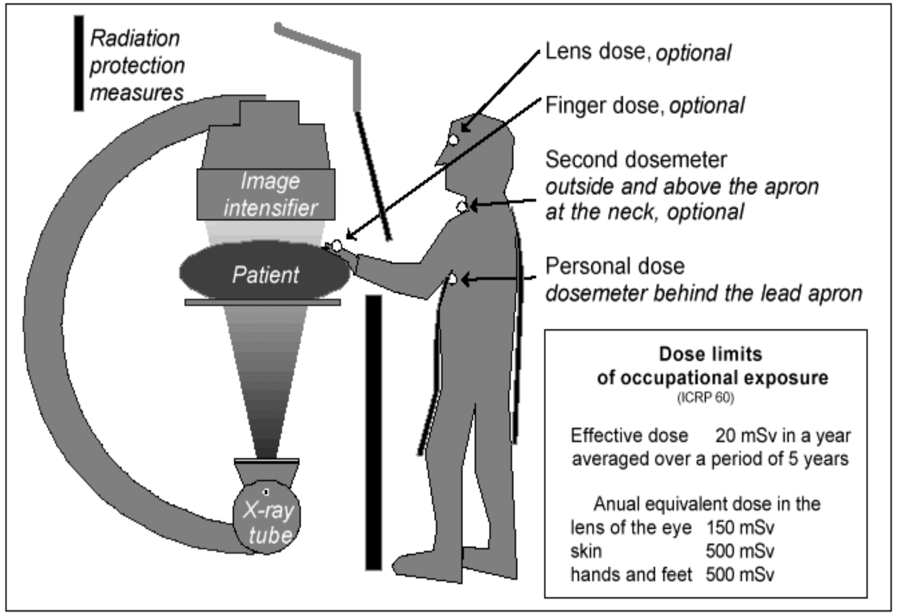
Filip Vanhavere – 02/10/2023

sck cen
Belgian Nuclear Research Centre

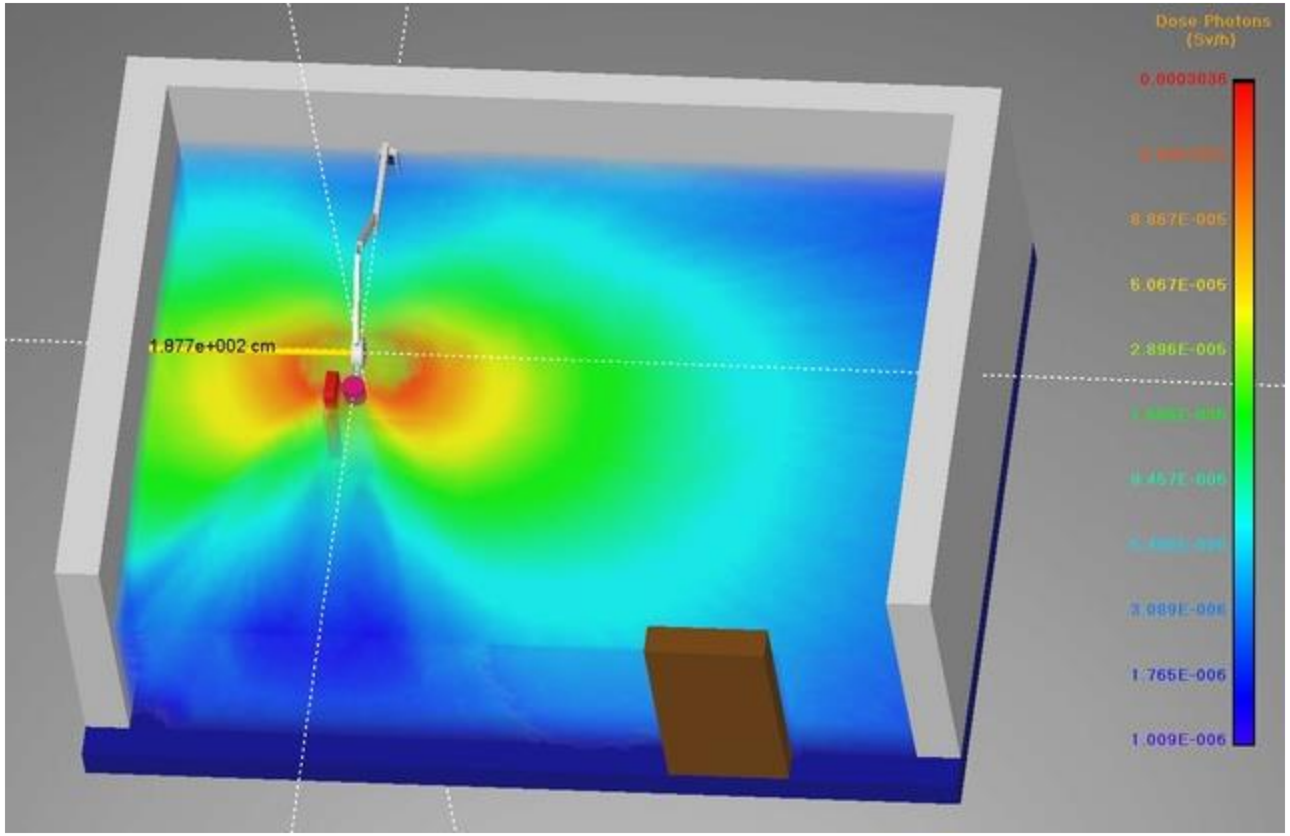
Computational dosimetry as a tool to optimize staff radiation protection during interventional procedures

