Development of Thyroid Model for ICRP Reference Pediatric Computational Phantoms

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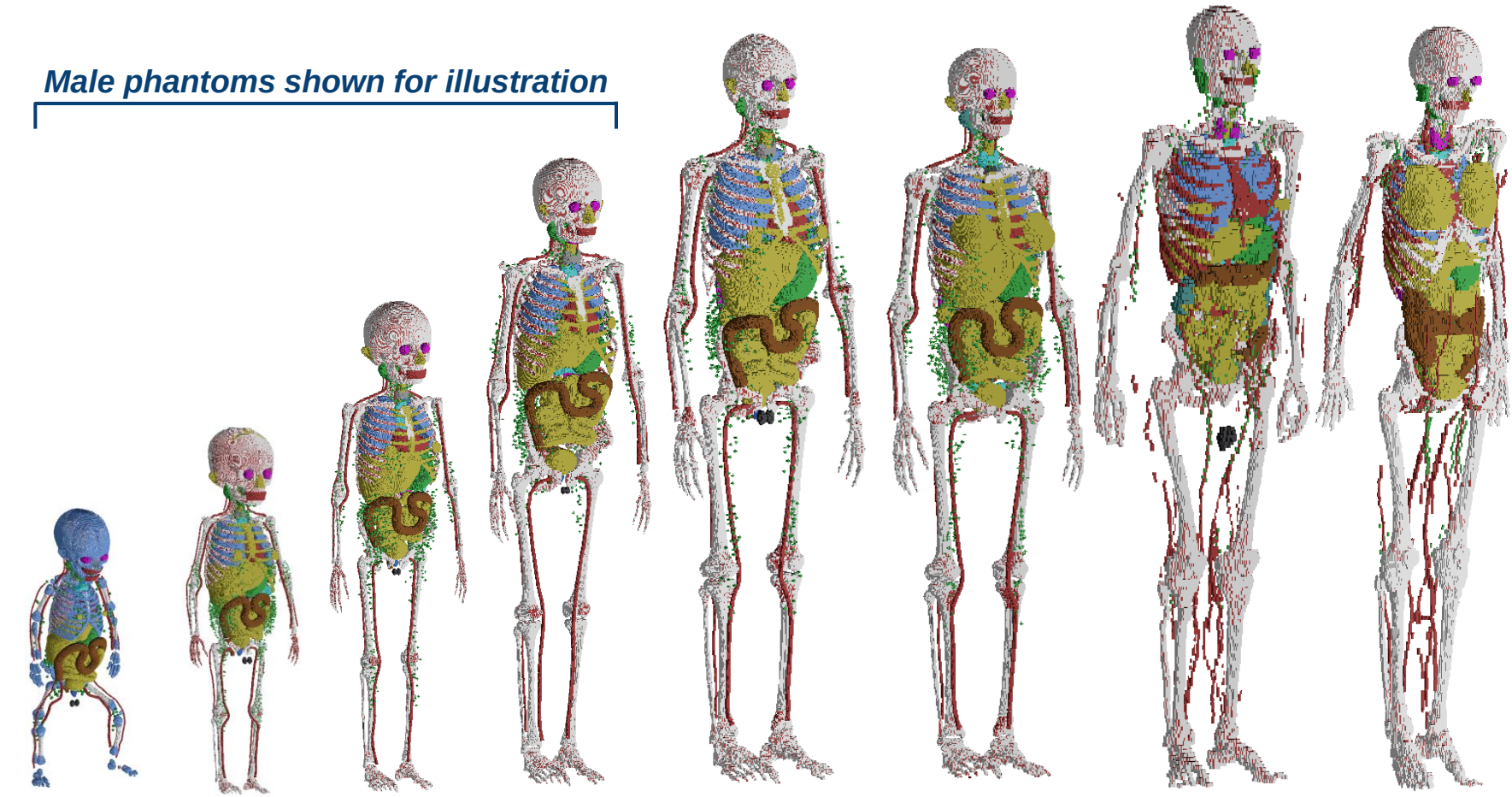
Introduction

VRCPs (Voxel-type Reference Computational Phantoms)

- **Adult phantoms**[1] **(2)** – adult male/female
- **Pediatric Phantoms**[2] **(10)** – newborn, 1, 5, 10, 15 years male/female

Male phantoms shown for illustration

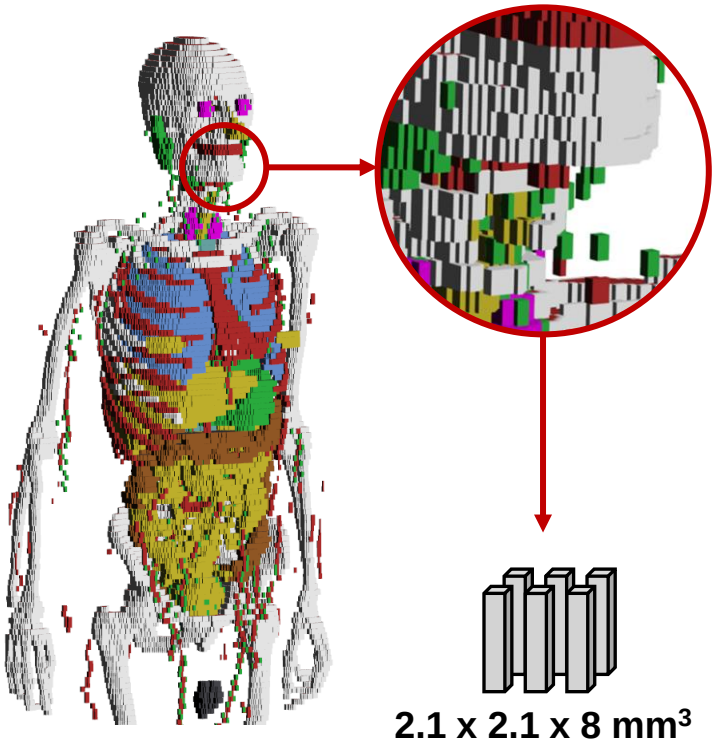


1) ICRP, ICRP Publication 110, Adult Reference Computational Phantoms, 2009.
2) ICRP, ICRP Publication 143, Paediatric Reference Computational Phantoms, 2020.

VRCPs – Limitations

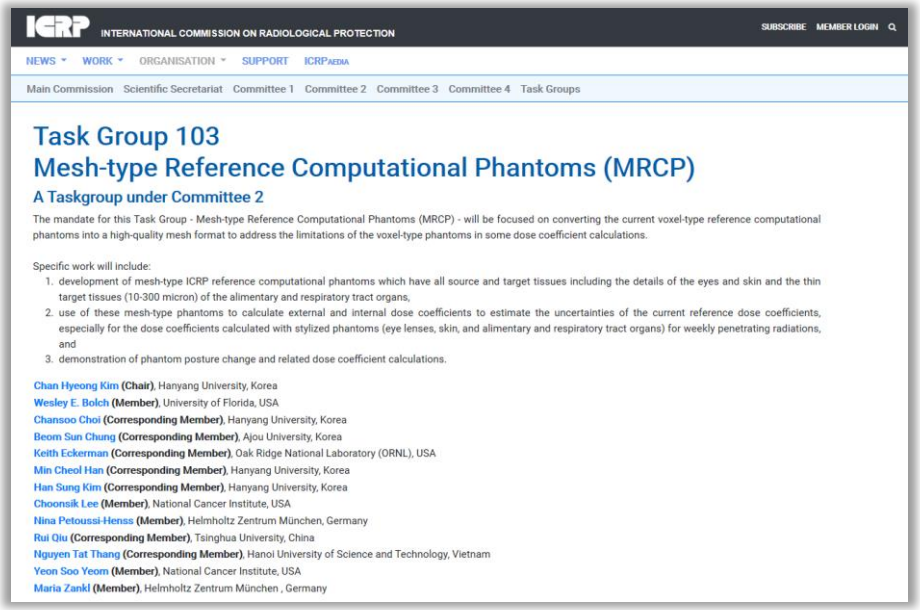
- **Difficult to define thin/tiny organs**
  - Holes in the skin and hollow organs
  - Difficult to define micron-thick radiosensitive target regions
    - ➢ Skin: 50-μm target layer
    - ➢ HATM/HRTM: 8−40-μm target layer
    - ➢ Eye lens: 400 μm on average
- **Stair-stepped surfaces**
  - Anatomically unrealistic
- **Difficult to deform the phantoms**
  - Practically difficult to deform phantoms into various postures and body sizes

