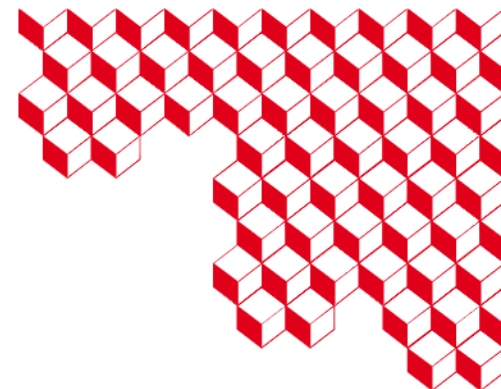




TRIPOLI-4[®] Simulation of Whole-Body Measurement for Children – Case of a 15-Year-Old Female (15F)

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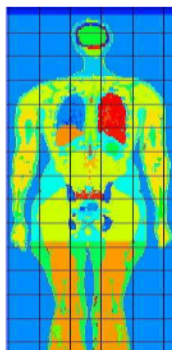


Outline

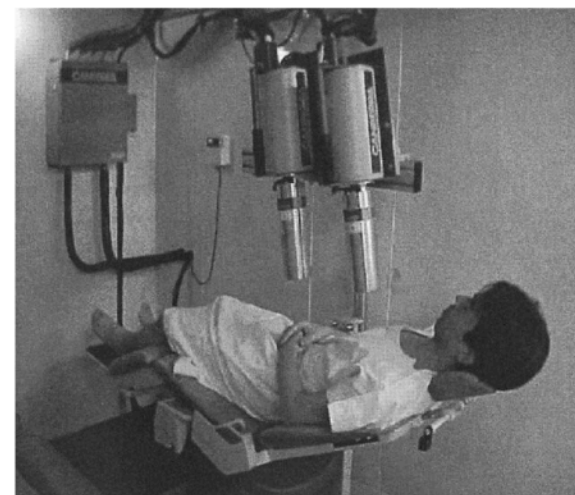
- Introduction
- TRIPOLI-4 Code, Calculation modes, & Application on HPGe detector
- Phantom Models: Brick vs. ICRP 143 - 15F
- Simulation Workflow: Validation Steps
- Calculation results
- Conclusions



Ref: BfS.de (2026).



TRIPOLI-4 model: AM



Dose Evaluation Based on ^{24}Na Activity in the Human Body at the JCO Criticality Accident

Ref: T. Momose, *J. Rad. Res.*, **42**(S95), (2001).