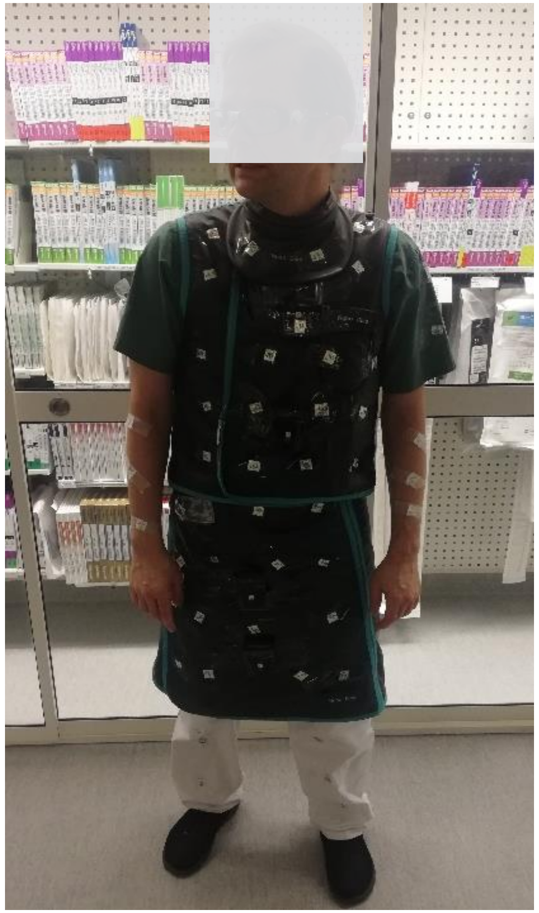
Occupational exposure staff in interventional procedures

