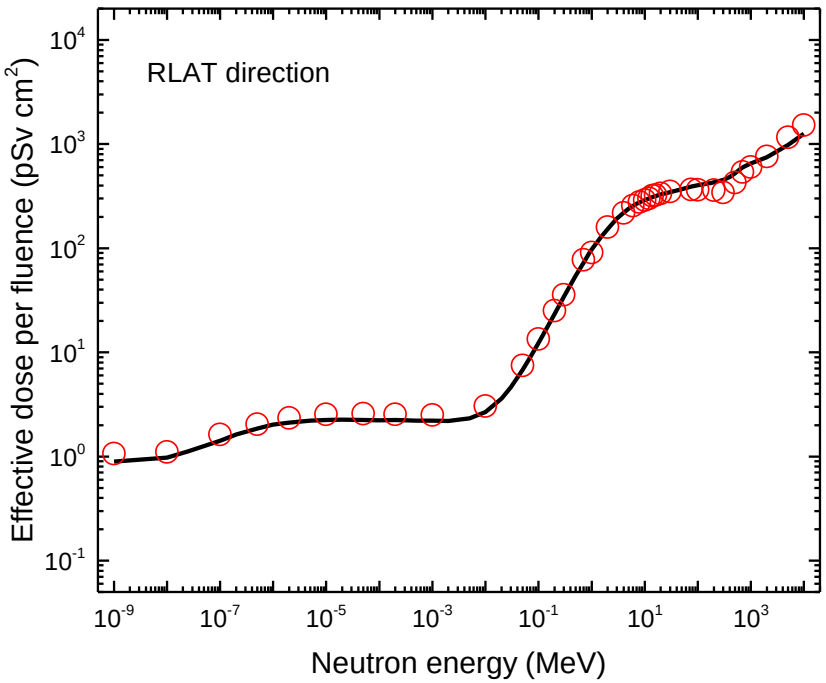


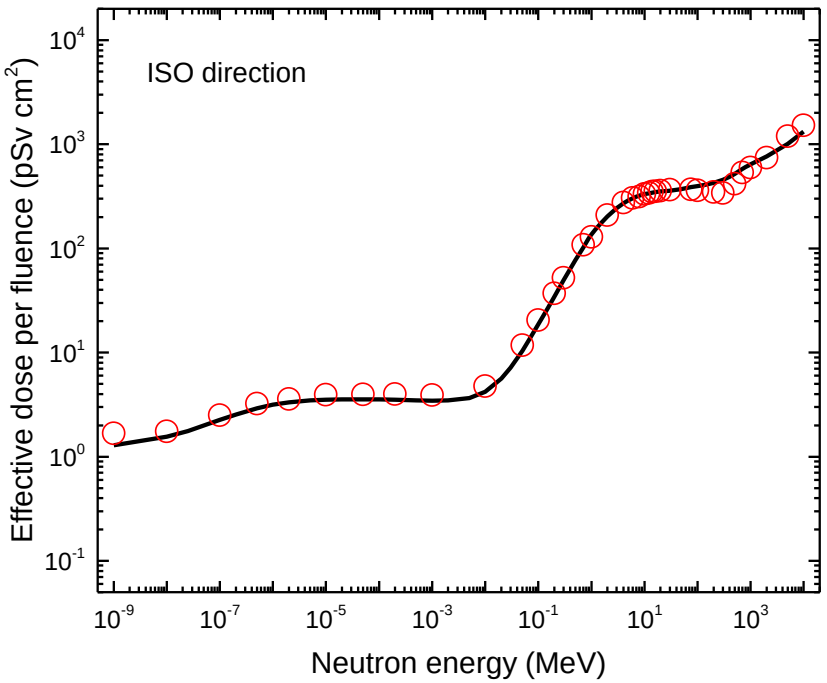


Effective Dose Coefficient – Neutron

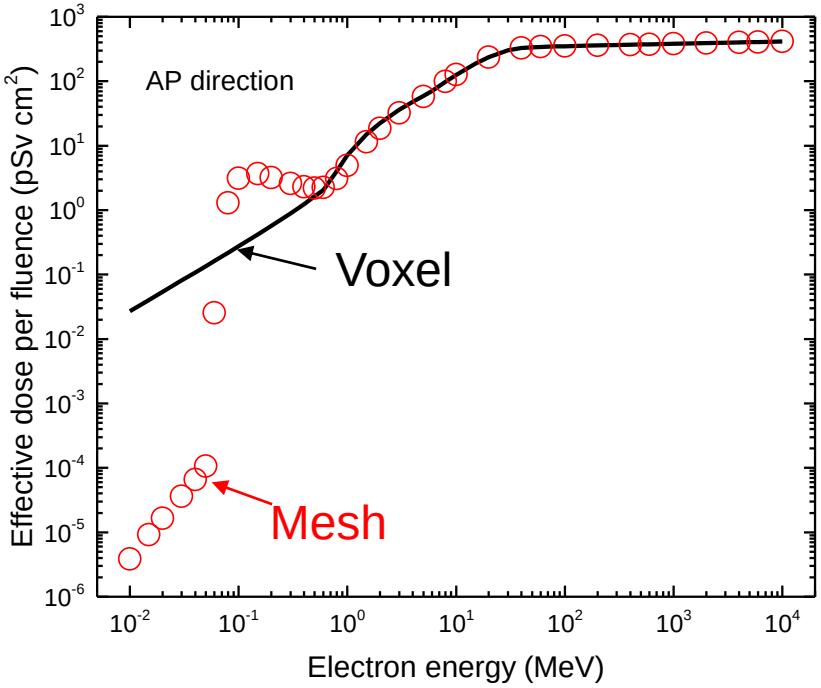


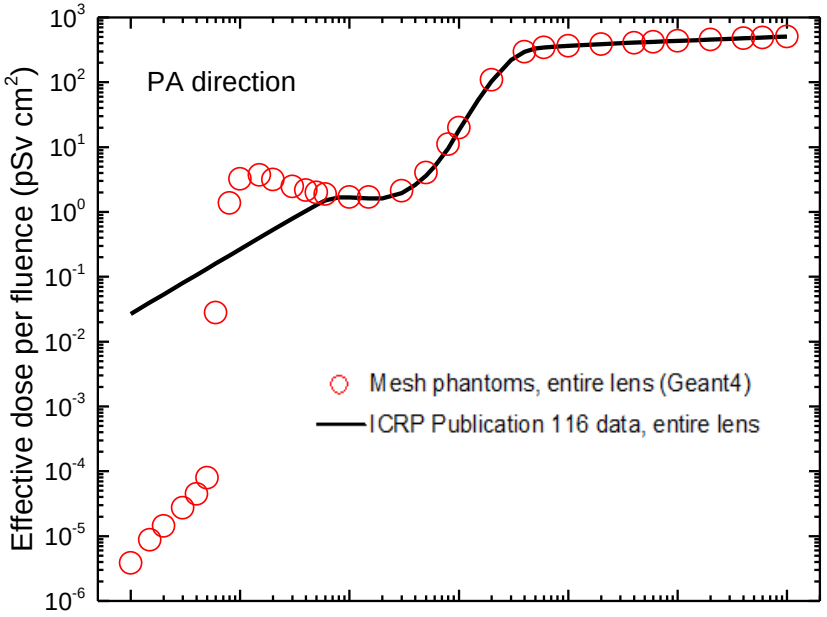


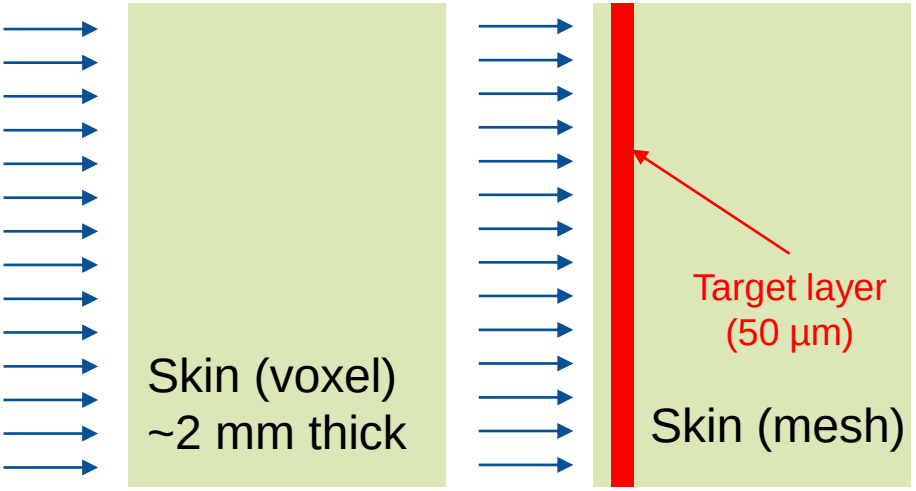


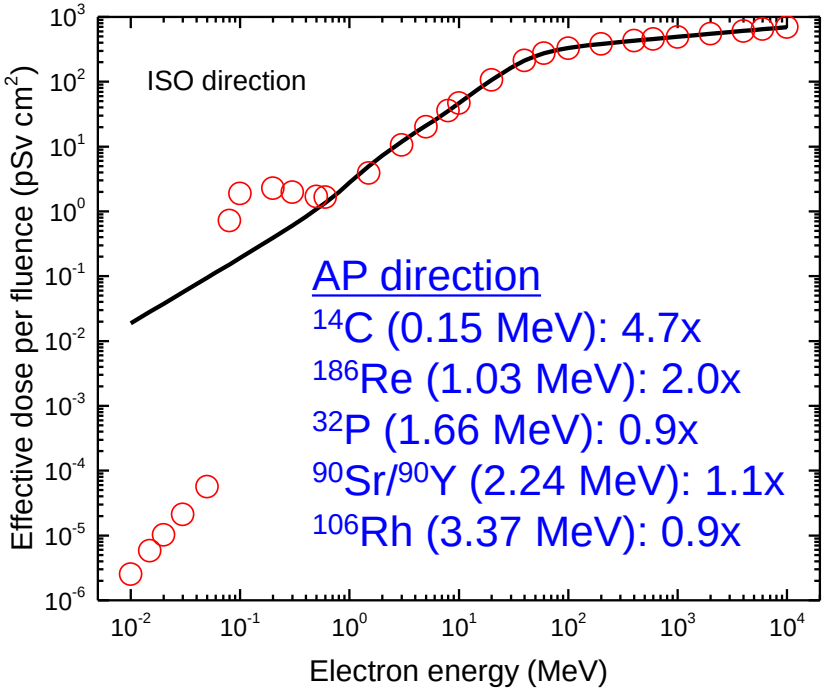


Effective Dose Coefficient – Electron

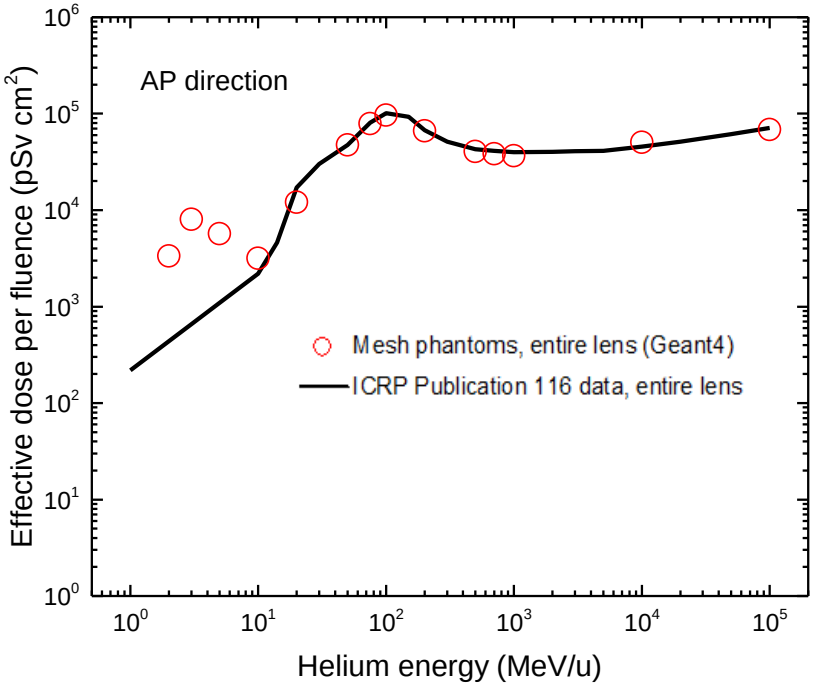




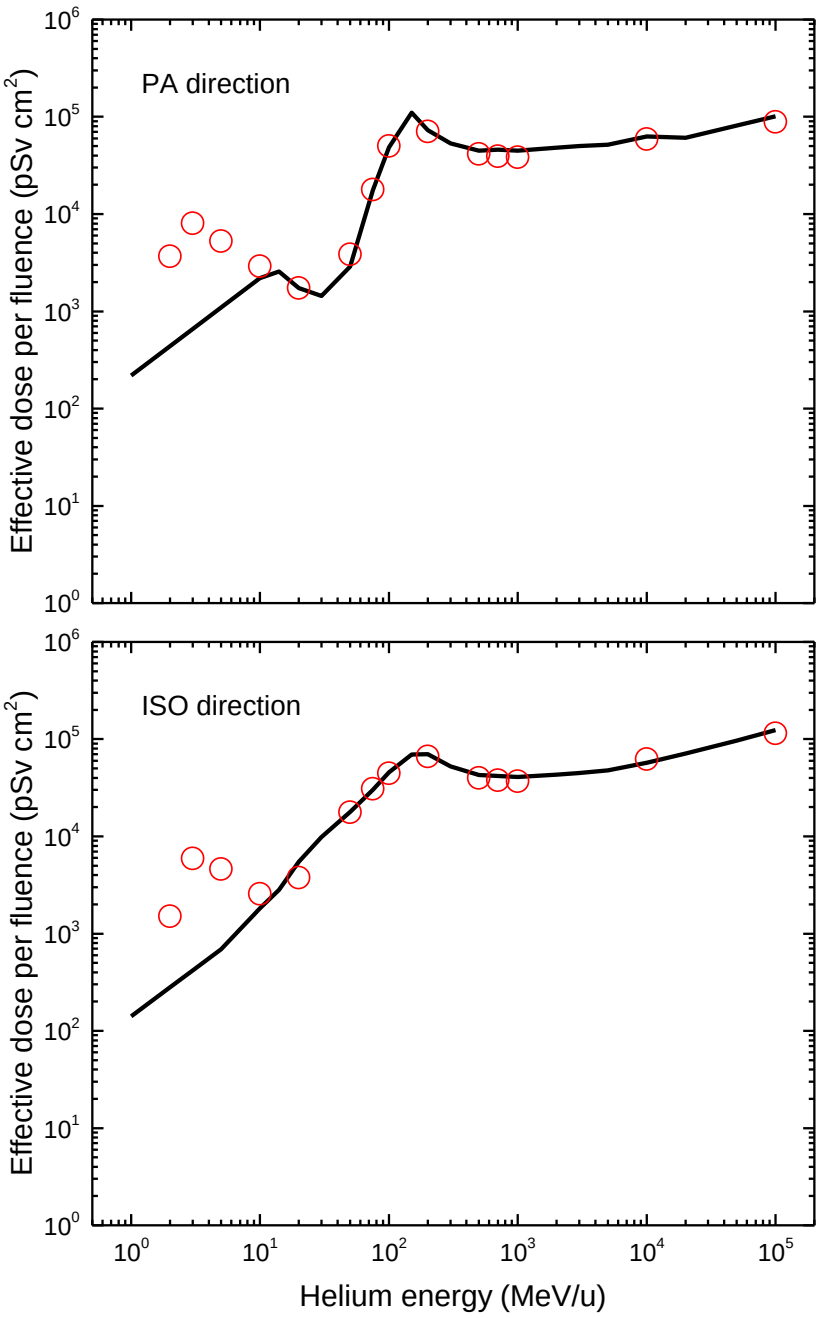




Effective Dose Coefficient – Helium Ion



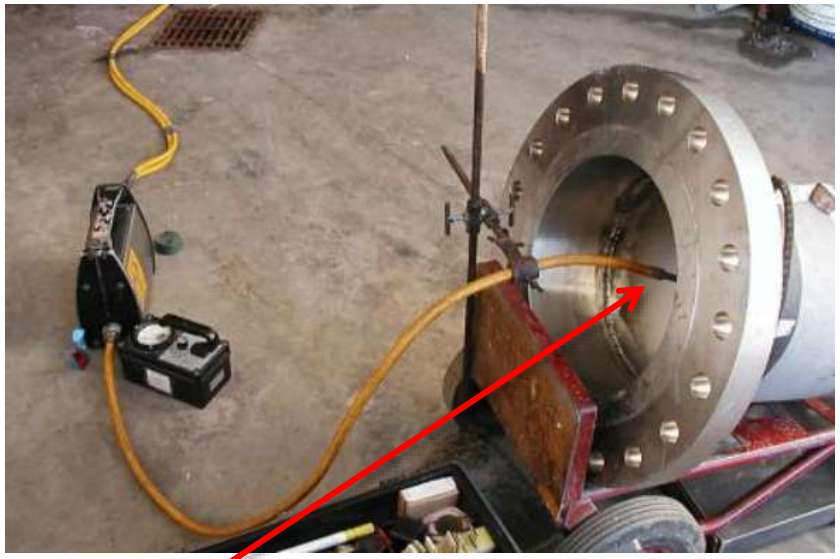