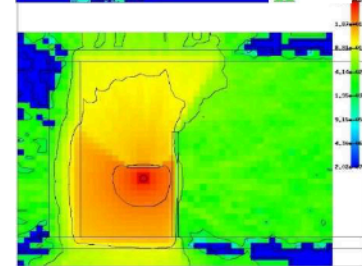
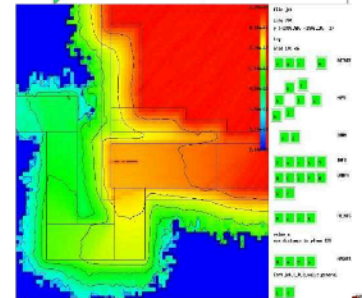
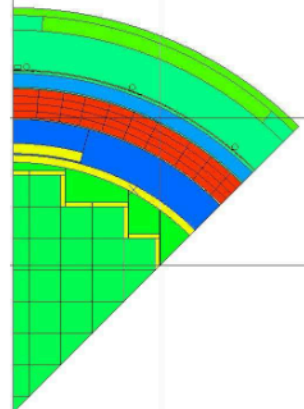
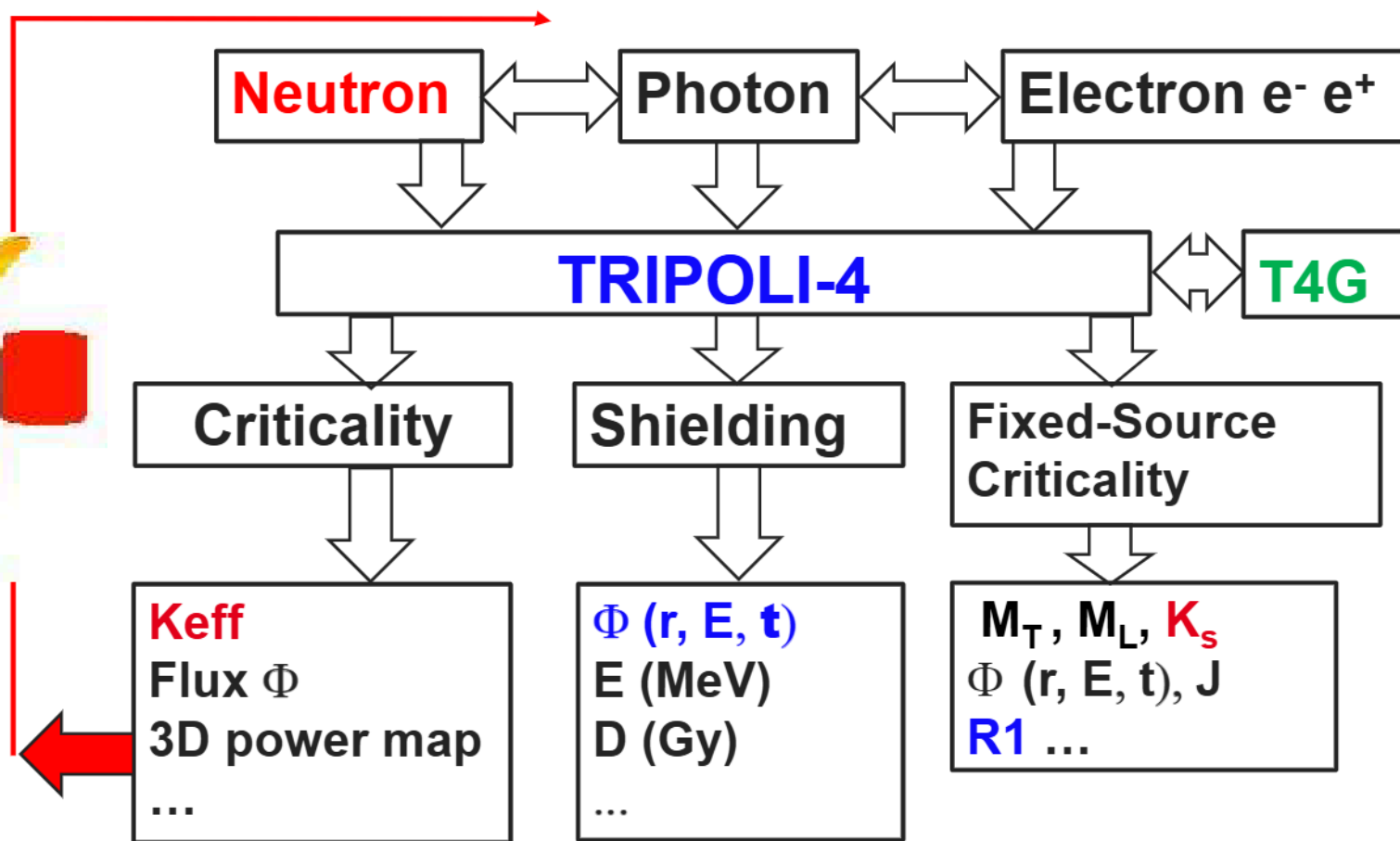
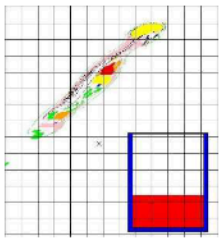


Introduction

- / . Within the framework of EURADOS Working Group 6 (WG 6) on Computational Dosimetry, this study performed Monte Carlo simulations of **whole-body counting for children** in vivo monitoring.
- / . Using **experimental** and **computational phantoms**, the **internal contamination** cases were taken into account for **a 15-Year-Old Female**.
- / . TRIPOLI-4 is a general-purpose Monte Carlo radiation transport code. Computational **dosimetry in organs for adults using TRIPOLI-4** was developed and applied on external and internal exposure studies for occupational, environmental and medical applications.
- / . The objectives of this study were to demonstrate the capability of TRIPOLI-4® code
 - to handle **large voxel geometries for children** at clinical scale,
 - to validate the **tally estimator and the model** for the **HPGe detector** calculations,
 - to benchmark the simulation using experimental anthropomorphic **brick phantoms**, and
 - to perform independent Monte Carlo calculations employing **ICRP voxel phantoms**.