Example: amVRCP

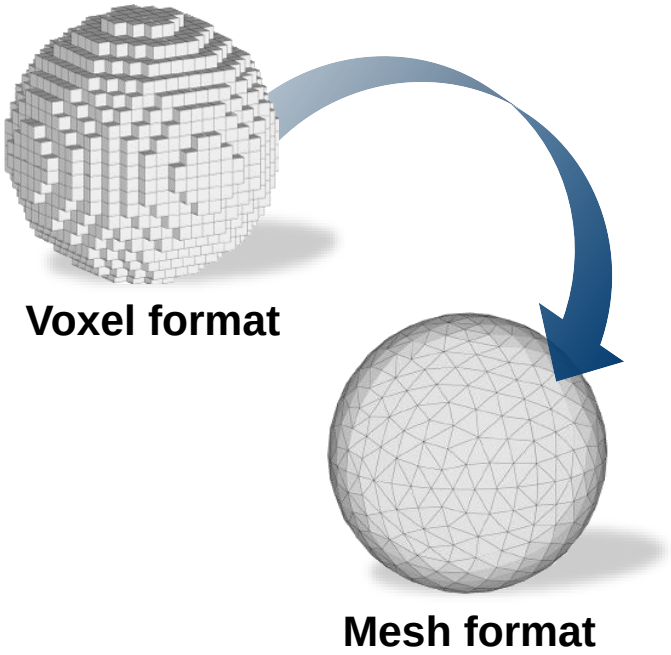


ICRP Task Group 103 (2016)

- The mandate of this task group is to develop the **next-generation ICRP reference phantoms, Mesh-type Reference Computational Phantoms (MRCPs)**, which are the mesh counterparts of the VRCPs but represent more improved anatomical structures than the VRCPs.

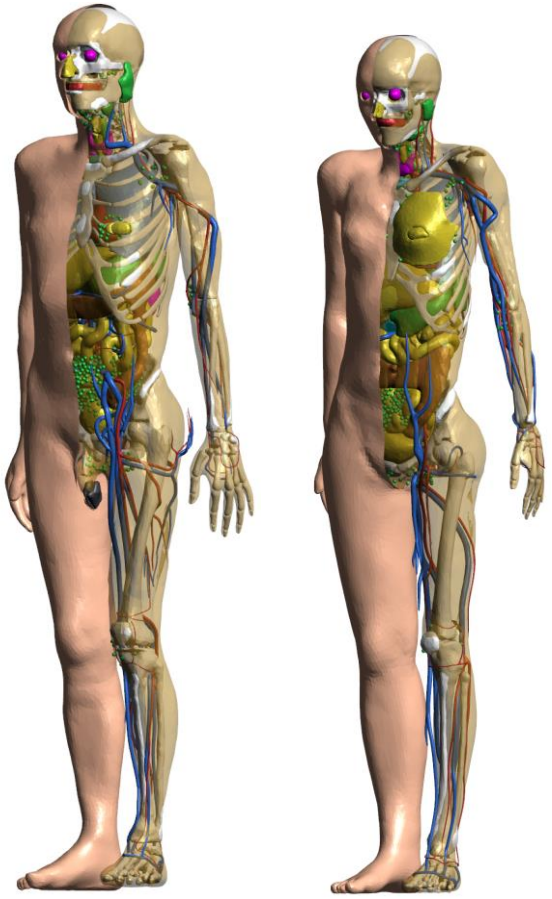


http://www.icrp.org/icrp_group.asp?id=97

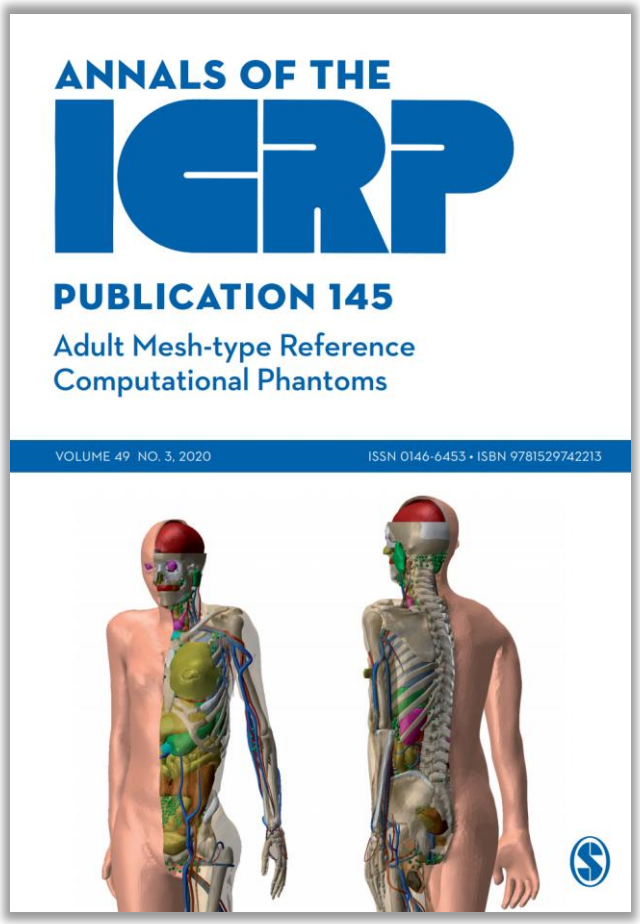


Adult MRCPs

- **ICRP Task Group 103 completed the adult male and female MRCPs** and currently distributes the phantoms through ICRP *Publication 145*[3].



amMRCP (left) and afMRCP (right)