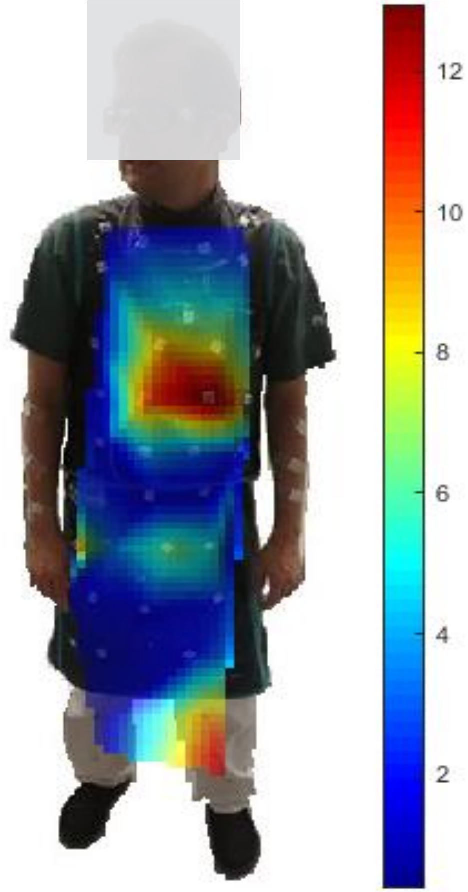
- Among highest doses for occupationally exposed professionals
  - Whole body doses (effective dose)
  - Eye lens doses
  - Extremity doses
  - Others… (brain, leg, heart,…)
- Many dosemeters needed (in theory) because of highly inhomogeneous field
  - Above and below lead apron
  - Eye lens
  - Ring



Personal Dosimetry: Inhomogeneous fields







Problems with individual dosimetry

- Workers don't like to wear dosimeter
- Workers especially don't like to wear more than one dosimeter

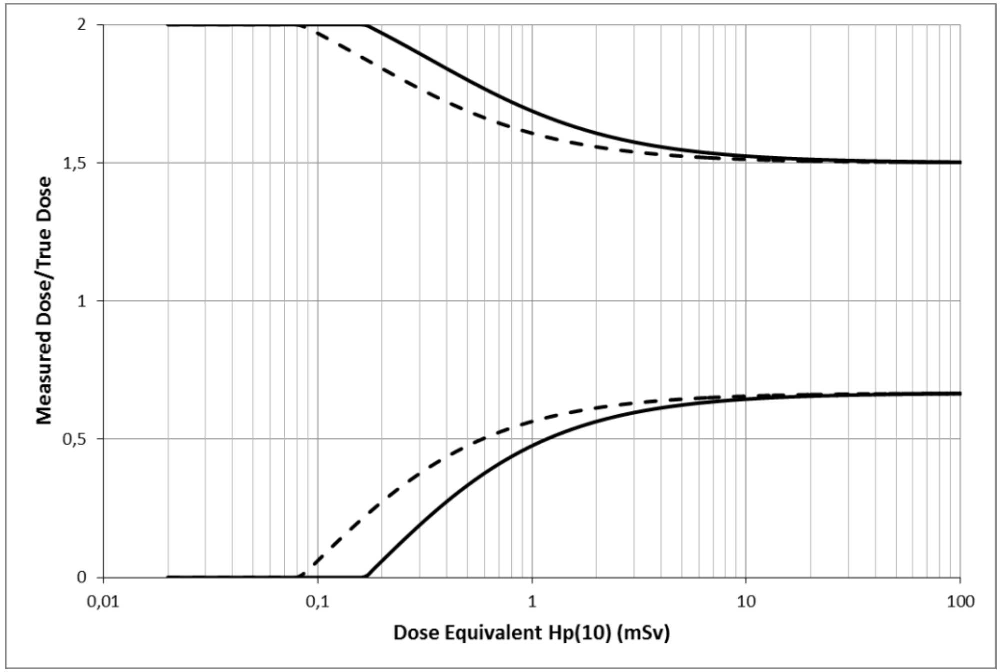
- Still not all parts of body covered
  - What if other parts of body need dosimetry in future (brain, heart,...)?

- Not always strict use of dosimeters:
  - Forgetting
  - Not correct place

- Personal dosimetry = 1 point measurement...