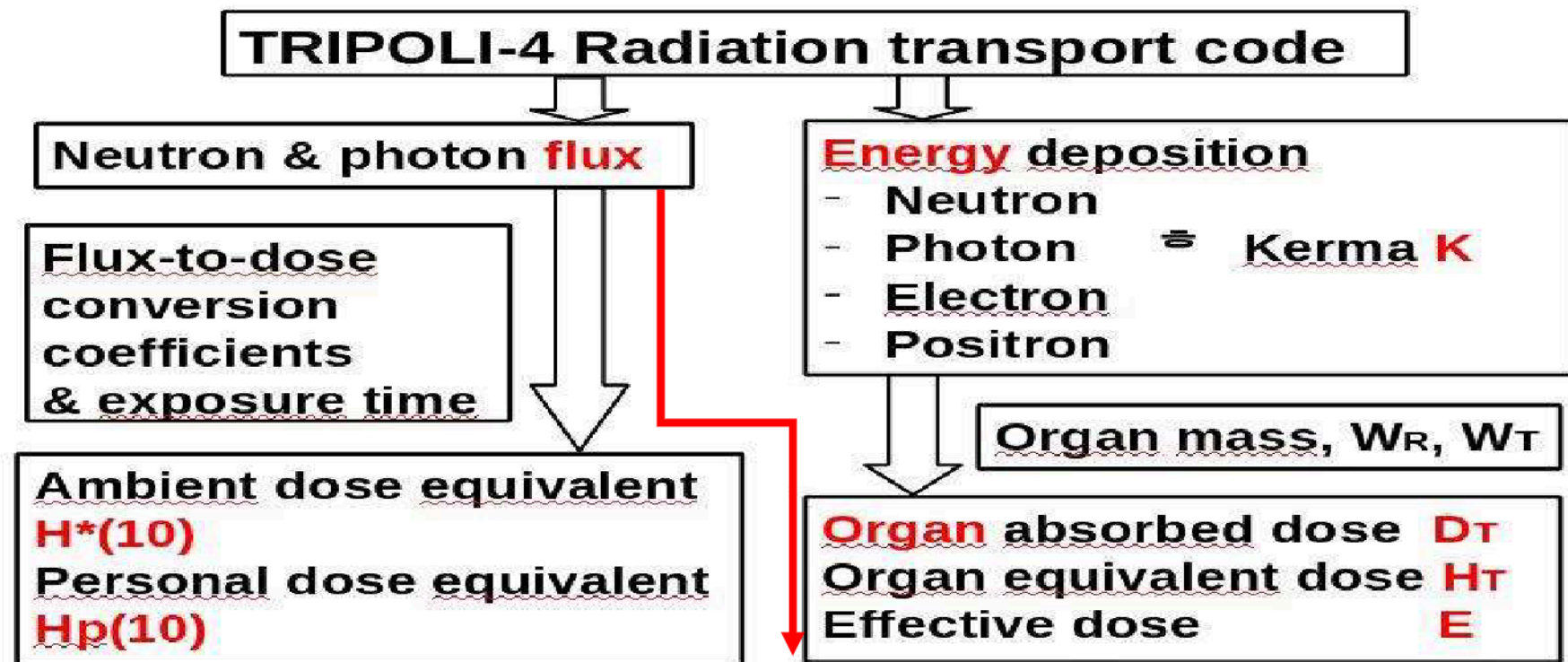
TRIPOLI-4 Radiation transport code

T4G – 2D & 3D I/O Viewer





TRIPOLI-4 radiation protection calculations



Ref: Y.-K. Lee and F.-X Hugot, *Nucl. Sci. Eng.*, **198**:2, 274-286, (2024).

Y.-K. Lee, *ASME J. of Nucl. Eng. and Radiation Science*, **6**(4): 041105, (2020).



TRIPOLI-4 – particle tally options

/ . Particle **flux** tallies can not be applied in this study for HPGe detector

- . **Point** detector flux tally
- . **Volume** cell flux tally
- . **Surface** flux tally
- . **Mesh** flux tally

/ . Two **energy deposition** tallies in TRIPOLI-4

- . **Deposited_Energy** tally (gamma-ray dose / nuclear heating in a detector)
- . **Deposited_Spectrum** tally (HPGe detector efficiency)



TRIPOLI-4 – HPGe detector efficiency

The **full-energy peak (FEP) efficiency** of a **high-purity germanium (HPGe)** detector is the probability that a gamma ray emitted by a source deposits **all of its energy** in the detector and is recorded in the corresponding **photopeak**.