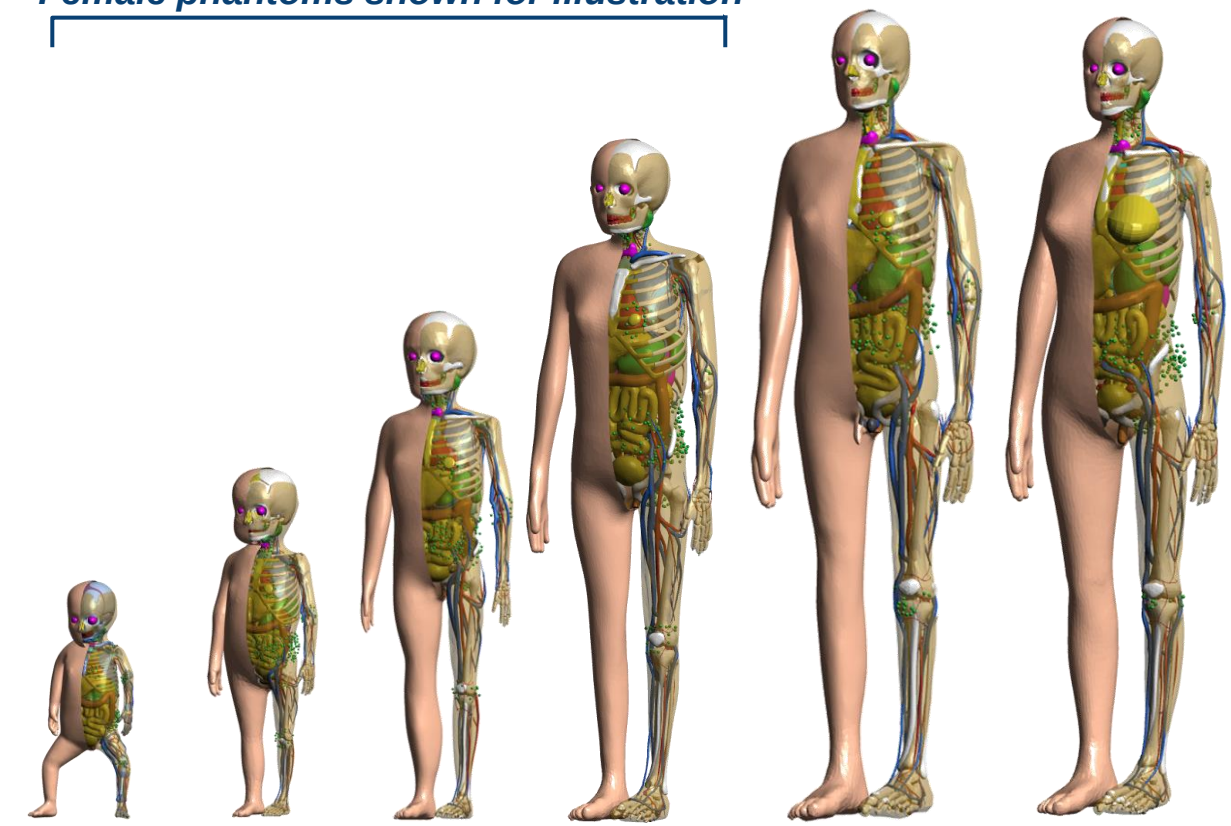
ICRP *Publication 145*

3) ICRP, ICRP Publication 145, Adult Mesh-type Reference Computational Phantoms, 2020.

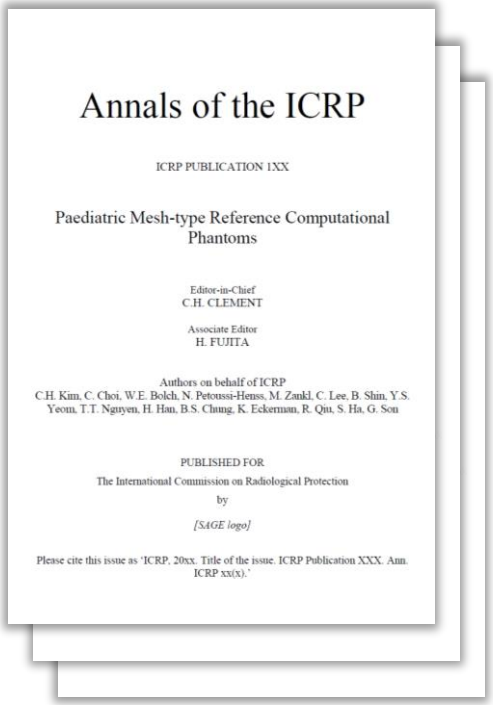
Development of Pediatric MRCPs

- **ICRP Task Group 103 is currently developing the pediatric MRCPs** by converting the pediatric VRCPs with substantial enhancements in the detailed anatomy of the organs and tissues.

Female phantoms shown for illustration



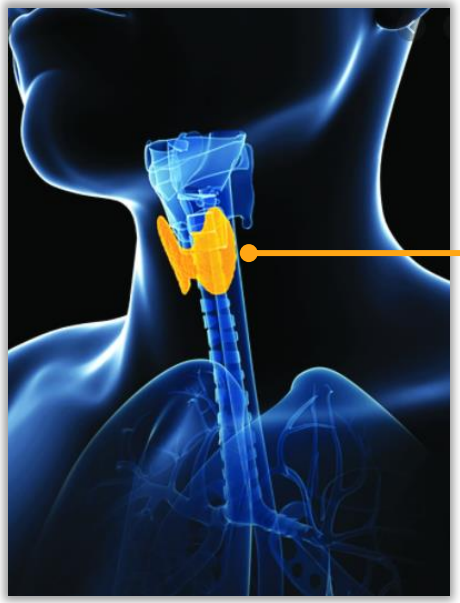
0fMRCP 1fMRCP 5fMRCP 10fMRCP 15mMRCP 15fMRCP



ICRP report on pediatric MRCPs

Objective of Present Study

- **To develop the new thyroid models of the pediatric MRCPs** to address limitations of those of the pediatric VRCP
- **To calculate dose coefficients (DCs) and specific absorbed fractions (SAFs)** for the thyroid to investigate dosimetric impacts of new thyroid models developed in the present study



Thyroid

Radiosensitive target organ required for effective dose calculation (w_T= 0.04)

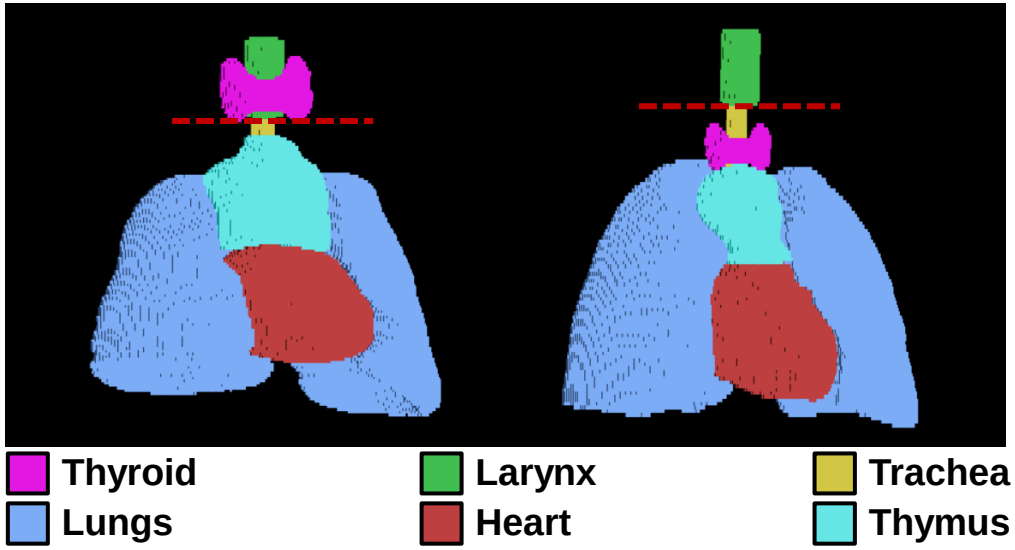
Important source organ especially for internal exposures to radioactive iodine

