* Fast Monte Carlo methods for interventional radiology

Maria A. Duch

Institute of Energy Technologies (INTE)

of the Universitat Politècnica de Catalunya (UPC)

EURADOS European Radiation Dosimetry Group

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PODIUM Personal Online Dosimetry Using computational Methods

EUROPEAN JOINT PROGRAMME FOR THE INTEGRATION OF RADIATION PROTECTION RESEARCH CONCERT

COMPUTATIONAL DOSIMETRY
IN FLUOROSCOPICALLY GUIDED PROCEDURES

- Many staff in the room
- Complex equipment present
- The radiation source changes many times during a procedure (from a few to hundreds of different events): primary beam conditions, table positions, angulation, collimation and other parameters

THE PODIUM PROJECT CHALLENGE:

Make MC simulations fast enough

The Monte Carlo (MC) method is a stochastic method for numerical integration

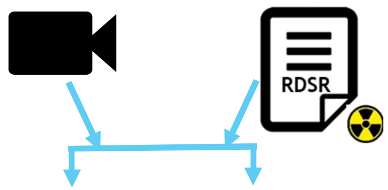
→ *Boltzmann equation of radiation transport*

Usually a large number of particle trajectories has to be simulated

radiation source and position of the staff change

Staff positioning
→ Tracking system

Radiation source
X-ray beam + patient →
Scattered field



Long simulation times

↓

Adapted fast MC codes

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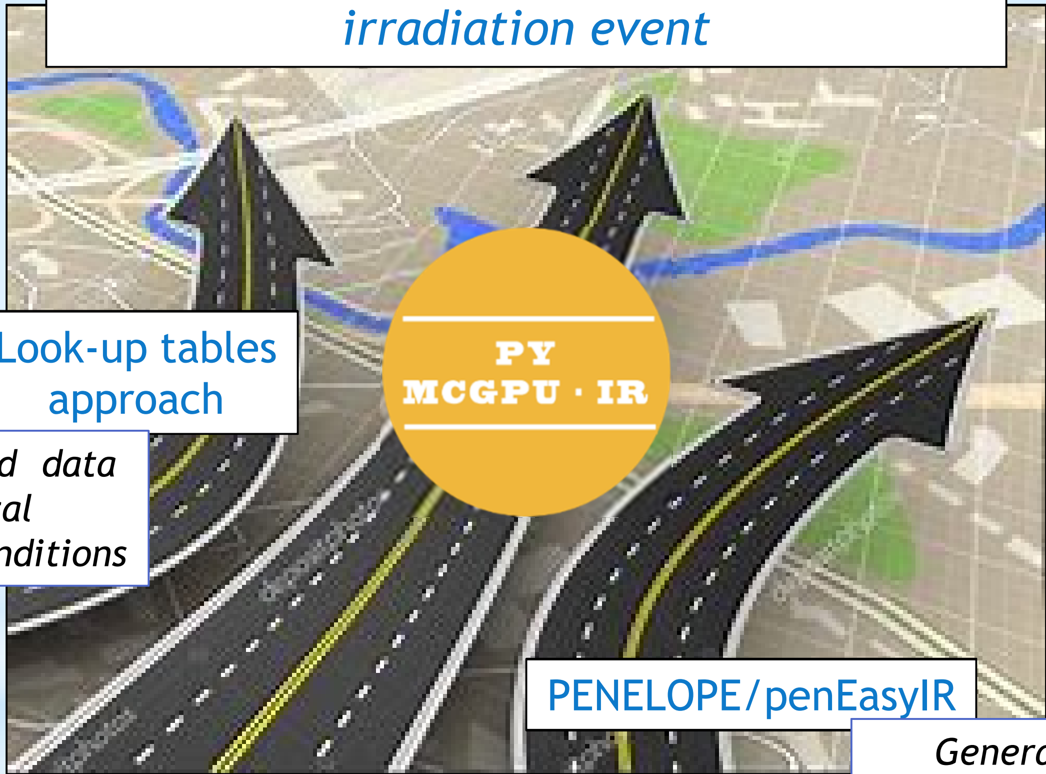
THE PODIUM PROJECT CHALLENGE