It is defined as

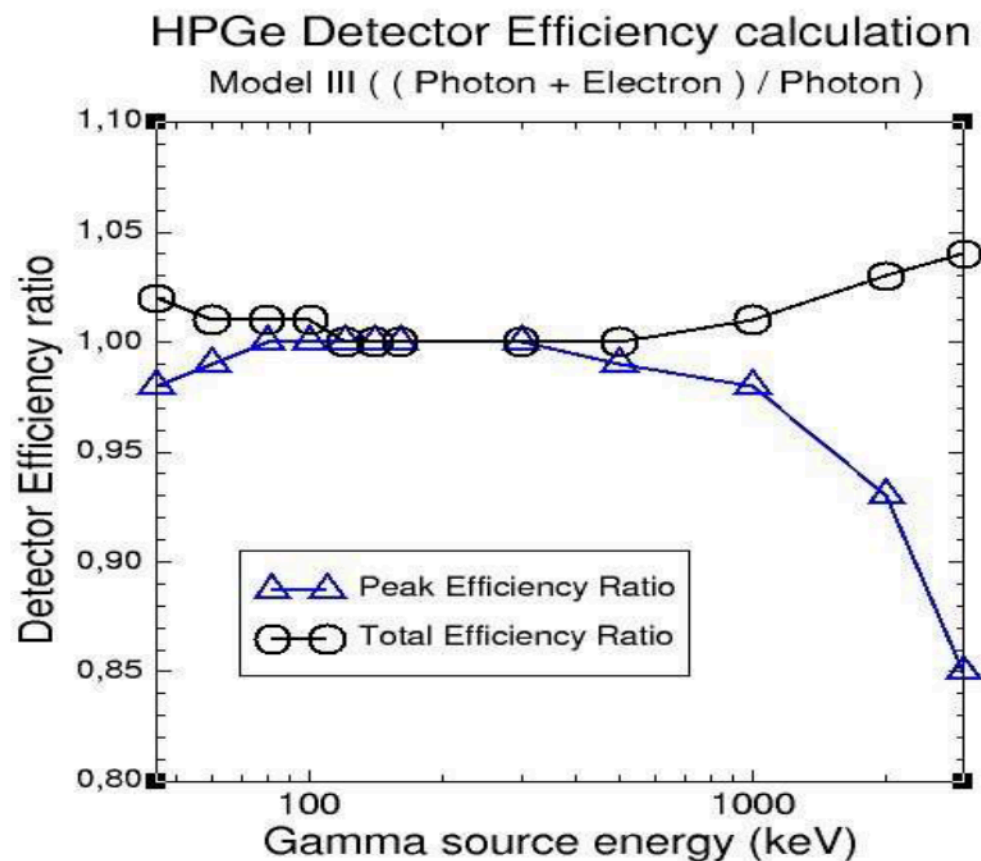
$$\epsilon_{\text{FEP}} = N_{\text{peak}} / N_{\gamma}$$

where:

- ϵ_{FEP} : full-energy peak efficiency,
- N_{peak} : number of counts in the photopeak (TRIPOLI-4 **bin width** 1 keV),
- N_{γ} = number of gamma rays emitted by the source (TRIPOLI-4 **Norm** 1).