Materials and Methods

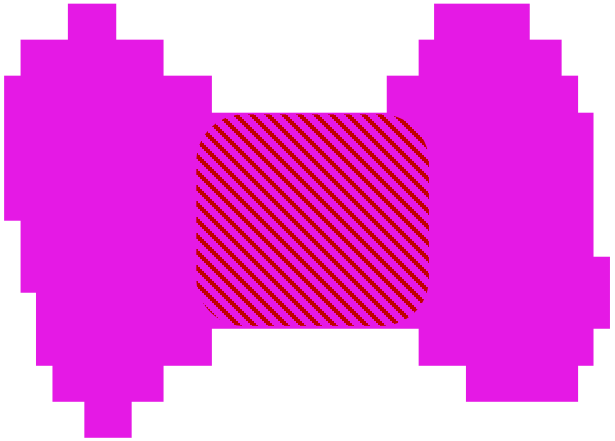
Problems with Thyroid Model of Pediatric VRCPs

- The issue on the typicality of the thyroid location of the pediatric VRCPs was raised in the 2019 annual meeting of the ICRP Committee 2.
- The anatomist confirmed that **the thyroid of the pediatric VRCPs for some ages is in an untypical position**.
- The anatomist additionally pointed out that **the isthmus region of the thyroid of the pediatric VRCPs is thicker** than the typical shape.

Example: 0mVRCP (left) and 1mVRCP (right)



Thyroid shown with other organs

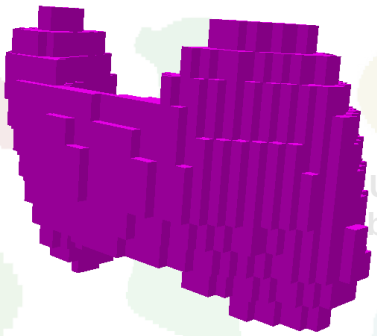


Thyroid isthmus region

Development of Primary Thyroid Model

- **Primary thyroid models**, along with other general organs, were produced using those of the pediatric VRCPs via **mesh conversion and rendering procedures** following the methods used in the previous studies[3-5].

Example: 5-year female

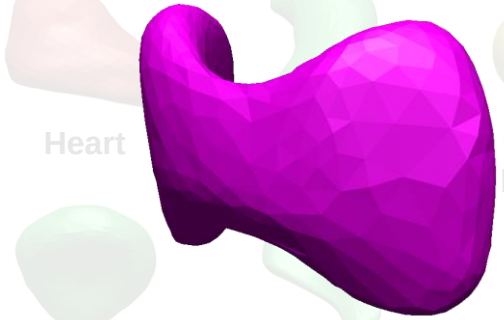


Thyroid of pediatric VRCPs

Mesh conversion and rendering procedures

RAPIDFORM

Rhinoceros



Thyroid of pediatric MRCPs

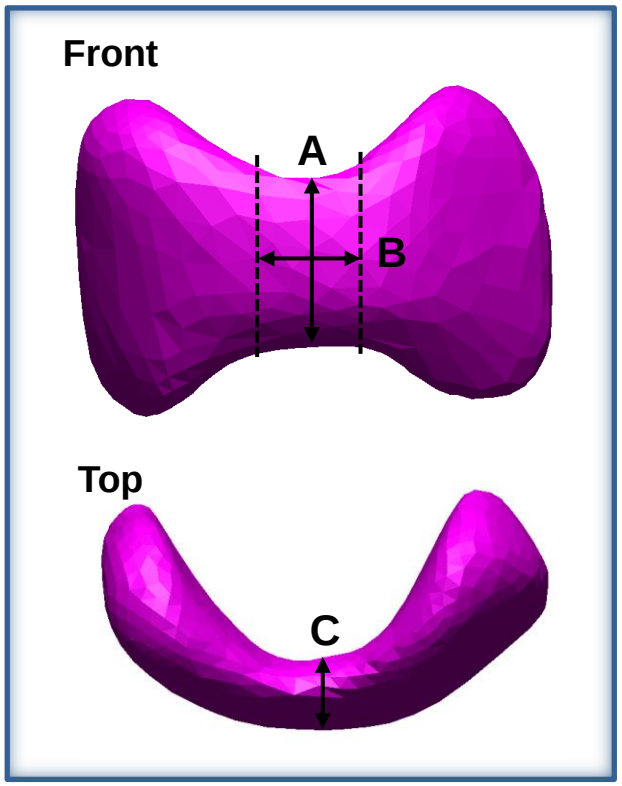
3) ICRP, ICRP Publication 145, Adult Mesh-type Reference Computational Phantoms, 2020.

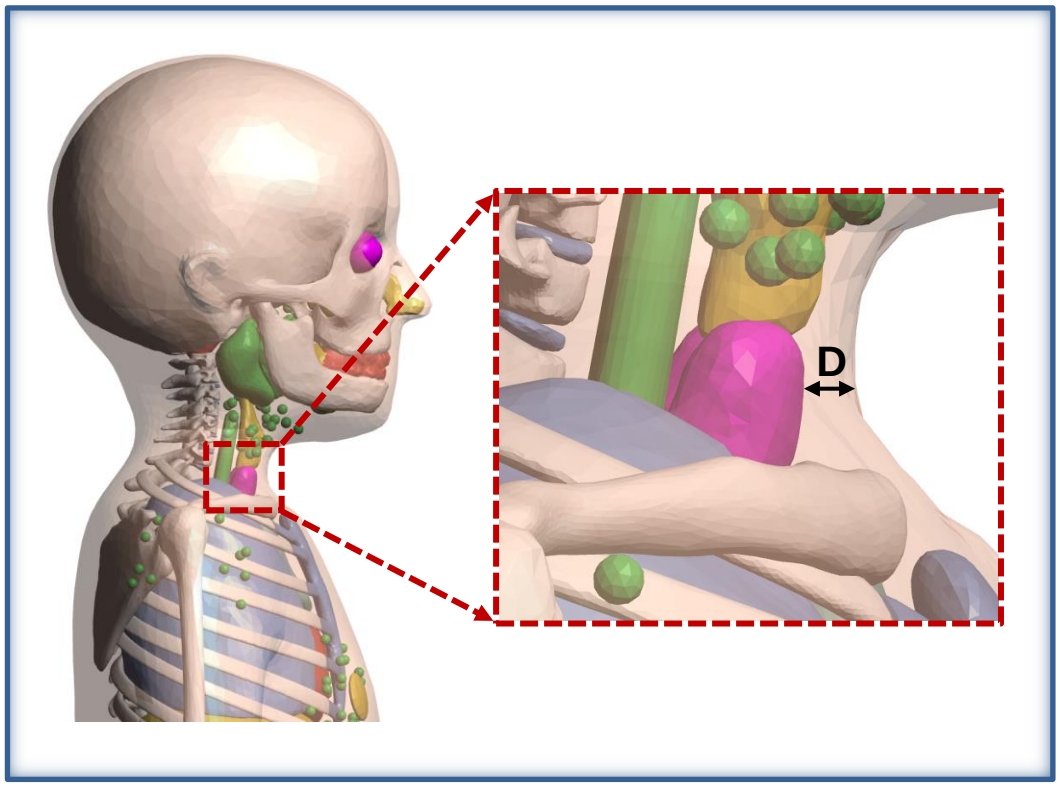
4) Choi, C., Nguyen, T.T., Yeom, Y.S., et al., 2019. Mesh-type reference Korean phantoms (MRKPs) for adult male and female for use in radiation protection dosimetry. Phys. Med. Biol. 64, 085020.

5) Choi, C., Shin, B., Yeom, Y.S., et al., 2021a. Development of Skeletal Systems for ICRP Pediatric Mesh-type Reference Computational Phantoms. J. Radiol. Prot. (in press).