GOAL

MC simulation times: ~ min per irradiation event



Look-up tables approach

Pre-calculated data for typical irradiation conditions

PENELOPE/penEasyIR

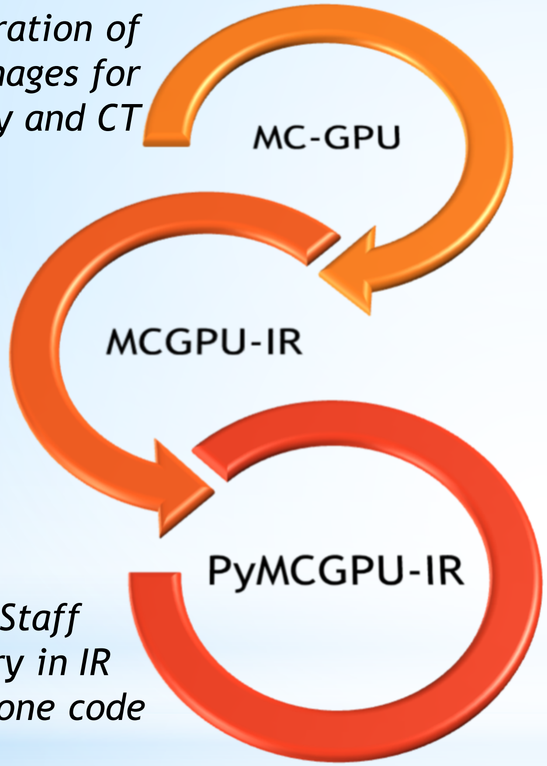
General purpose code + variance reduction techniques+ simplifications

You've never heard of PyMCGPU-IR? Should I have?

Generation of synthetic images for radiology and CT

Staff dosimetry in IR with an online application

Patient+Staff dosimetry in IR Stand-alone code



"Fast ship? You've never heard of the Millennium Falcon?"-"Should I have?"-"It's the ship that made the Kessel run in less than 12 parsecs" - Han Solo/Ben Kenobi

Andreu Badal and Aldo Badano, "Accelerating Monte Carlo simulations of photon transport in a voxelized geometry using a massively parallel Graphics Processing Unit", Medical Physics 36, pp. 4878-4880 (2009)

PY MCGPU · IR

MCGPU-IR

Multi-threaded code written in CUDA (each GPU card > 3000 CUDA cores)

python™

Tested in different conditions:

- General purpose code PENELOPE/penEasy
- Experimental values
- Static controlled conditions and Real IR procedures

Vanhavere, F. et al. EJP Concert deliverable: D9.121. Final Report of the PODIUM project
Fernández-Bosman, D. et al. Validation of organ dose calculations with PyMCGPU-IR in realistic interventional set-ups. Phys. Med. 93(6), 29-37 (2022)
García-Balcaza, V. et al. Fast Monte Carlo codes for occupational dosimetry in interventional radiology. Phys. Med. 85(2), 166-174 (2021)
O'Connor, U et al. Feasibility study of computational occupational dosimetry: evaluating a proof-of-concept in an endovascular and interventional cardiology setting. J. Radiol. Prot. 42 (2022) 041501

GENERAL CHARACTERISTICS

Type of particles simulated and energy range:
- *Photons up to 120 keV (kerma approximation)*