TRIPOLI-4 – HPGe detector efficiency tally options



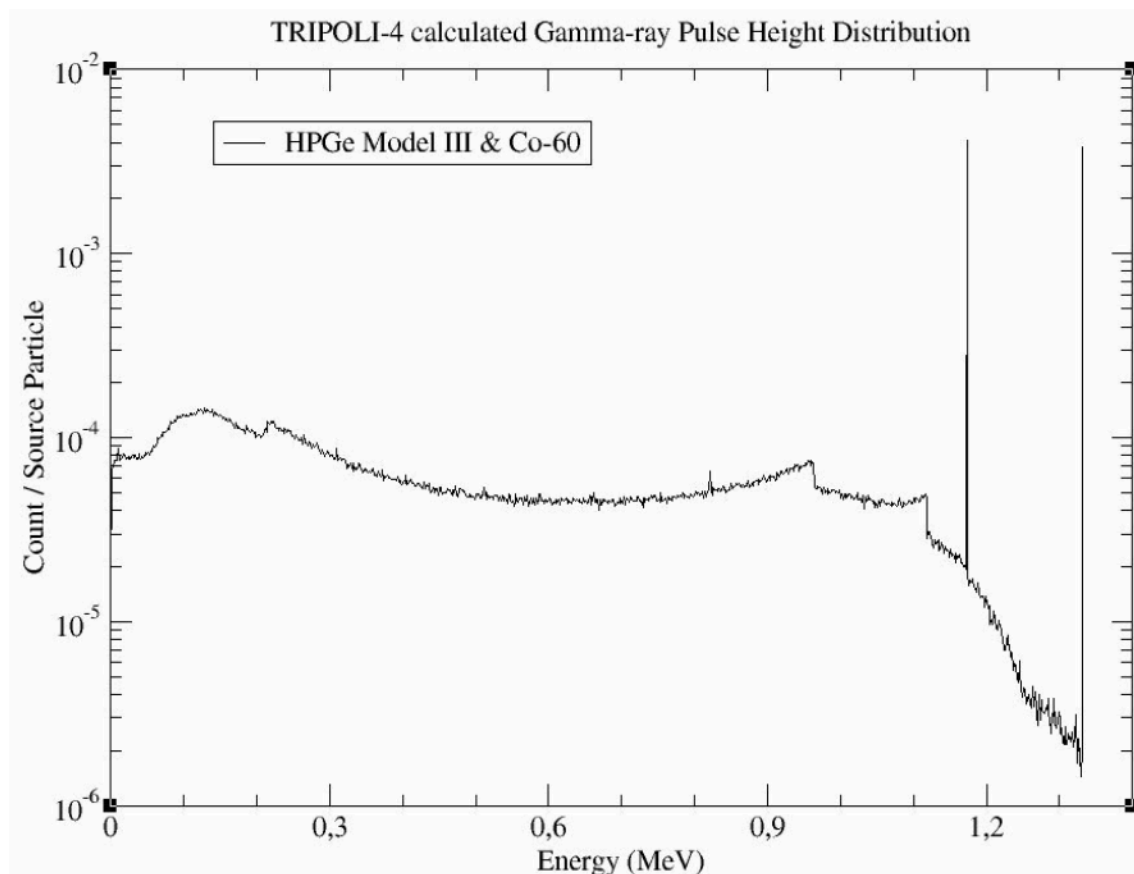
P + E
=> Photon +
Electron +
Positron

P
=> Photon
transport only

==> If P only
Over-estimate
Detector **Peak**
Efficiency



TRIPOLI-4 – HPGe detector efficiency (Peak & Total)