Uncertainties in personal dosimetry

- Risk is given by effective dose
  - Complicated system of operational quantities to estimate effective dose
  - $H_p(10)$ is only estimation of E
- No dosemeter is perfect for $H_p(10)$
  - Non-linearity, fading, …
  - Energy and angular dependence….
- Not wearing correctly



Factor 1.5 in either direction for doses near the limit
Factor 2.0 for lower doses (ICRP 75)

For ALARA: feedback on doses helps

- Active personal dosemeters (APD) give more feedback to worker
  - Often used as ALARA or alarm dosemeter
  - Mostly in combination with passive dosemeter as Dose-of-Record
- More feedback (on-line)
  - Better use and care on dosemeters by workers
  - Makes dosimetry more “useful”

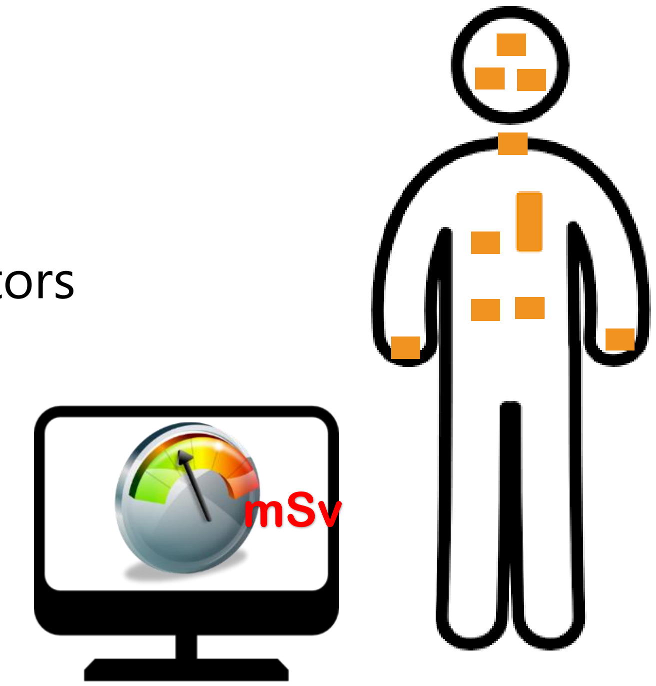
- Use of APD will continue to increase
  - Smaller and more sensitive devices
- They do not always work in all fields…!