Interaction models and cross-sections:
- *PENELOPE v 2014*

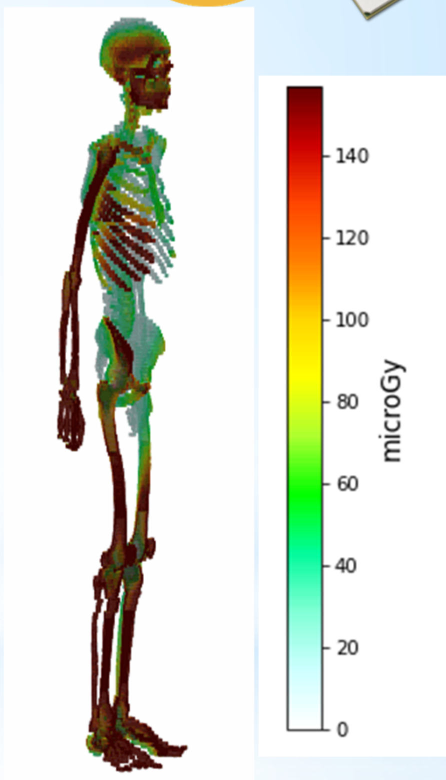
Source description and Geometry:
- *X-ray beams (Spektr 3.0)*
- *Rectangular fields defined by the shape and size at the image detector plane*
- *Voxelized geometries*

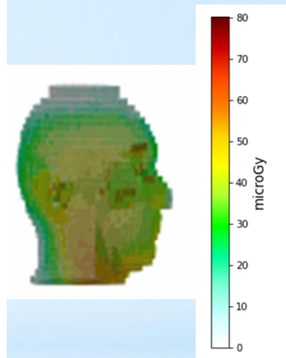
Parallelization among several GPU cards:
- *MPI implementation*

Computational time performance:
- *Automatic set of the optimal values for:*
  - *Blocks/kernel, Threads/block*
  - *Histories/thread to be simulated in the GPU*

Results:
- *Patient dosimetry*
- *Staff dosimetry*

}
- *Dose at voxel level*
- *Organ doses*
- *$H_p(d)$*





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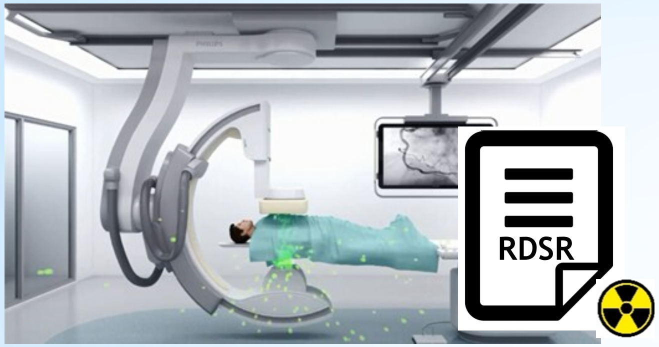
ADAPTED FOR COMPUTATIONAL DOSIMETRY IN INTERVENTIONAL RADIOLOGY