Parameters Related to Thyroid Shape and Location

- Isthmus height (A)
- Isthmus width (B)
- Isthmus thickness (C)
- Overlying tissue thickness (D)
- Anatomical location





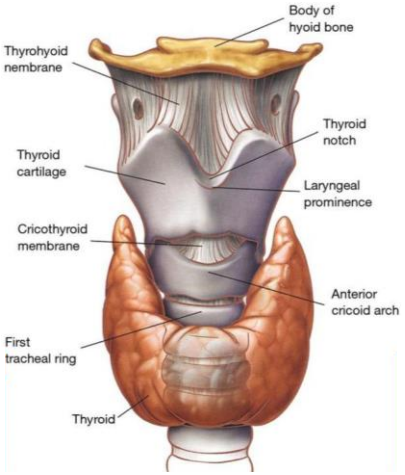
Determination of Isthmus Dimensions

<table>
<tr><th>Dimensions</th><th>Newborn</th><th>1 year</th><th>5 years</th><th>10 years</th><th>15 years</th><th>Adult
(regarded as 18 years[8-10])</th></tr>
<tr><td>Isthmus height</td><td rowspan="2">Ozguner and Sulak (2014)[6)]</td><td colspan="4" rowspan="2">Linear interpolation</td><td rowspan="2">Tong and Rubenfeld (1972)[11)]
Harjeet et al. (2004)[8)]
Joshi et al. (2010)[12)]
Ozgur et al. (2011)[13)]
Won et al. (2013)[10)]</td></tr>
<tr><td>Isthmus width</td></tr>
<tr><td>Isthmus thickness</td><td colspan="5">Sea et al. (2019)[7)]</td></tr>
</table>

6) Ozguner, G., Sulak, O., 2014. Size and location of thyroid gland in the fetal period. Surg. Radiol. Anat. 36, 359–367.
7) Sea, J.H., Ji, H., You, S.K., et al. 2019. Age-dependent reference values of the thyroid gland in pediatric population; from routine computed tomography data. Clin. Imag. 56, 88–92.
8) Harjeet, A., Sahni, D., Jit, I., et al., 2004. Shape, measurements and weight of the thyroid gland in northwest Indians. Surg. Radio. Anat. 26, 91–95.
9) Sultana, S.Z., Khalil, M., Khan, M.K., et al., 2011. Morphometry of isthmus of thyroid gland in Bangladeshi cadaver. Mymensingh Med. J. 20, 366–370.
10) Won, H.S., Han, S.H. Oh, C.S., et al., 2013. The location and morphometry of the thyroid isthmus in adult Korean cadavers. Anat. Sci. Int. 88, 212–216.
11) Tong, E.C.K., Rubenfeld, S., 1972. Scan measurements of normal and enlarged thyroid gland. Am. J. Roentgenol. Radium Ther. Nucl. Med. 1–5, 706–708.
12) Joshi, S.D., Joshi, S.S., Daimi, S.R., et al., 2010. The thyroid gland and its variations: a cadaveric study. Folia Morphol. 69, 47–50.
13) Ozgur, Z., Celik, S., Govsa, F., et al., 2011. Anatomical and surgical aspects of the lobes of the thyroid glands. Eur. Arch. Otorhinolaryngol. 268, 1357–1363.

Determination of Thyroid Location

- **Anatomical location**
  - The thyroid is typically located in front of the second and third tracheal cartilage[14-15].



- **Overlying tissue thickness**
  - The overlying tissue thickness was derived from the equation given in Likhtarev et al. (1995)[16].
  - This equation is applicable from 1 year to 18 years.

$$d = 0.0007a^2 + 0.025a + 5.2$$

$d = overlying\ tissue\ thickness\ (mm)$
$a = age\ (y)$

14) Ellis, H, 2007. Anatomy of the thyroid and parathyroid glands. Surgery (Oxford). 25, 467–468.
15) Naqshi, B.F., Seth, S., Shah, A.B., et al., 2016. Thyroid Hemiagenesis with Agenesis of Isthmus a Case Report. J. Med. Sci. Clin. Res. 4, 10799–10801.
16) Likhtarev, I.A., Gulko, G.M., Sobolev, B.G., et al., 1995. Evaluation of the 131I thyroid-monitoring measurements performed in Ukraine during May and June of 1986. Health Physics. 69, 6–15.