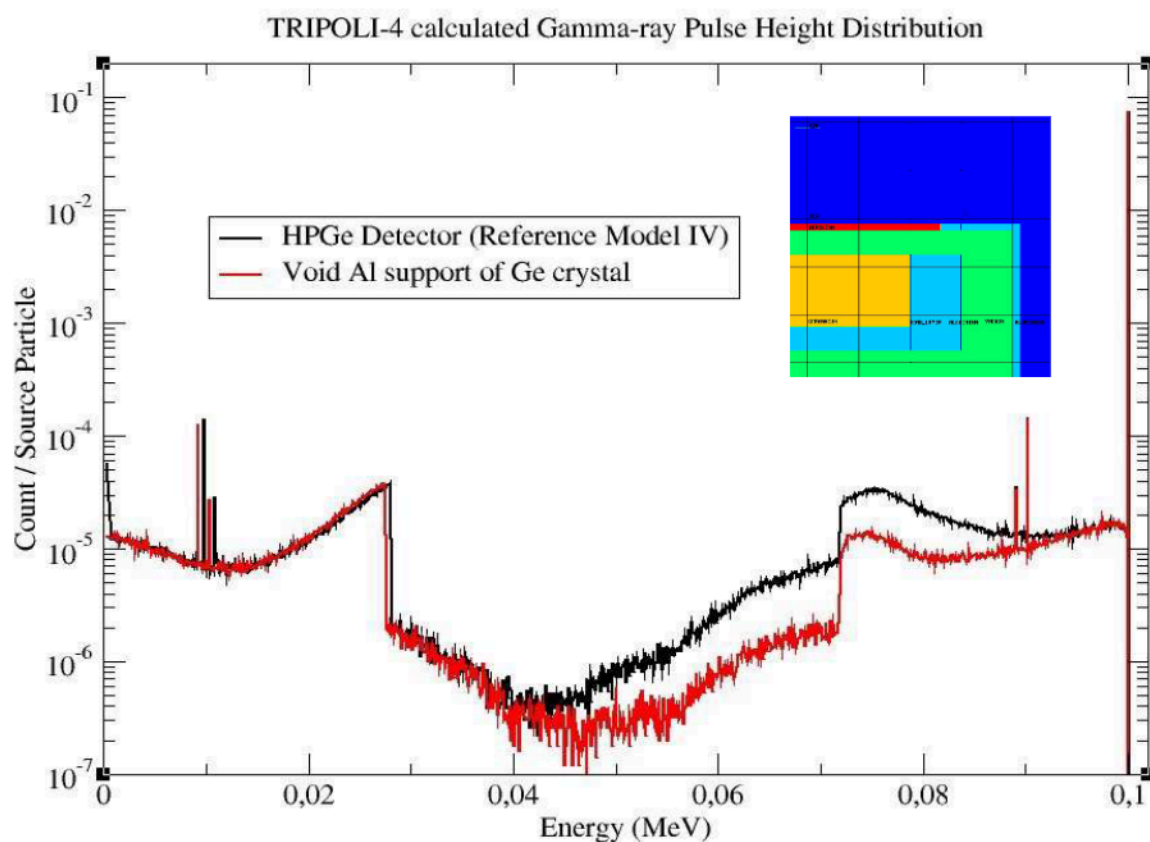
Source:
Co60

=> **1.33,**
1.17 MeV
peaks

=> **Compton**
edges



TRIPOLI-4 – HPGe detector efficiency (Peak & Total)



Source Energy:
100 keV

=> K-shell X-ray
peaks

=> Compton
edge

=> Backscatter
peak



Whole-Body Measurement Simulation

Whole-Body Counter (WBC) Model: HPGe detector CIEMAT WBC

- The **crystal** is germanium (Ge), 31 mm thick and 89 mm in diameter.
- The front, lateral, and back Ge **dead layers** in model: 0.02, 1, and 3 mm.
- The **entrance window** is carbon fibre and epoxy resin of thickness 0.6 mm with a vacuum gap 7.4 mm between the window and the detector crystal.
- The copper **holder of the Ge crystal** lined with a layer of HD polyethylene.
- The Stainless steel **endcap** and the lead **shielding** were also modeled



Whole-Body Measurement Simulation

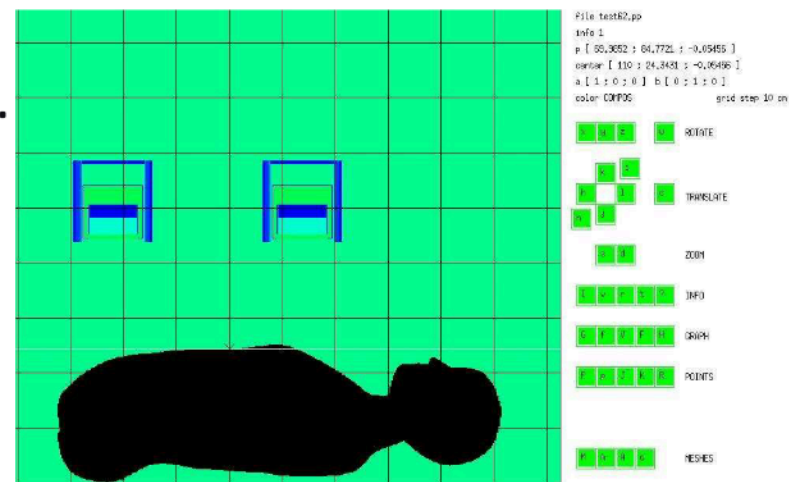
Phantom Models: Brick vs. ICRP 143 - 15F

- **Phantom A (Brick):** Saint Petersburg polyethylene **brick** phantom.
 - 61 bricks total (45 full, 16 half bricks).
 - Used with **line sources** inserted into each brick.
- **Phantom B (Voxel):** ICRP 15-year-old Female (15F).
 - Over **54 million voxels**.
 - **57 distinct tissue materials**.
 - Used with **uniform volume sources** distributed across 136 organs/tissues.