APDs also have limitations

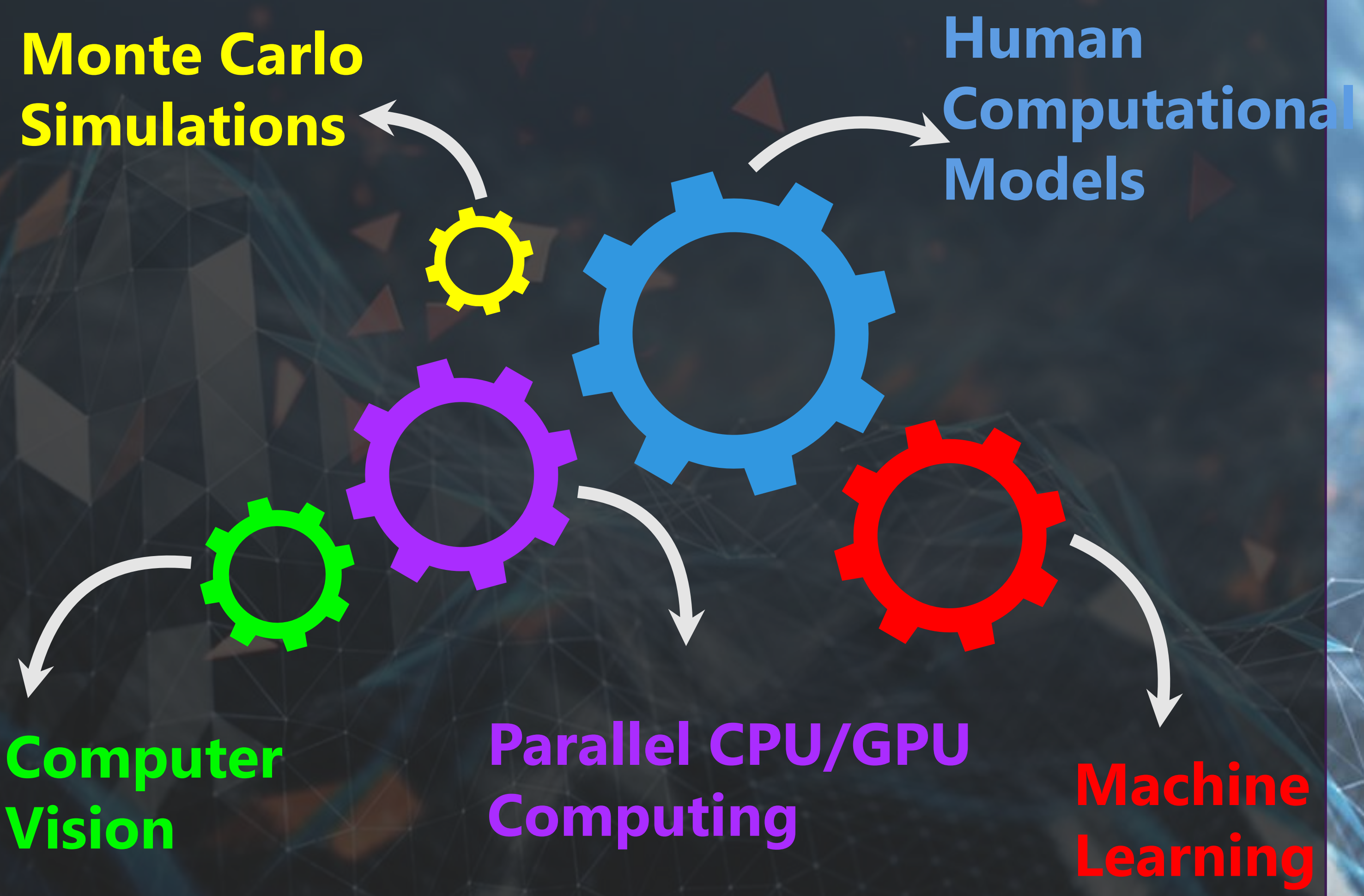
- Dosemeter cost
- Potential lack of security of data storage
- Mass and size of dosemeter
- Battery type and life span
- **Possibly poor low energy photon energy dependence**
- Poor beta radiation response
- Sensitivity to electromagnetic fields (older models)
- Possibly saturation at high dose rates
- **Poor behavior under pulsed radiation (instantenous dose rate)**