LAT (not given in ICRP-116)



DCs for Industrial Radiography Sources

Why Industrial Radiography Sources?

- Industrial radiography sources account for ~50% of all the reported accidents in the nuclear related industry (IAEA, 1998).



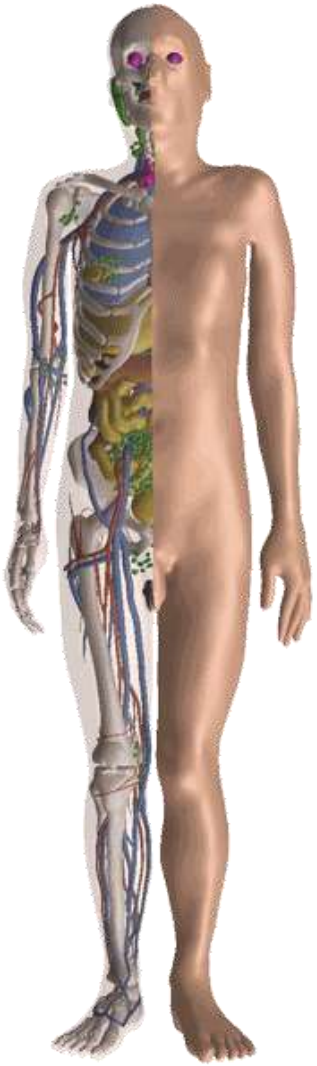
- Dose coefficients for -
  - red bone marrow (RBM), brains, lungs, and small and large intestines
  - effective dose (for comparison purpose)

Different Body Sizes

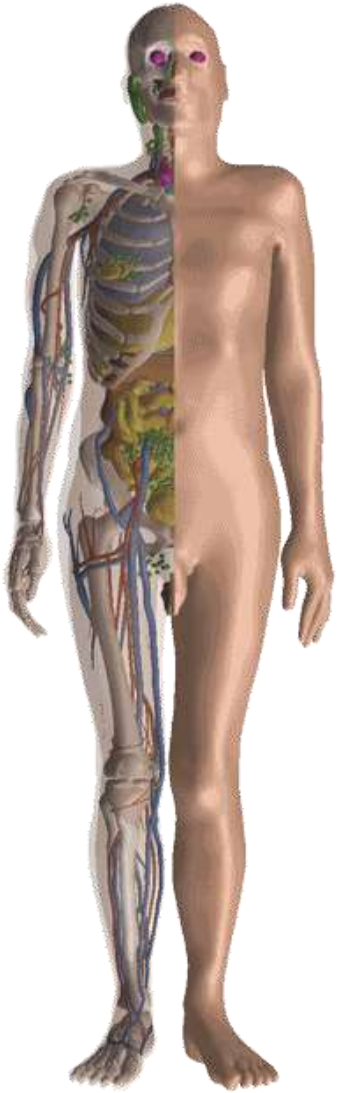
- Non-reference-size phantoms:
  - 10th percentile phantom (H10M10)
  - 90th percentile phantom (H90M90)

- Procedure (3 steps)
  1. Height & weight (standing height, weight, sitting height, head height): PeopleSize 2008 software
  2. Organ mass (adjustment in planar direction): lean body mass (LBM) equation (Deurenberg et al. 1991)
  3. Detailed dimensions
     - calf, upper arm, waist, hip, and thigh circumferences, sagittal abdominal diameter: NHANES Continuous (1999-2014) & III (1988-1994)
     - Head breadth, head length: ANSUR II (2010-2012)