Modification of Thyroid Model

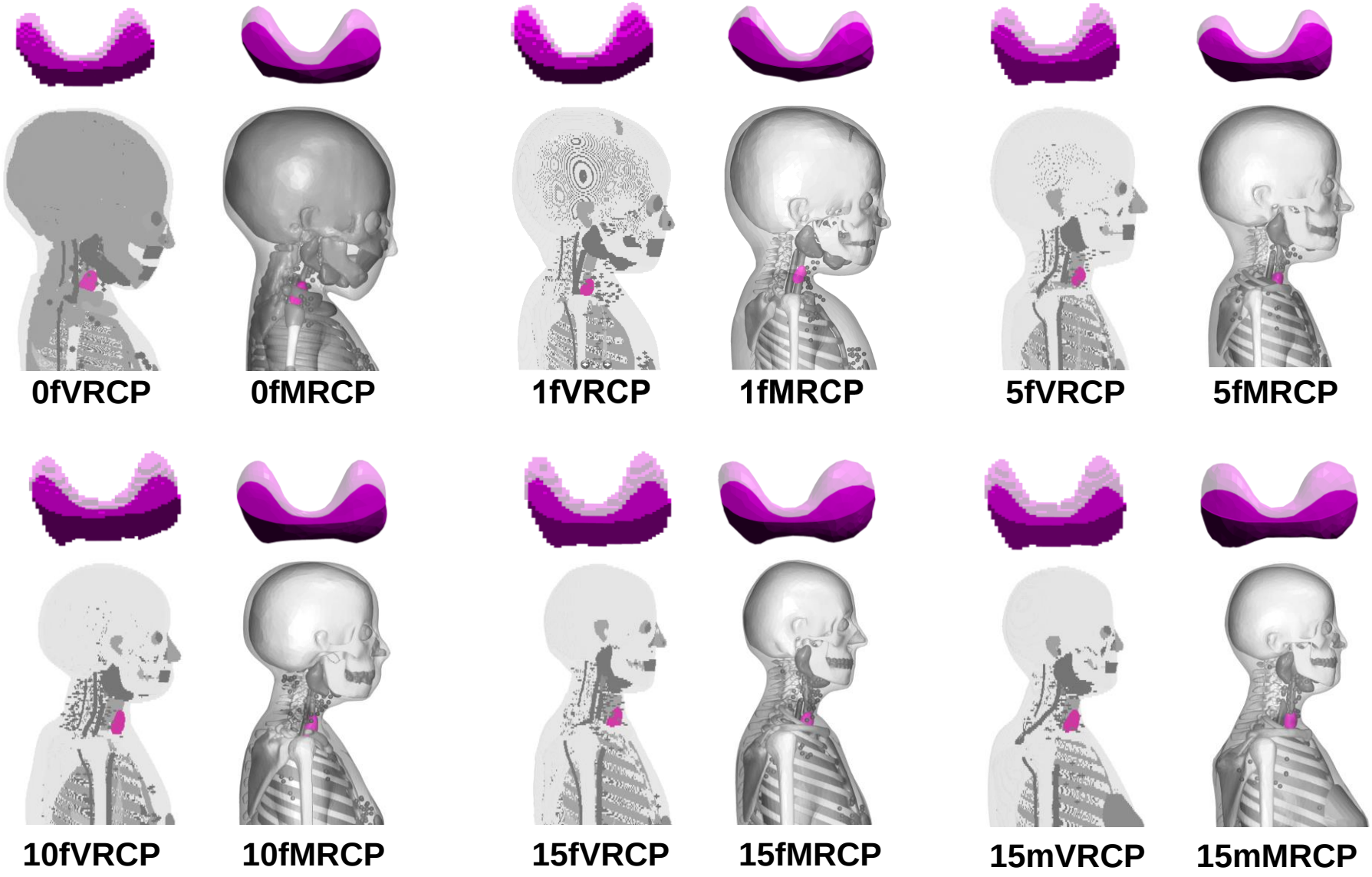
- **Determined thyroid parameters**

Parameters	Newborn	1 year	5 years	10 years	15 years
Isthmus height (mm)	8.6	8.9	10.2	11.8	13.5
Isthmus width (mm)	9.2	9.5	10.4	11.5	12.6
Isthmus thickness (mm)	1.5	1.5	2.0	3.0	3.0
Overlying tissue thickness (mm)	–	5.23	5.34	5.52	5.73
Anatomical location	In front of the second and third tracheal cartilage				

- **The thyroid isthmus** was adjusted to match the target height, width, and thickness values **within 5% difference**.
- **The thyroid was placed on its typical position**, i.e., in front of the second and third tracheal cartilage.
- **The overlying tissue thickness** was matched to the target values **within 5% difference** by adjusting the skin near the front neck.

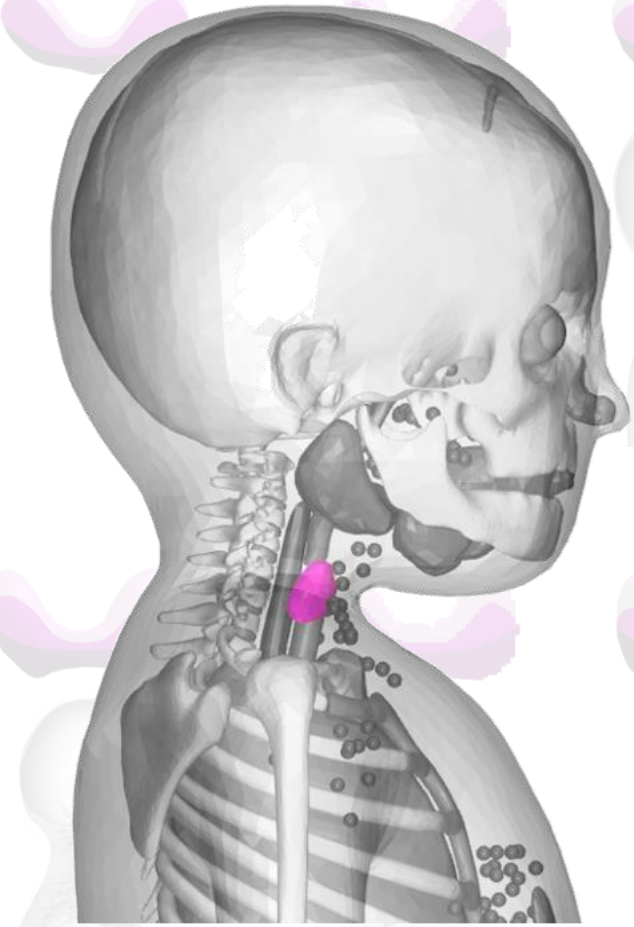
Results and Discussion

Thyroid of Pediatric MRCPs (vs. Pediatric VRCPs)



**For ages up top and including 10 years, only female phantoms are shown*

Thyroid of 1-year MRCPs (vs. Pediatric VRCPs)



1fVRCP

1fMRCP

0fVRCP

5fMRCP

10fVRCP

10fMRCP

15fVRCP

15fMRCP

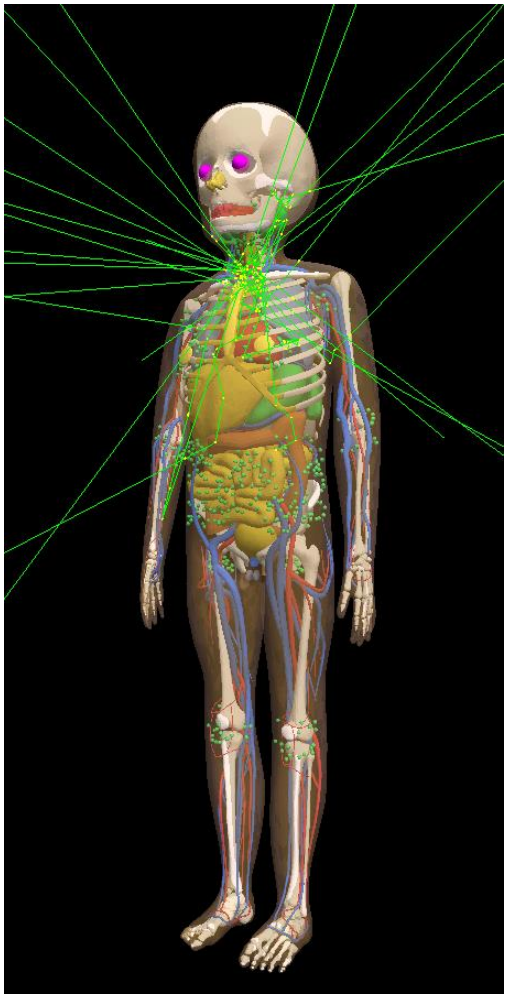
15mVRCP

15mMRCP

*For ages up top and including 10 years, only female phantoms are shown

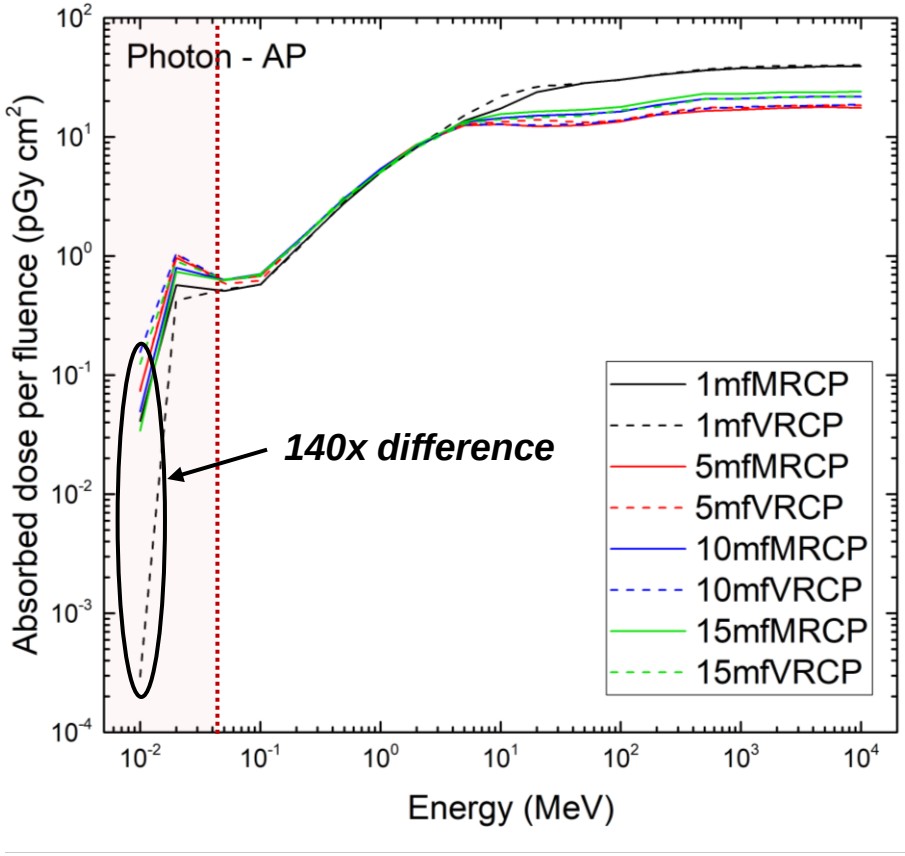
Monte Carlo Dose Calculations with Geant4