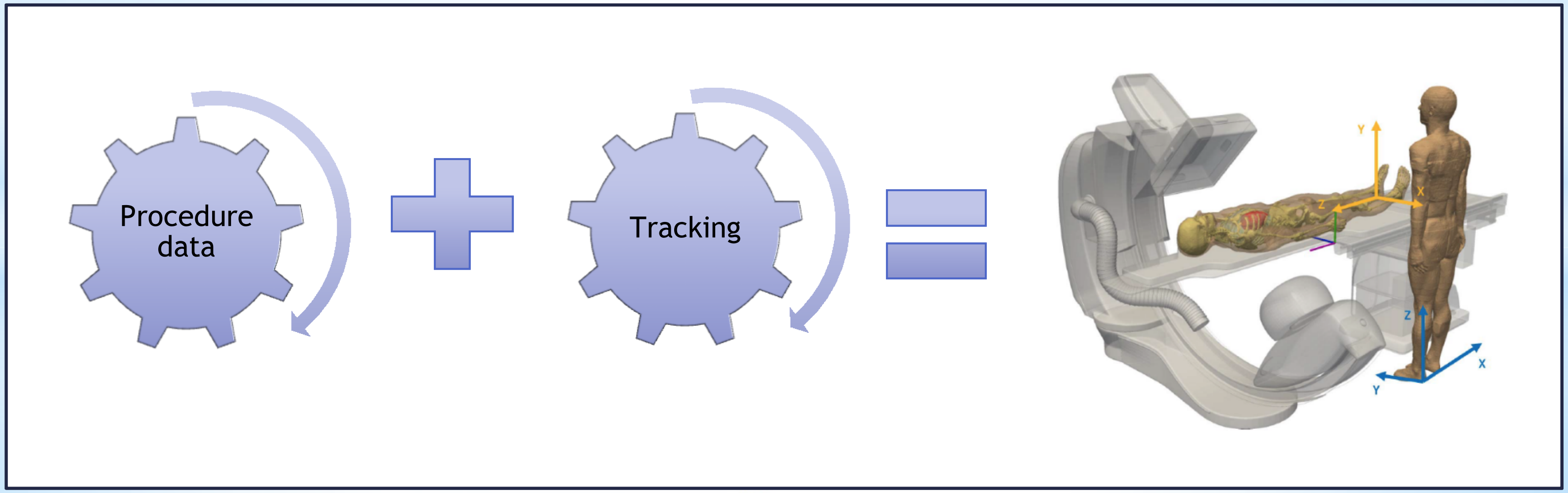
RADIATION DOSE STRUCTURED REPORT



X-ray beam → *Patient* → Scattered field

TRACKING

Operator phantom→ *Staff dosimetry*



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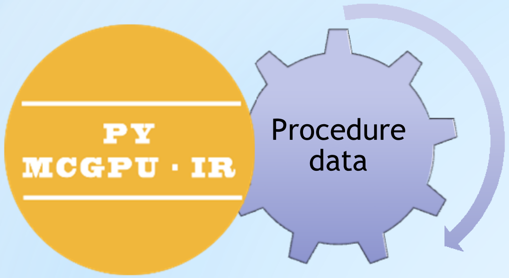
Procedure data

Radiation Dose Structured Report

RDSR

For each irradiation event (can be up to several hundreds)

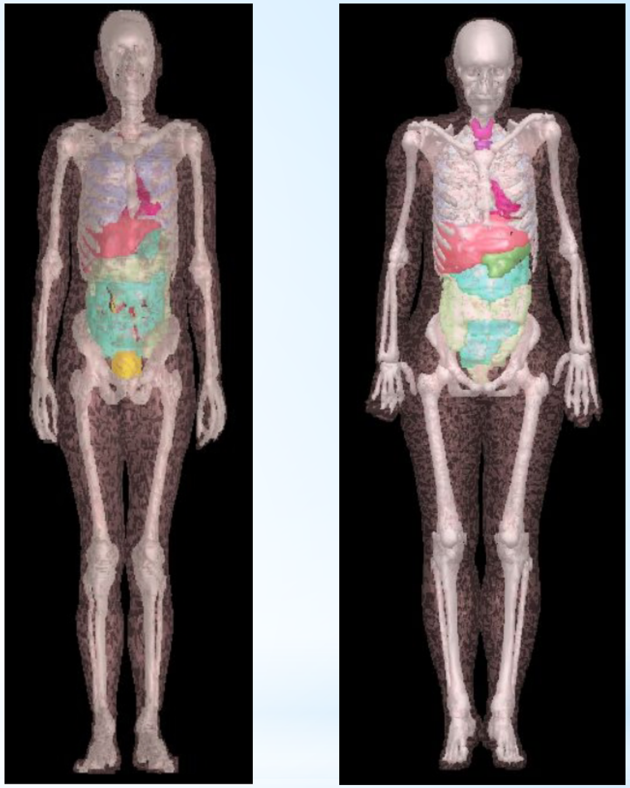
- kV, filtration → X-ray beam
- Field shape/size
- Isocentre/Reference point location
- Source-detector distance
- C-arm rotation angles
- Table position
- DAP
- Patient/operator information →