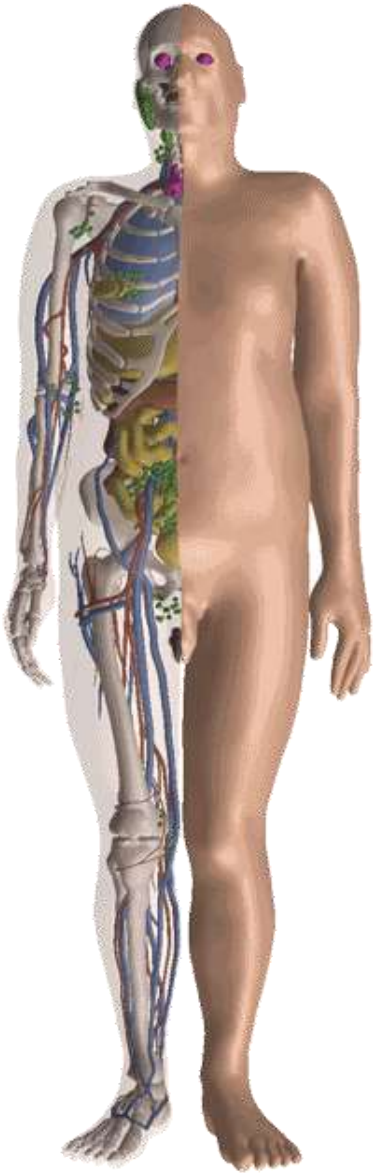
Male phantoms



10th percentile

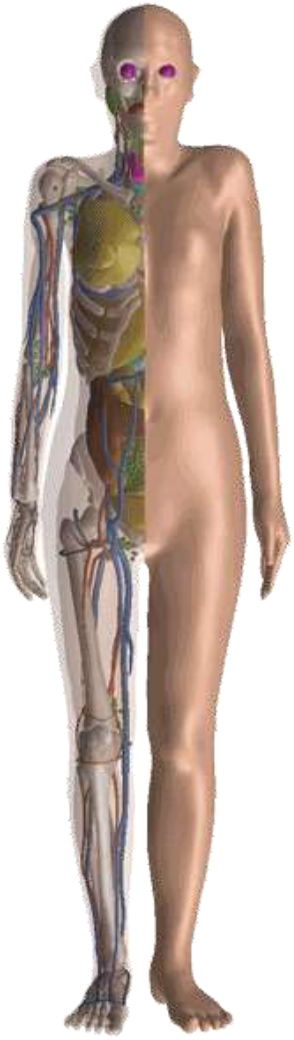


MRCP

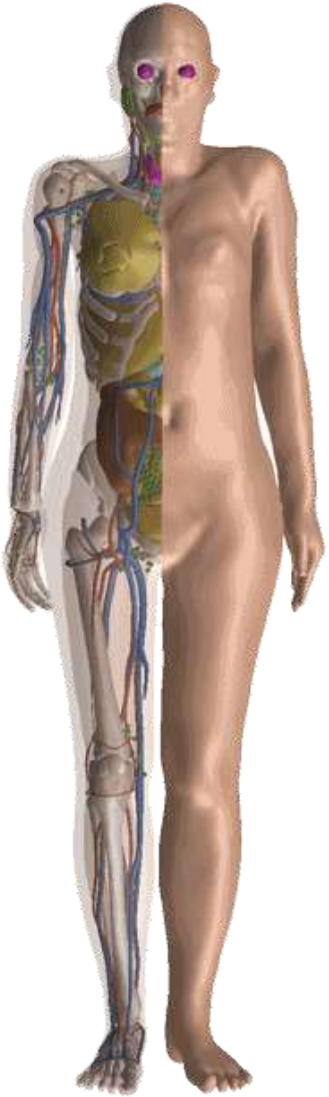


90th percentile

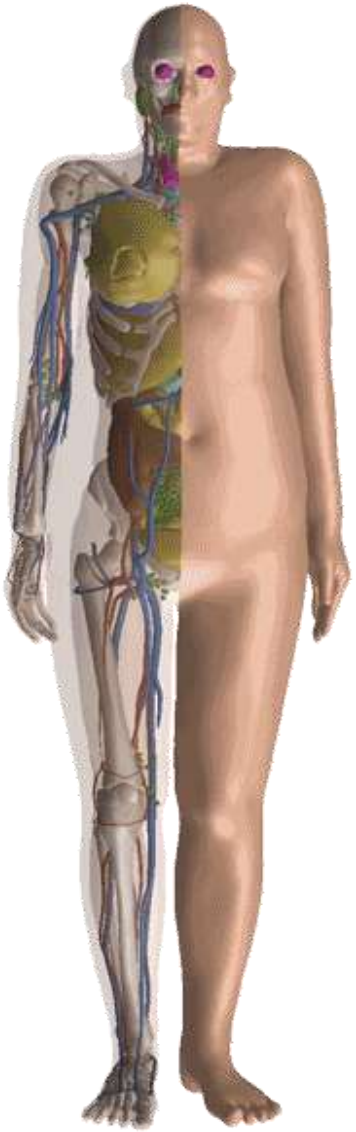
Female phantoms



10th percentile



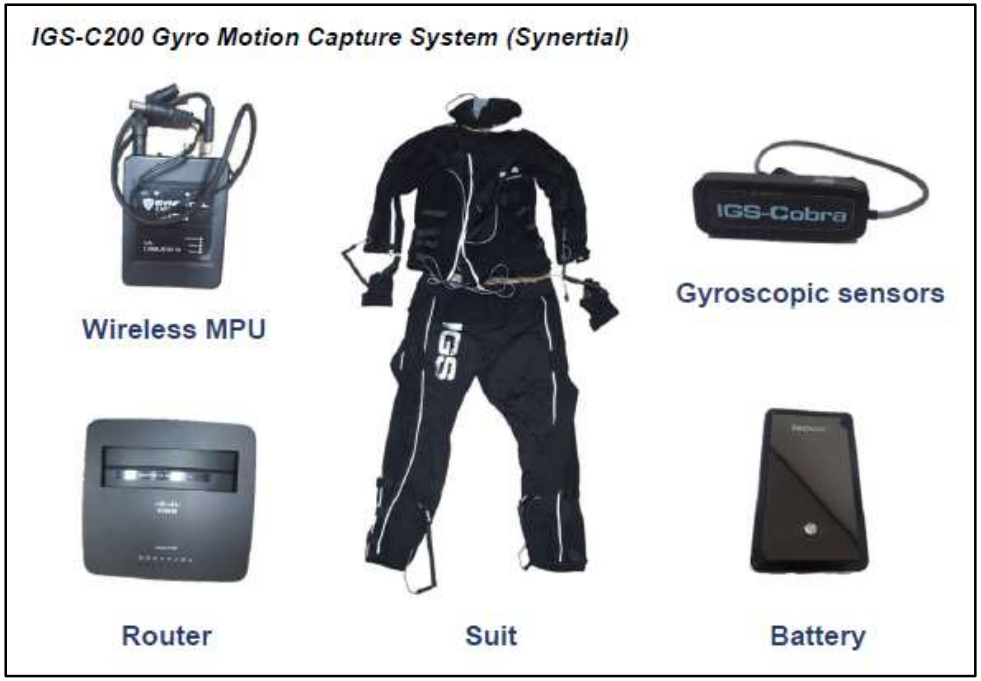
MRCP

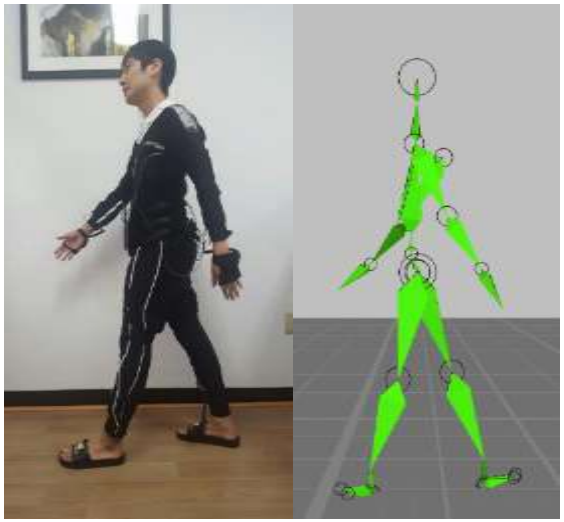


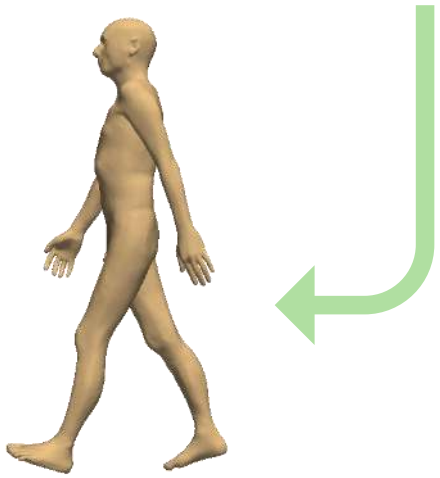
90th percentile

Different Postures

- 5 arbitrary postures produced with a motion capture device.