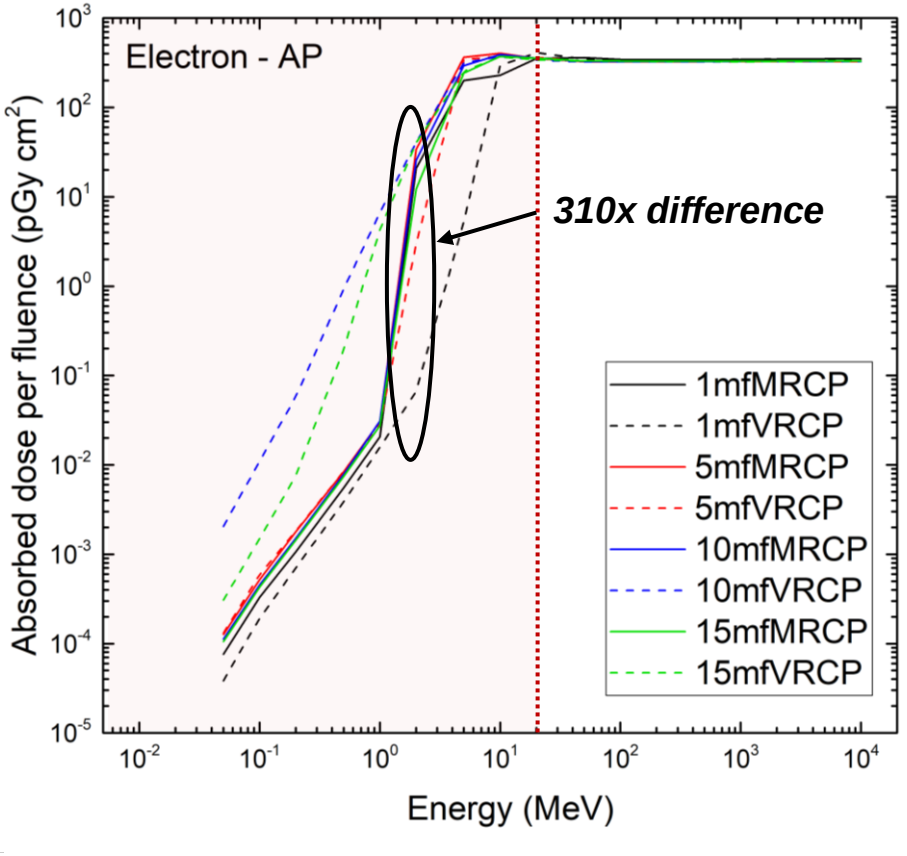
- **Simulation cases**
  - External exposure
    - Calculated value: thyroid dose coefficients (DCs)
    - Irradiation geometry: AP
    - Primary energy: 10 keV – 10 GeV
  - Internal exposure
    - Calculated value: specific absorbed fractions (SAFs)
    - Source organ: thyroid
    - Target organs: Oesophagus, ET, brain
    - Primary energy: 10 keV – 10 MeV
  - Particle: photon, electron
  - Relative error: less than 5%
- **Geant4 conditions**
  - Version: 10.06.p02
  - Physics library: G4EmLivermorePhysics
  - Secondary range cut: 1 mm