TRIPOLI-4 Numerical Model Setup

- **Detector Type:** Two HPGe detectors.
- **Position:** Positioned **20 cm above** the phantom surface.
- **Target Regions:** Positioned over the **Chest** and **Abdomen (ventre)**.
- **Phantom Position:** **Supine** (lying face up).





TRIPOLI-4 Model of Brick Phantom



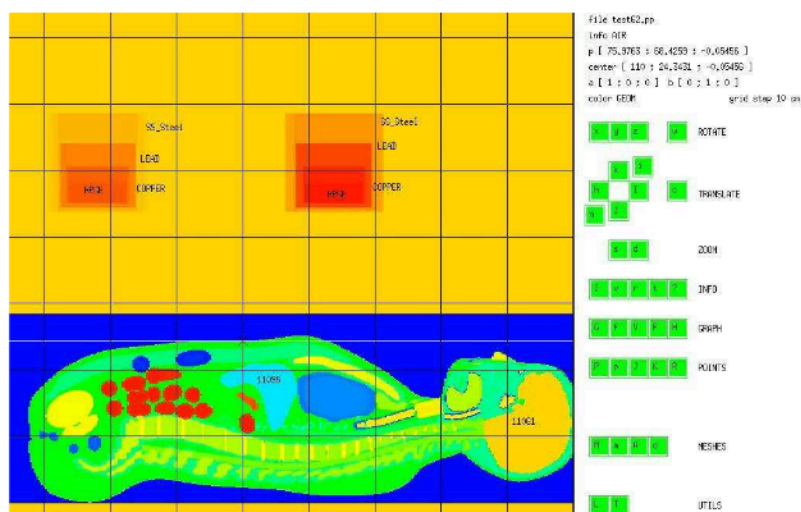
- Two **line sources** inserted in each brick, at gamma energies from 81 keV to 1.33 MeV (^{133}Ba , ^{137}Cs , ^{60}Co).



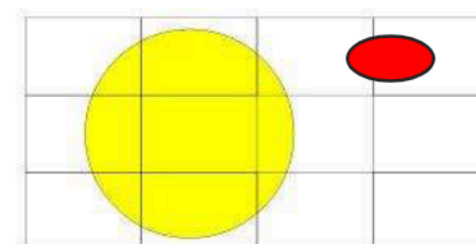
TRIPOLI-4 Model of ICRP 143 Reference Phantom

Phantom B (Voxel): ICRP 15-year-old Female (15F).

- Over **54 million voxels**.
- **57 distinct tissue materials**.
- Used with **uniform volume sources** distributed across 136 organs/tissues.



An intersection operation for **Sources** sampling



- **T4G** display ICRP 15F voxel phantom, X-Z view, grid size 10 cm.



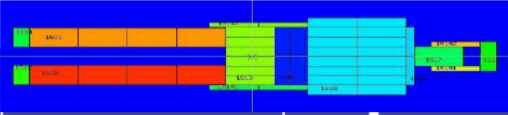
TRIPOLI-4 Simulation Workflow: Validation Steps

- **Task 0:** HPGe Detector validation – **Point source** (external) & Peak efficiency calculation.
- **Task 1:** Brick phantom – **Line sources** (81 keV to 1.33 MeV: ^{133}Ba , ^{137}Cs , ^{60}Co).
- **Task 2:** ICRP 15F voxel phantom – Whole-body **volume sources** distribution.

Cross-Validation: All tasks were simulated with **TRIPOLI-4**[®] and independently
tasks 0 and 1 calculated with **MCNP6** by Montse Moraleda (CIEMAT, Spain) and
tasks 1 and 2 calculated with **MCNP6** (p mode) by Kevin Capello (Health Canada).



Results: Detector Efficiency (15F Brick Phantom)



Gamma-ray Energy (keV)	Peak eff.*	sigma (%)	Peak eff.*	sigma (%)	TRIPOLI-4 Sum Peak eff. (count /photon)
	HPGe (ventre) (count/photon)		HPGe (chest) (count/photon)		
81	7.67E-04	0.5	7.09E-04	0.5	1.48E-3
356	4.36E-04	0.5	4.00E-04	0.5	8.36E-4
662	2.78E-04	0.5	2.58E-04	0.5	5.36E-4
1173	1.95E-04	0.7	1.79E-04	0.8	3.74E-4
1332	1.77E-04	0.8	1.66E-04	0.9	3.43E-4

- Detection efficiency is highly energy-dependent.
- Efficiency at **81 keV** is approximately **4.4 times higher** than at **1.33 MeV**.