Walking

Bending

Sitting

Kneeling

Squatting

Source Locations

Total 60 source locations

- Level: ground, middle thigh, lower torso, middle torso, and upper torso
- Direction: front, back, right, and left
- Distance: 0.5, 10, 30, 100, 150, and 300 cm

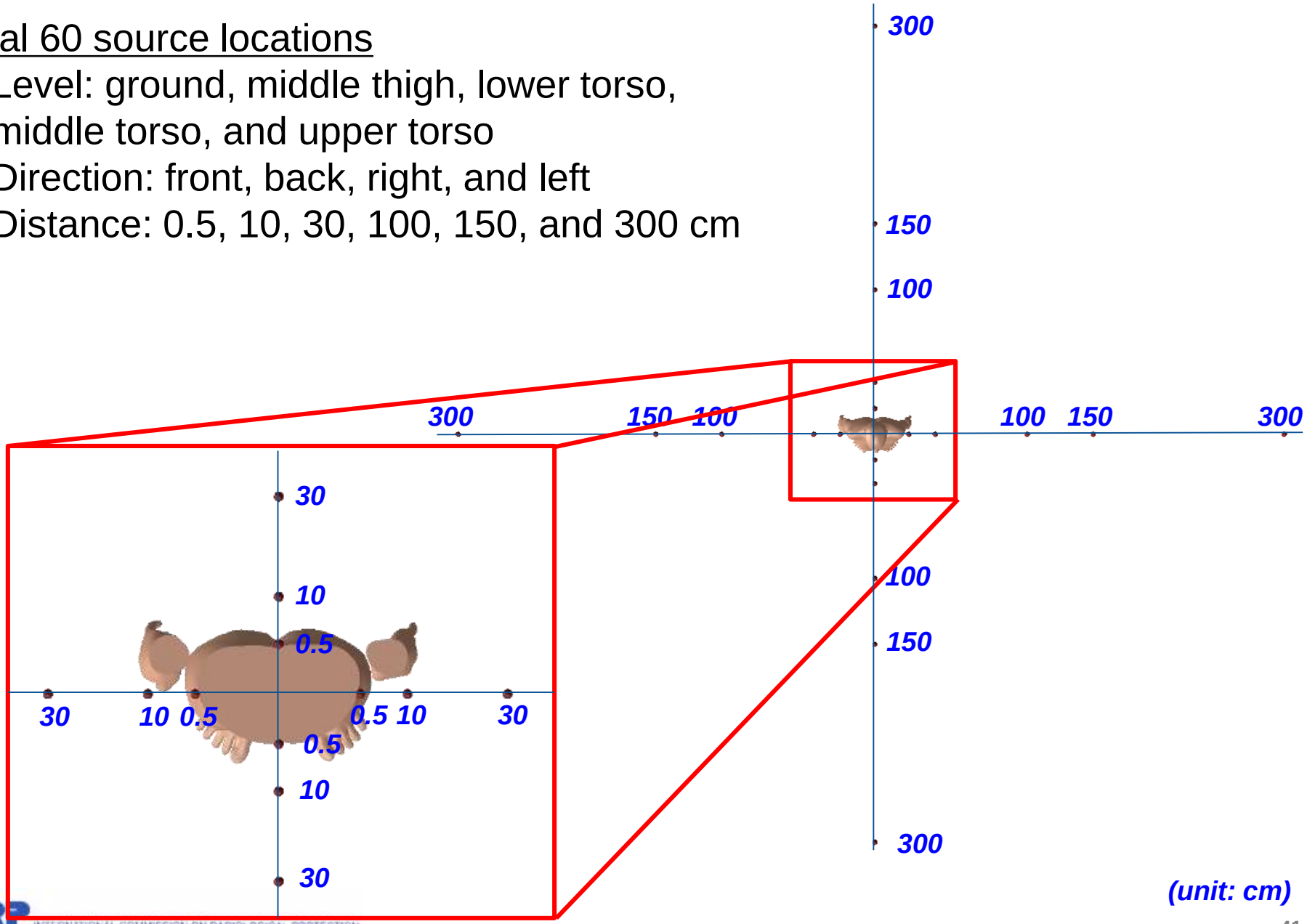
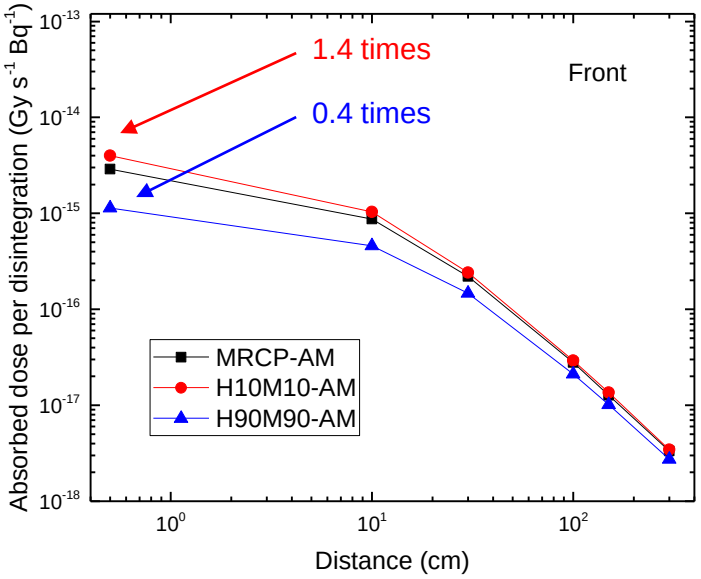
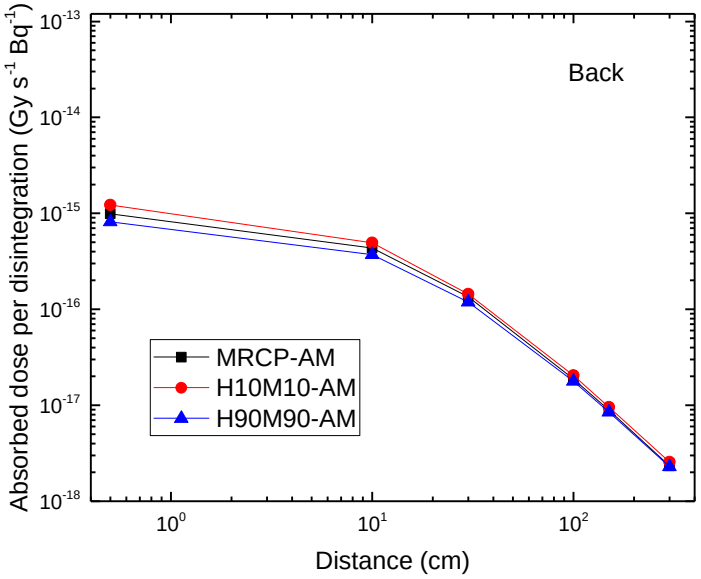


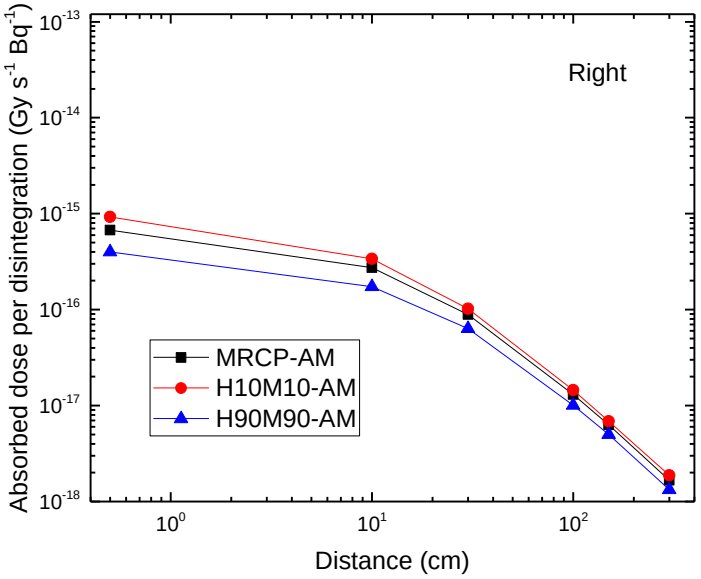
Table J.1. Ir-192: RBM absorbed dose per disintegration (in Gy s^{-1} Bq^{-1}) for external point sources.