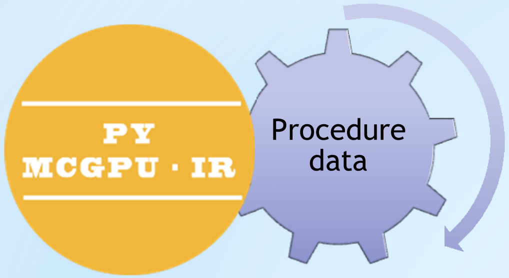
PATIENT GEOMETRY

Required data:
- Gender
- Height, weight
- Anatomical region examined

PyMCGPU-IR can adjust the voxel size applying three (x,y,z) scaling factors

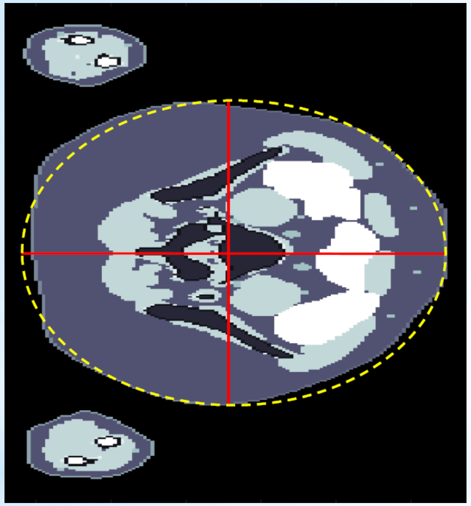


Rex and Regina, developed by Helmholtz Zentrum München



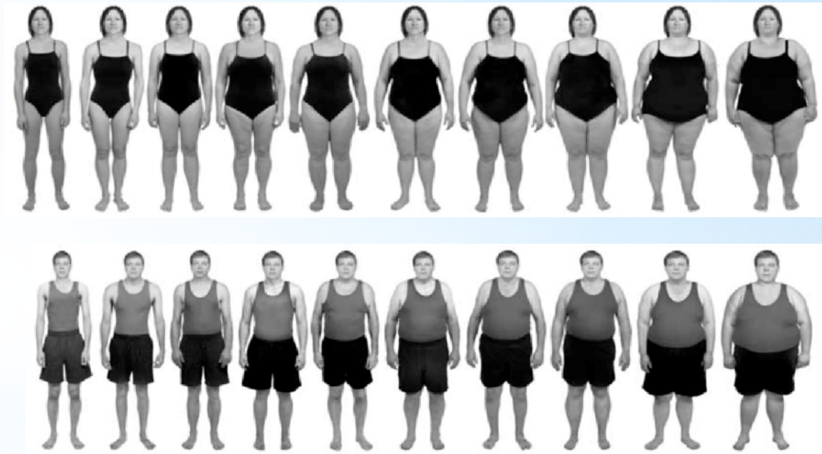
PATIENT GEOMETRY

$$\text{BMI} = \frac{\text{weight(kg)}}{\text{height(cm)}^2}$$



Perimeter is scaled according BMI of the patient

Scaling



National Health and Nutrition Examination Survey Data (NHANES) (1999-2018), USA