Results: Detector Efficiency (ICRP 143 15F Voxel Phantom)

Gamma-ray Energy (keV)	Peak eff.*	sigma (%)	Peak eff.*	sigma (%)	TRIPOLI-4 Sum Peak eff. (count /photon)
	HPGe (ventre) (count/photon)		HPGe (chest) (count/photon)		
81	6.68E-04	0.4	5.97E-04	0.4	1.27E-3
356	3.72E-04	0.5	3.43E-04	0.6	7.14E-4
662	2.35E-04	0.6	2.16E-04	0.7	4.51E-4
1173	1.64E-04	0.8	1.49E-04	0.8	3.13E-4
1332	1.51E-04	0.8	1.39E-04	0.8	2.89E-4

- The Brick phantom yields **17–20% higher** full-energy peak efficiency than the ICRP 15F phantom.



Results: Efficiency Comparison – Brick vs. ICRP 15F

The Brick phantom yields **17–20% higher** full-energy peak efficiency than the ICRP 15F phantom.

Primary Reasons for Difference:

- 1. Geometry:** Modular **bricks** differ from **realistic body contours** (scattering differences).
- 2. Material:** **Polyethylene** vs. heterogeneous **human tissues** (bone, lung, muscle).
- 3. Source Distribution:** **Line sources** (discrete) vs. **volume sources** (homogeneously distributed in organs).

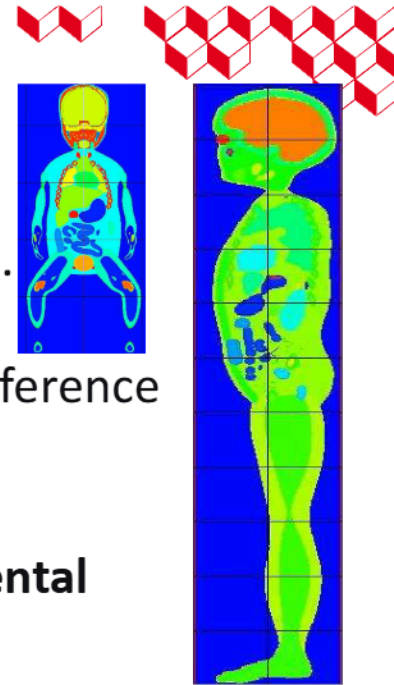
Results: Benchmarking & Computational Performance

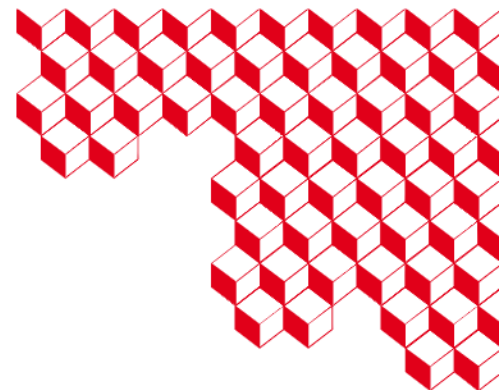


- **Validation:** TRIPOLI-4[®] shows excellent agreement with MCNP6 – **deviation** $< \pm 4\%$.
agreement with MCNP6 (p mode only) - **3–21% difference**.
- **Performance:** Factor of **4 reduction** for TRIPOLI-4[®] in memory usage for the ICRP 15F voxel phantom compared to previous version.

Conclusion

- / . TRIPOLI-4® is validated for complex paediatric voxel phantom simulations.
- / . Realistic paediatric voxel phantoms may replace brick phantoms as the reference geometry for in vivo monitoring calibration.
- / . It is interesting to compare these simulation results with future **experimental measurements** using calibrated sources.
- / . It is planning to extend the TRIPOLI-4 study to other **distance** (20 → 50 cm) and **age** groups (1yr, 5yr, 10yr).
- / . For realistic **inhomogeneous** contamination scenarios (e.g., lungs, **GI tract, bones**), realistic voxel phantoms can provide better calibration for **Whole-Body Measurement**.





Thank you for your attention

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