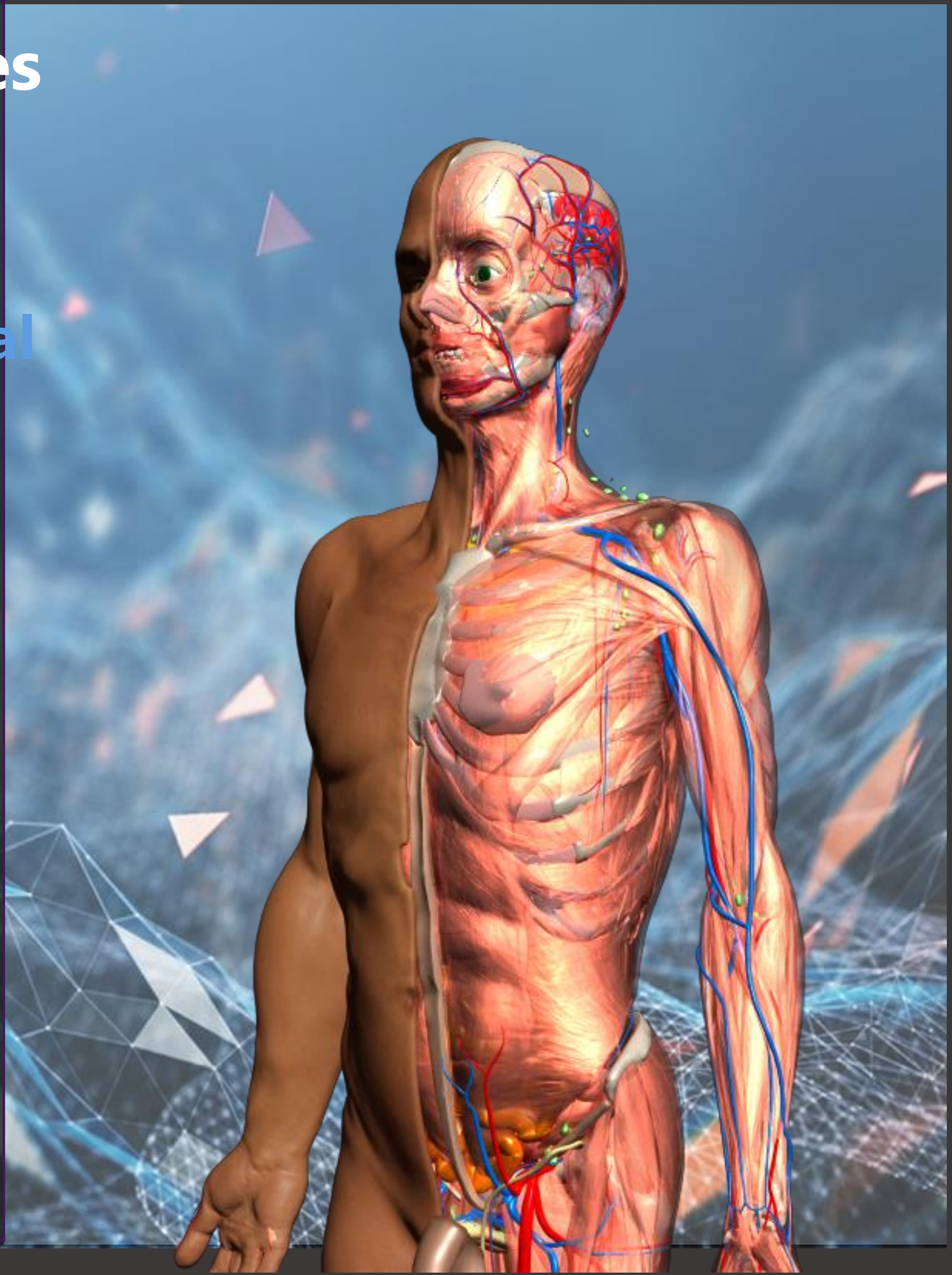
Personal Dosimetry: what brings the future?

- More use of active personal dosemeter: direct feedback
- Suppose we can use Monte-Carlo simulations to calculate on-line all doses
- Advantages:
  - No more need for physical dosimeter
  - No more loosing dosimeters
  - No more need for operational quantities
  - No more worries for changing quantities/weighting factors
  - Doses to all organs can be known
  - Personalized dosimetry possible
  - Better accuracy possible
  - Faster feedback to workers (ALARA tool)