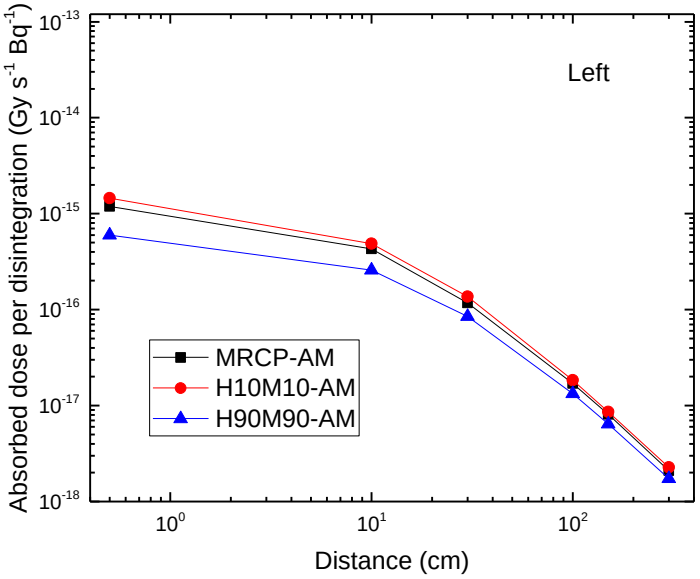
Level	Dist. (cm)	Gender	Direction											
			Front			Back			Right			Left		
			10%ile	MRCP	90%ile	10%ile	MRCP	90%ile	10%ile	MRCP	90%ile	10%ile	MRCP	90%ile
Ground	0.5	Male												
		Female												
	10	Male												
		Female												
	30	Male												
		Female												
Middle thigh	0.5	Male												
		Female												
	10	Male												
		Female												
	30	Male												
		Female												
Lower torso	0.5	Male	5.36E-16	4.00E-16	1.91E-16	1.33E-15	1.13E-15	9.48E-16	4.63E-16	3.56E-16	1.96E-16	4.32E-16	3.59E-16	1.82E-16
		Female	6.35E-16	4.80E-16	2.93E-16	1.38E-15	1.19E-15	9.17E-16	4.84E-16	4.33E-16	2.19E-16	4.51E-16	4.12E-16	2.00E-16
	10	Male	2.65E-16	2.19E-16	1.18E-16	5.08E-16	4.52E-16	3.98E-16	2.30E-16	1.88E-16	1.22E-16	2.21E-16	1.88E-16	1.16E-16
		Female	3.20E-16	2.66E-16	1.64E-16	5.27E-16	4.71E-16	3.90E-16	2.43E-16	2.17E-16	1.29E-16	2.26E-16	2.00E-16	1.22E-16
	30	Male	1.12E-16	9.77E-17	6.05E-17	1.62E-16	1.50E-16	1.36E-16	7.98E-17	6.85E-17	5.08E-17	7.63E-17	6.68E-17	4.88E-17
		Female	1.24E-16	1.10E-16	7.40E-17	1.66E-16	1.53E-16	1.34E-16	8.40E-17	7.61E-17	4.98E-17	7.80E-17	7.35E-17	5.11E-17
	100	Male	2.03E-17	1.88E-17	1.42E-17	2.49E-17	2.37E-17	2.27E-17	1.32E-17	1.18E-17	9.80E-18	1.29E-17	1.16E-17	9.46E-18
		Female	2.14E-17	2.01E-17	1.55E-17	2.54E-17	2.40E-17	2.24E-17	1.40E-17	1.28E-17	1.03E-17	1.38E-17	1.26E-17	1.02E-17
	150	Male	9.95E-18	9.32E-18	7.31E-18	1.19E-17	1.13E-17	1.09E-17	6.40E-18	5.77E-18	4.94E-18	6.29E-18	5.69E-18	4.80E-18
		Female	1.05E-17	9.86E-18	7.89E-18	1.21E-17	1.15E-17	1.08E-17	6.88E-18	6.28E-18	5.24E-18	6.79E-18	6.17E-18	5.19E-18
	300	Male	2.66E-18	2.57E-18	2.10E-18	3.13E-18	3.00E-18	2.93E-18	1.73E-18	1.58E-18	1.39E-18	1.71E-18	1.56E-18	1.35E-18
		Female	2.80E-18	2.70E-18	2.22E-18	3.17E-18	3.02E-18	2.89E-18	1.87E-18	1.71E-18	1.48E-18	1.84E-18	1.68E-18	1.47E-18
Middle torso	0.5	Male												
		Female												
	10	Male												
		Female												
	30	Male												
		Female												
Upper torso	0.5	Male												
		Female												
	10	Male												
		Female												
	30	Male												
		Female												