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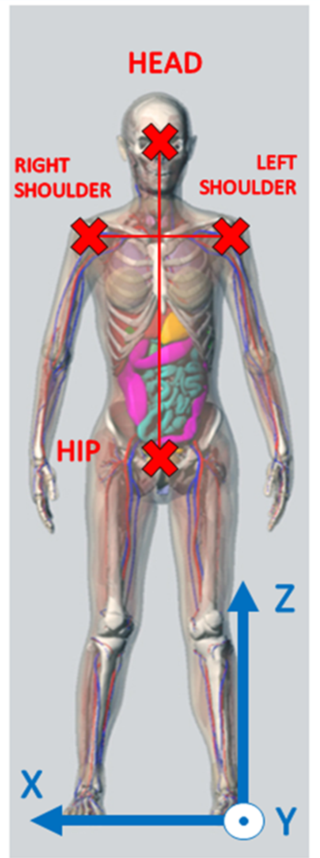
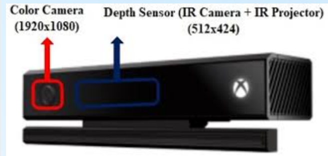
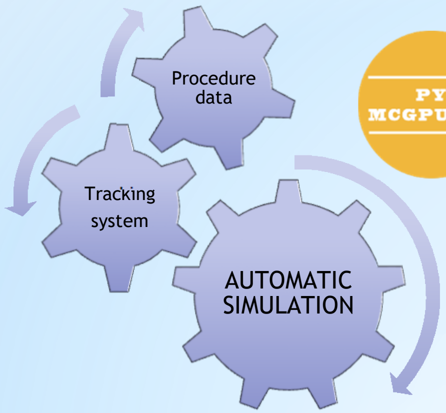
TRACKING SYSTEM





System based on Kinnect cameras → *Joint coordinates*

The position is calculated from the Hip location
Shoulders and Head are used to determine rotations of the operator phantom (bending…)



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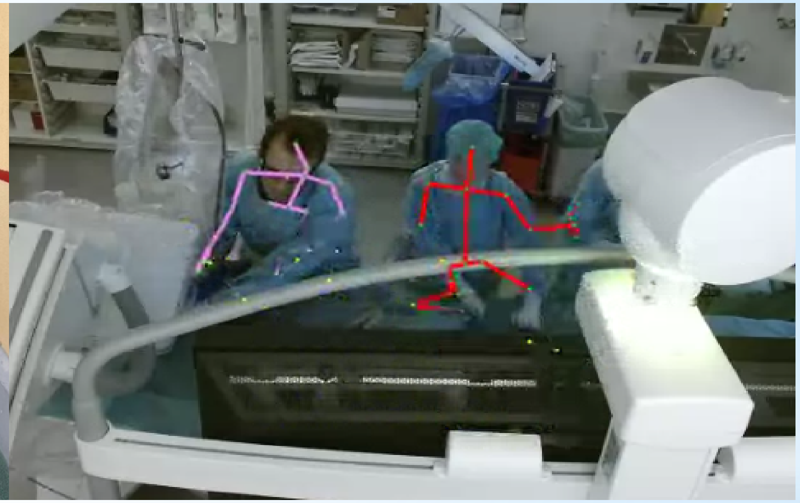
SYNCHRONIZATION