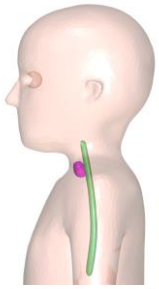
Example: 5mMRCP

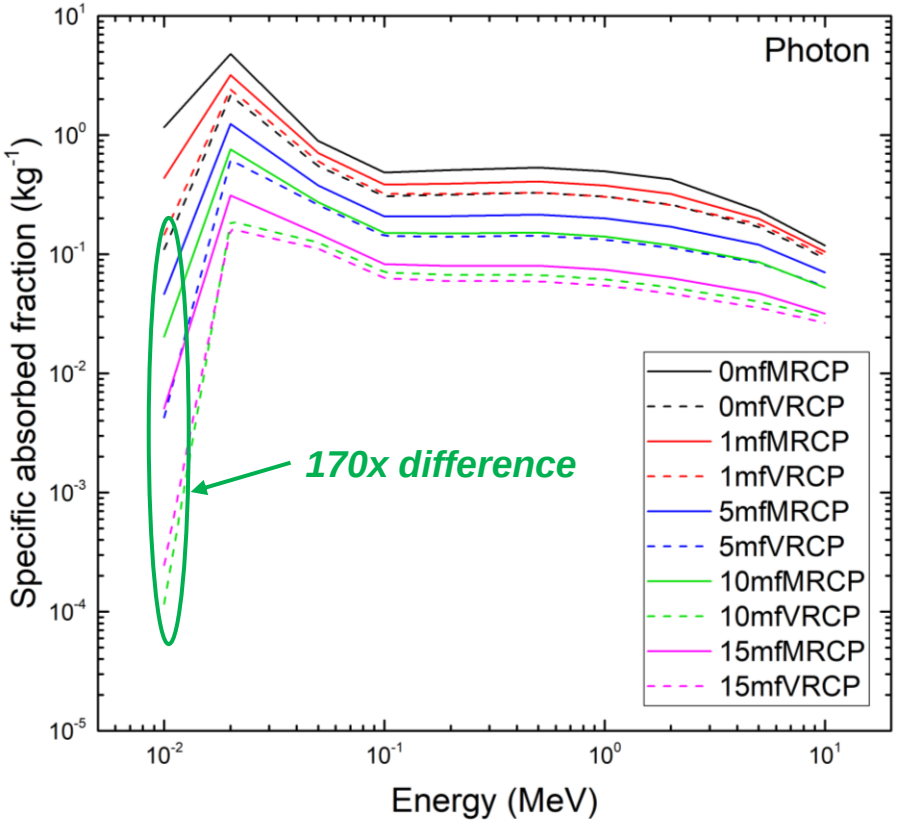
Thyroid DCs for External Exposures

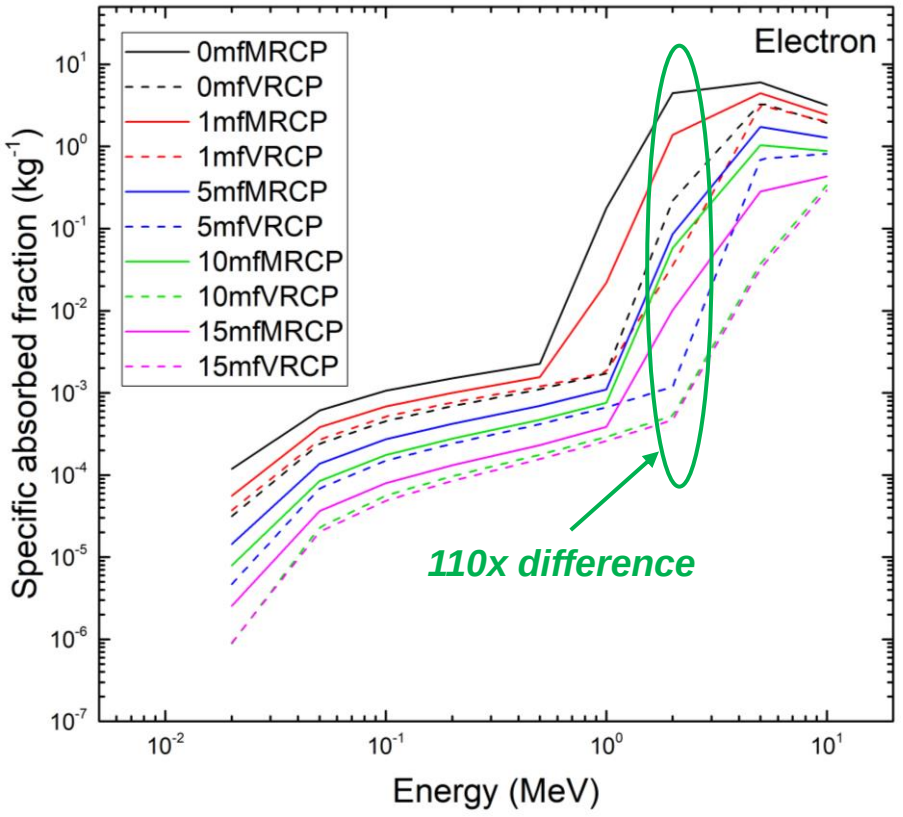




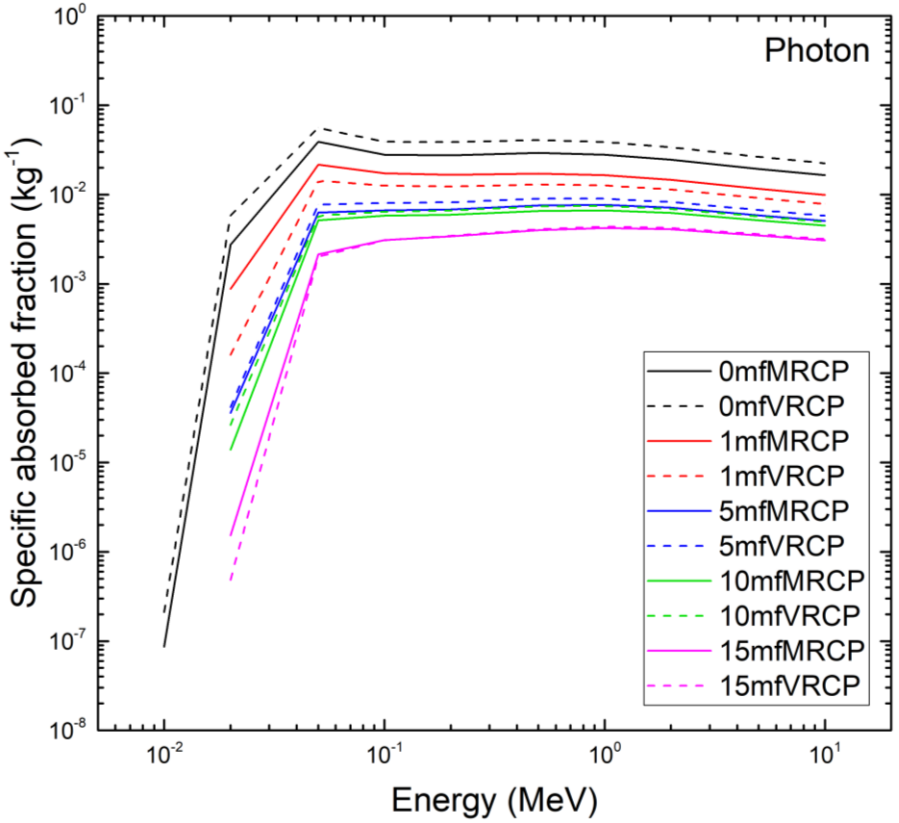
SAFs for Internal Exposures – Oesophagus

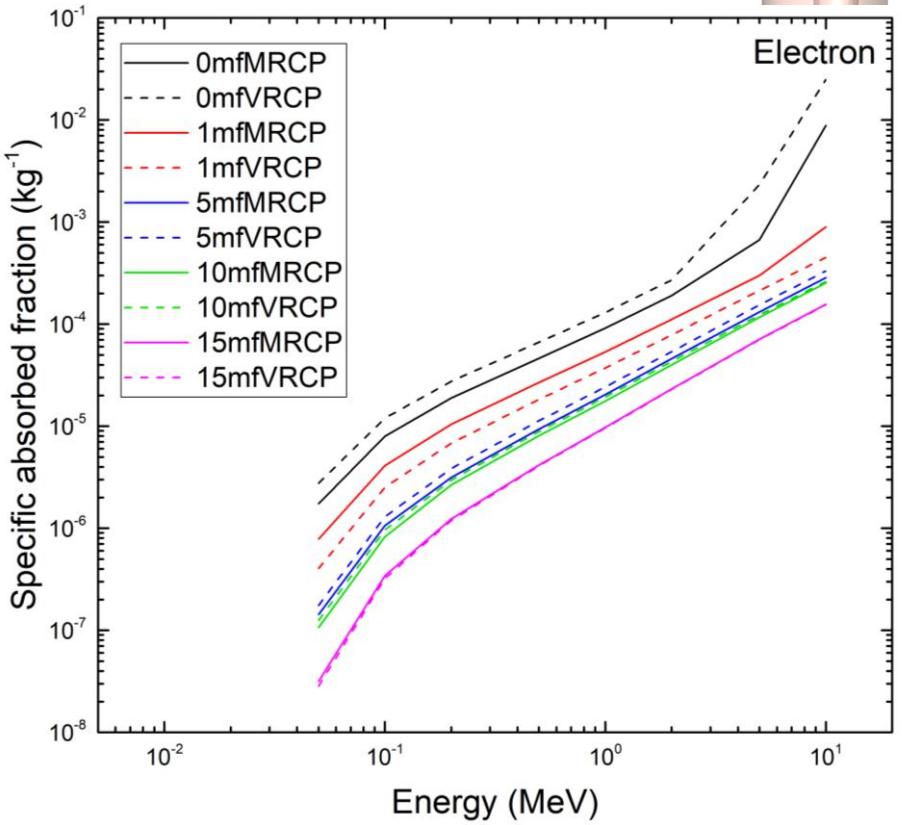






SAFs for Internal Exposures – Brain





Conclusion

Conclusion

- In the present study, we developed **the newborn, 1-year, 5-year, 10-year, and 15-year male and female thyroid models** for the pediatric MRCPs.

- The developed thyroid models represent **the typical features** of the thyroid shape (especially the isthmus shape) and locations **of the pediatric population**.

- The developed thyroid models provide oesophagus **significantly different DCs and SAFs for both the external and internal exposures** to photons and electrons especially at low energies.

- Considering anatomical improvements and reasonable tendency of the dose values with age, it is expected that **the pediatric MRCPs will provide more reliable dose values in other exposure cases** where the thyroid is considered as source and/or target regions.

- The developed thyroid models can also be used for **the virtual calibration of the thyroid monitoring system for the radioactive iodine content**.

Thank you!