Result - Male SI for ^{192}Ir at Lower Torso Level

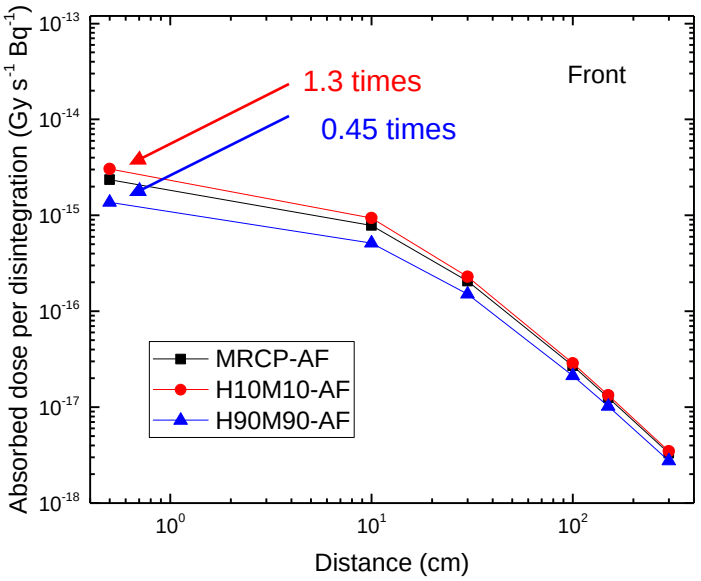


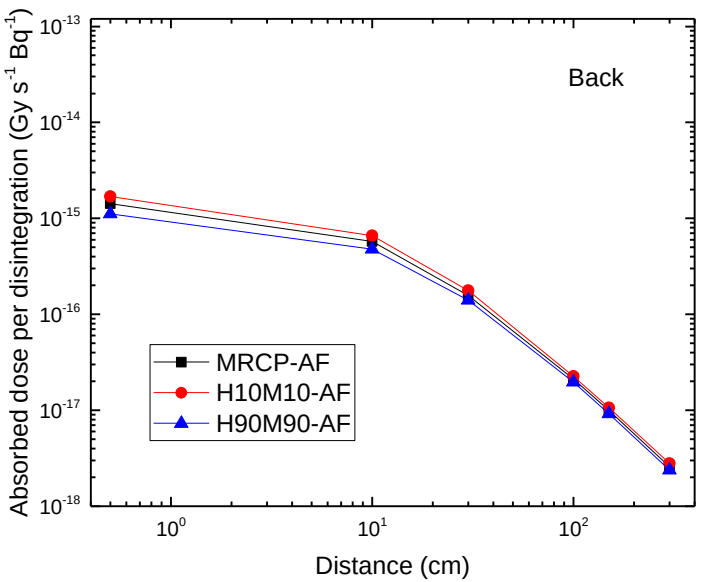


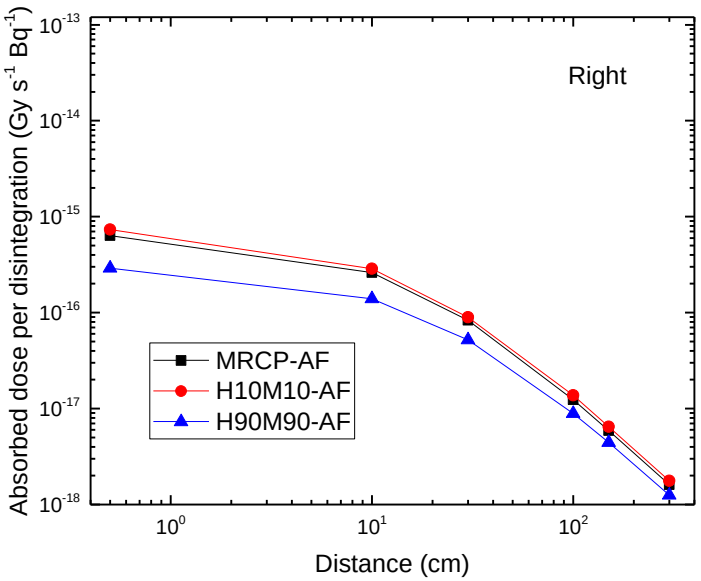


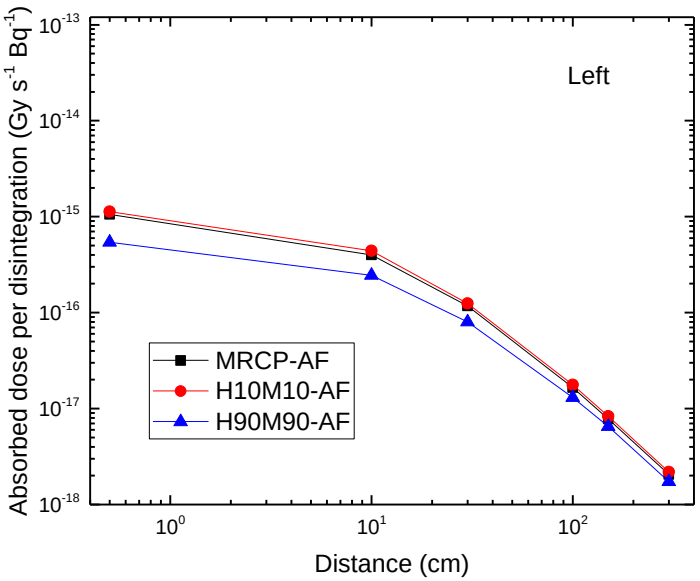


Result - Female SI for ^{192}Ir at Lower Torso Level

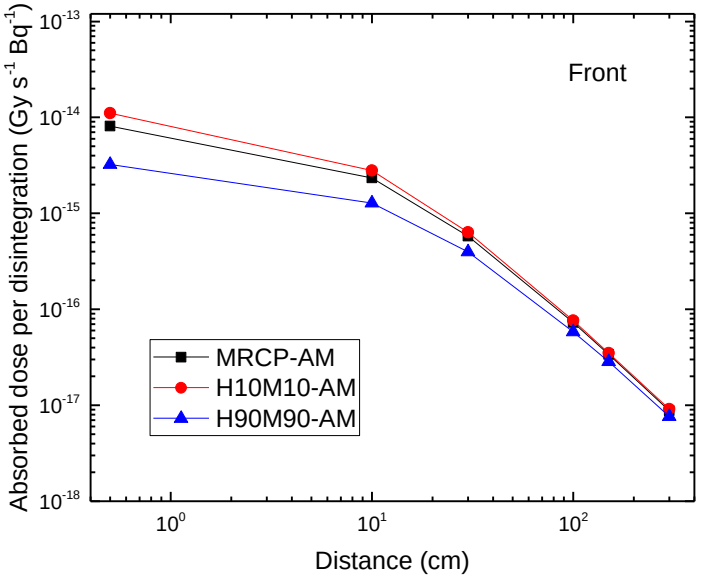


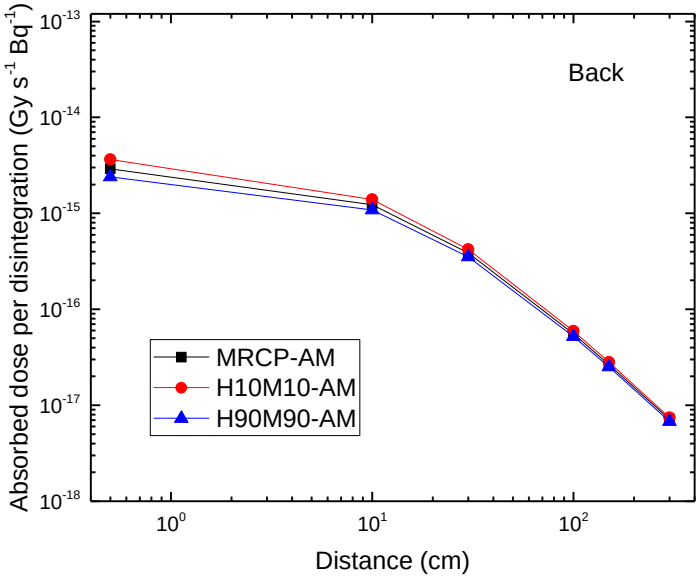


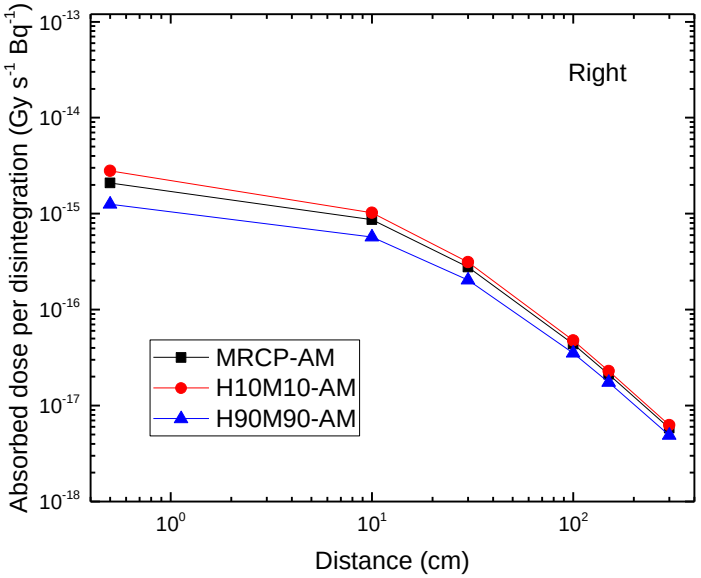


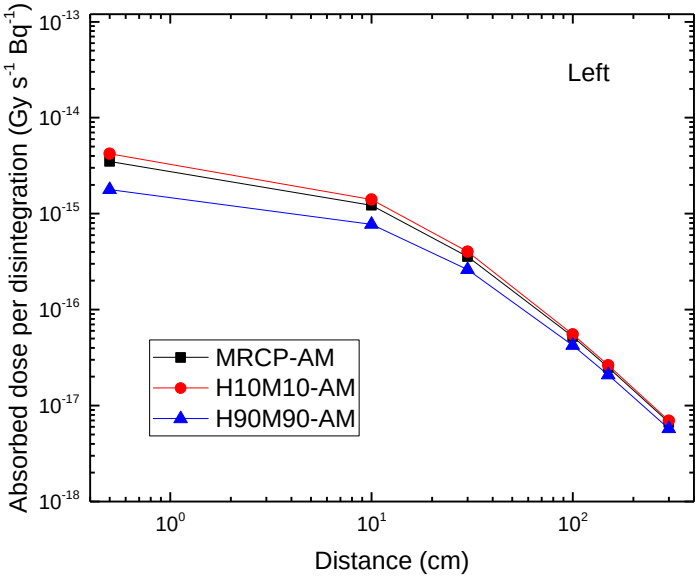


Result - Male SI for ^{60}Co at Lower Torso Level

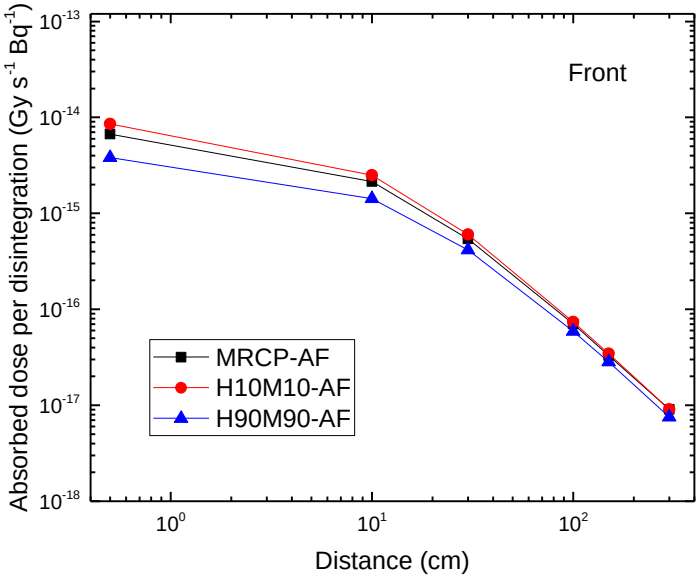


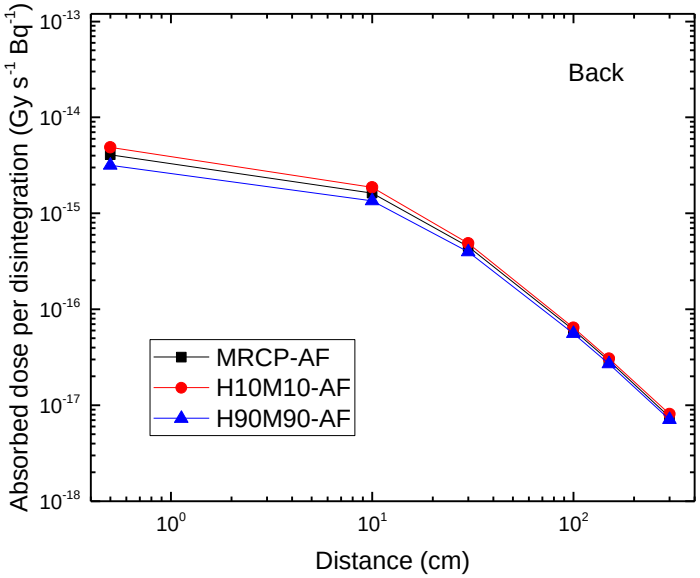


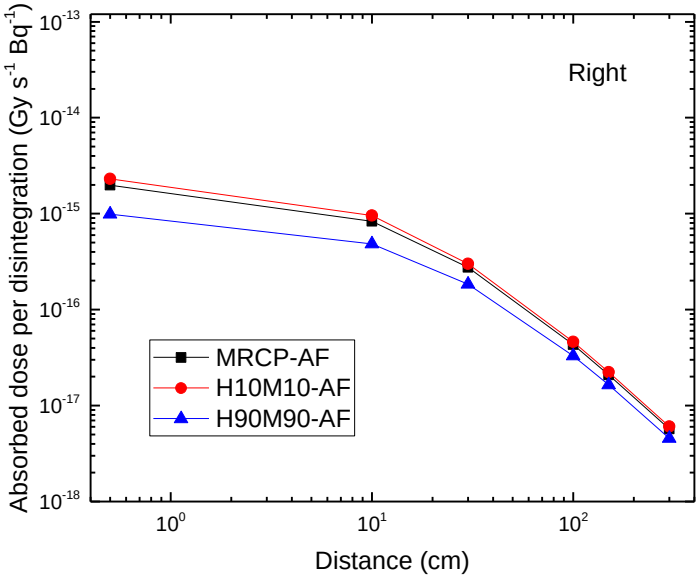


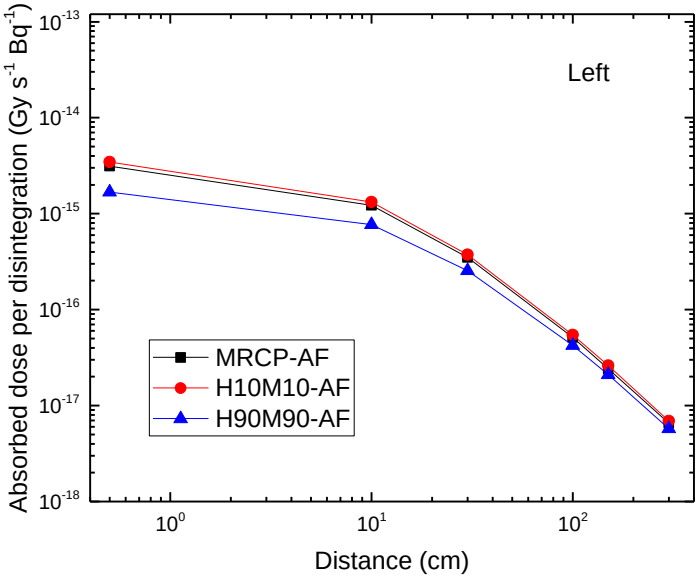


Result - Female SI for ^{60}Co at Lower Torso Level









Summary & Conclusion

Summary & Conclusion

- The ***mesh-type reference computational phantoms (MRCPs)*** for adult male and female have been developed to overcome the limitations of the current voxel-type reference computational phantoms.

- The developed mesh phantoms were
  - ✓ tested for compatibility with some general-purpose Monte Carlo codes (Geant4, PHITS, and MCNP6)
  - ✓ used to calculate some dose coefficients (DCs)
    - similar DCs for highly-penetrating radiations
    - different DCs for weakly-penetrating radiations
  - ✓ used to calculate dose coefficients (DCs) for industrial radiography sources, for which we considered different statures and postures.

- These phantoms are ***all-in-one*** phantoms, including the thin target layer of the skin, the thin source and target layers (10-300 μm) of the respiratory and alimentary tract organs, and the detailed eye model.

- The developed phantoms are ***deformable***, which can provide different statures and postures to calculate dose coefficients for emergency exposure situations* in ICRP.
  (*planned for the next term of the ICRP, 2017-2021).

- The developed phantoms will be released within ~2 years.
  - ✓ 2018 – public consultation
  - ✓ 2019 – publication

Thank you!