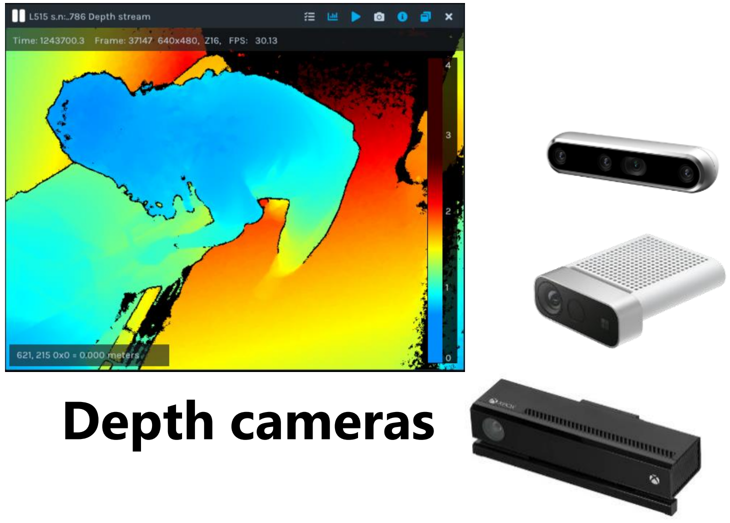


Exploiting most advanced technologies

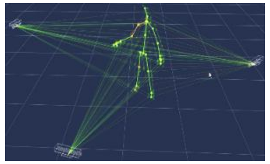




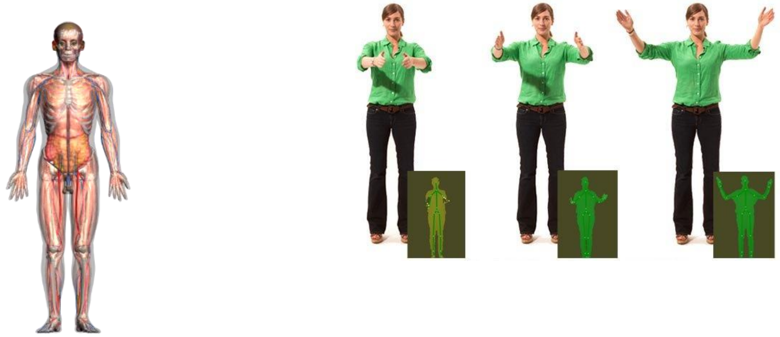
Methodology:
staff movement monitoring and radiation field mapping