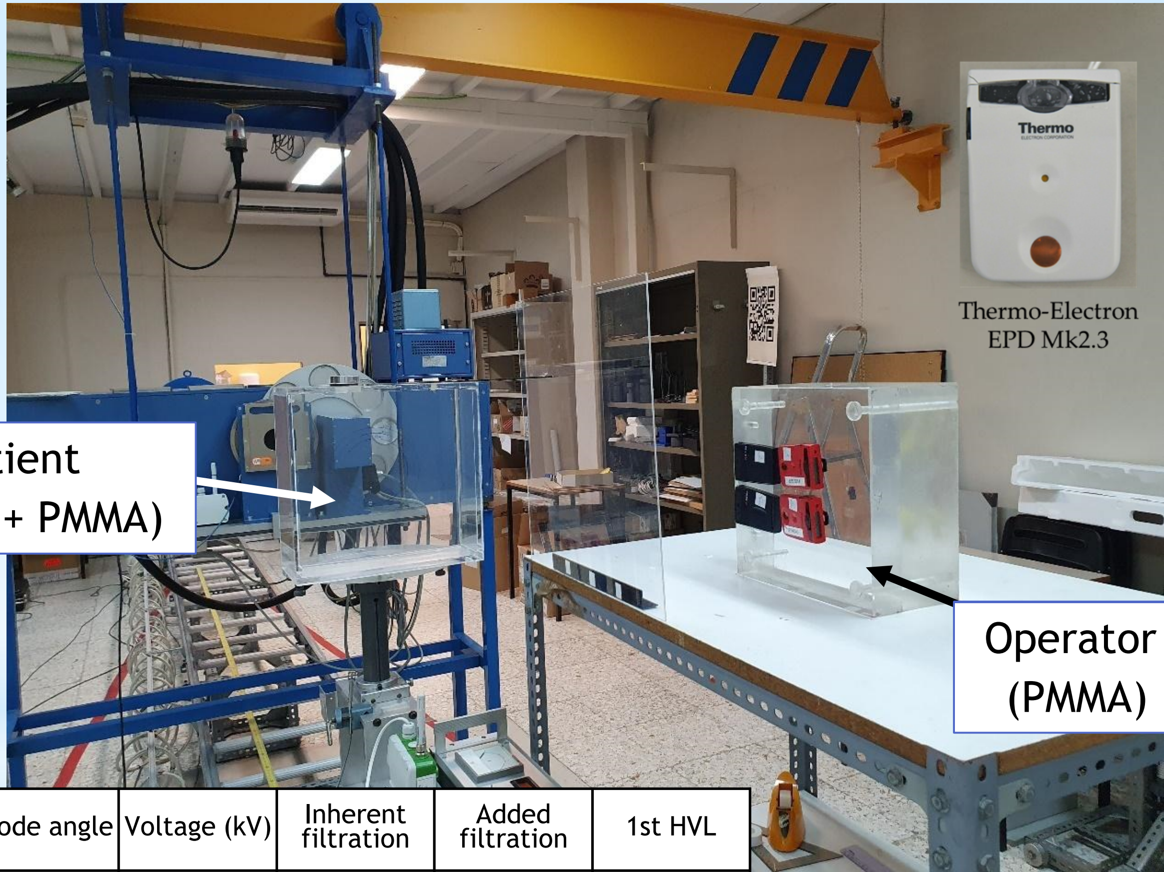
A statues game: The location of the main operator is determined at the beginning of each irradiation event and it is kept constant all along the event

- all clocks should be synchronised to the greatest possible degree of accuracy -

Some results of static cases

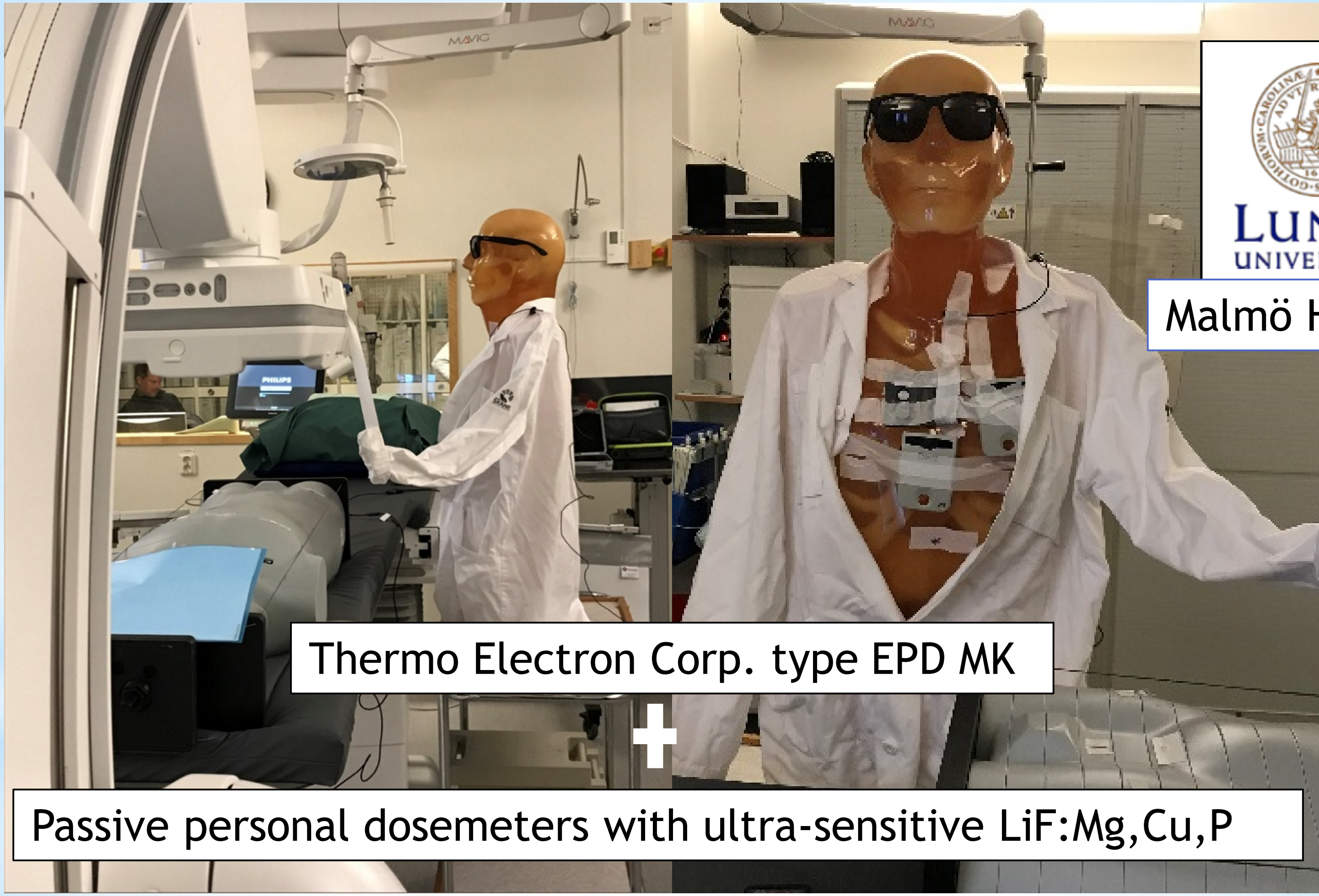
(Real Cases→ U.O'Connor presentation)

STATIC TESTS: INTE-UPC SECONDARY CALIBRATION FACILITY



Beam Quality	Anode angle	Voltage (kV)	Inherent filtration	Added filtration	1st HVL
RQR5	18°	70	7 mm Be	2.5 mm Al	3.07 mm Al
RQR7	18°	90	7 mm Be	3.3 mm Al	3.46 mm Al

STATIC TESTS: REALISTIC CONDITIONS



LUNDS UNIVERSITET

Malmö Hospital

Thermo Electron Corp. type EPD MK

+

Passive personal dosemeters with ultra-sensitive LiF:Mg,Cu,P

CONCLUSIONS

* STATIC CASES:

  * Results were considered satisfactory for the purpose of the PODIUM validation study:

    * Simulation times:
      * Organ (many voxels involved) doses can be calculated in a few s per irradiation event
      * $H_p(10)$ (a few voxels) can be calculated in some tens of s per irradiation event

        Example: ~ 60 s with a statistical uncertainty lower than 2.6% (k = 2)

        by using an old cluster with 2 GPU cards

    * Comparison with measurements/standard simulations:
      * MCGPU-IR tends to underestimate $H_p(10)$ up to ~20 % when compared with a full simulation with a standard code or experimental values
      * Other developed codes, such as PENELOPE/penEasyIR, tend to overestimate doses

Thank you for your attention…questions at the end of the webinar…