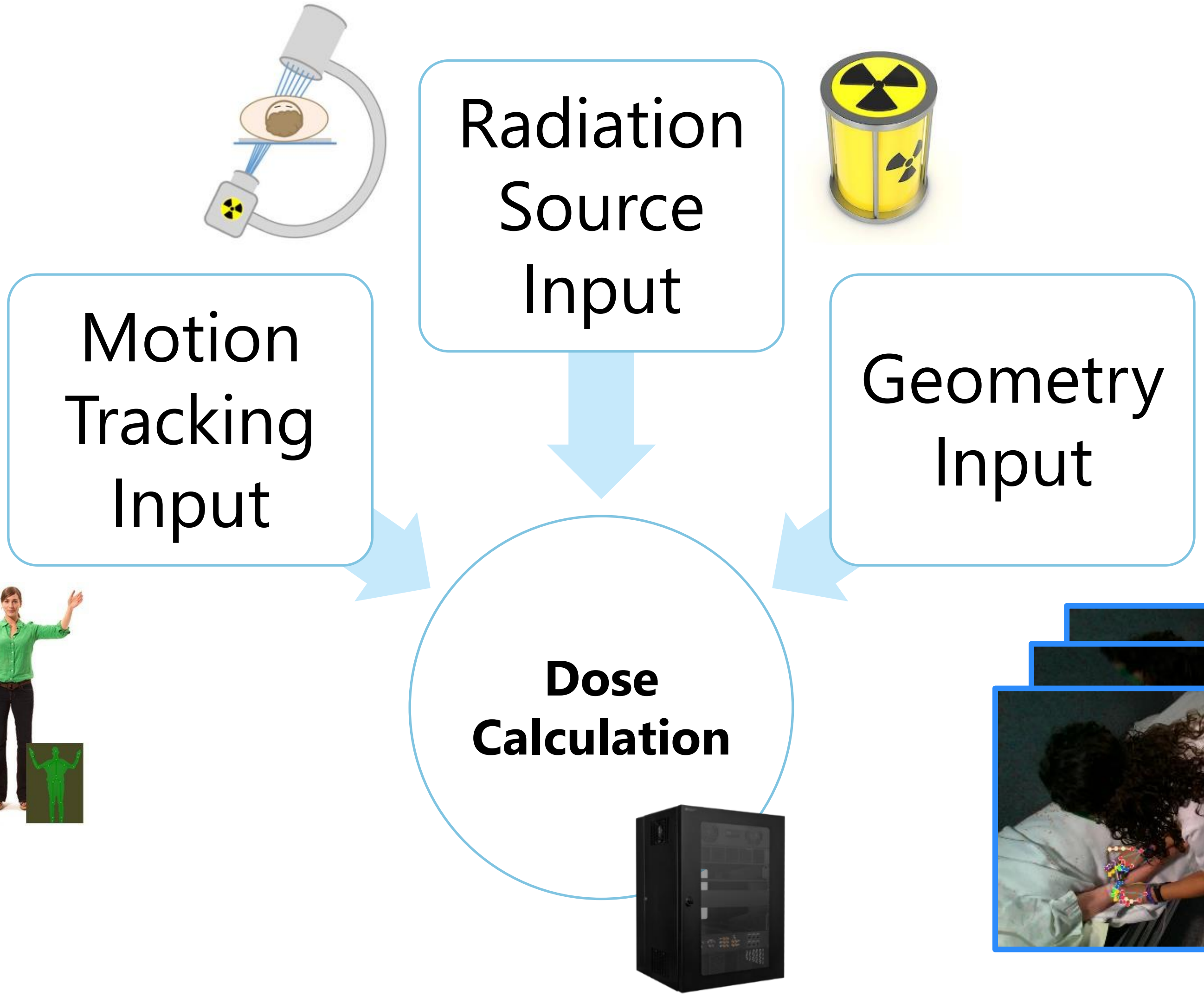


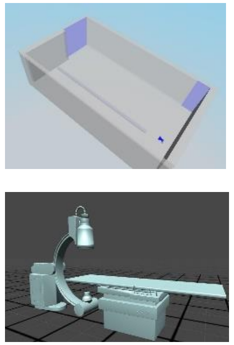
Depth cameras



Flexible phantoms







RAF: Realistic Anthropomorphic Flexible Phantom

- Polygonal Mesh Boundary Representation
- Organ and tissue masses adjusted according to ICRP 89
- Computational model with 2900 tissues segmented
- Dosimetric validation in comparison with ICRP 116

Development and Validation of the Realistic Anthropomorphic Flexible (RAF) Phantom

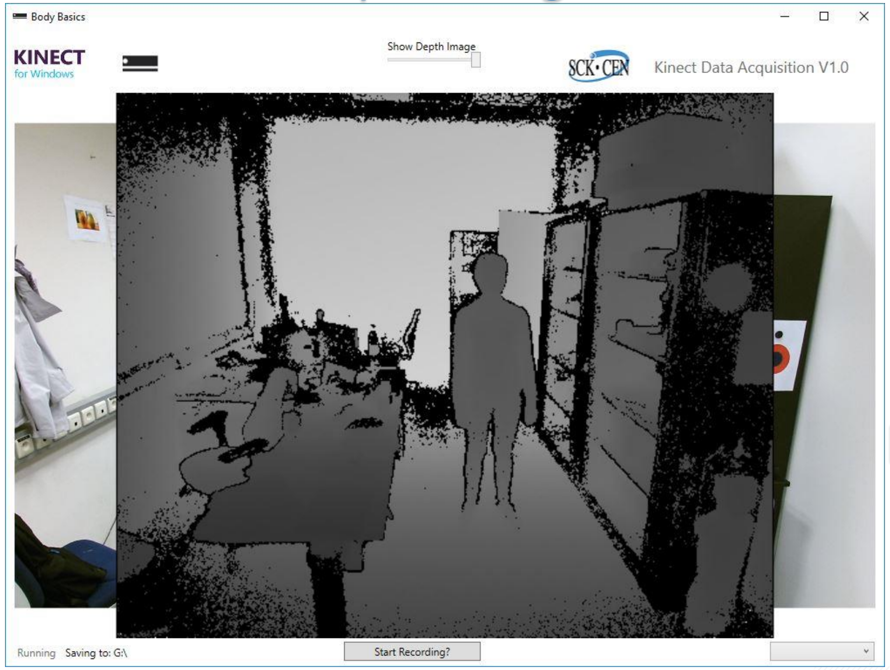
Lombardo, Pasquale A.; Vanhavere, Filip; Lebacq, Anne L.; Struelens, Lara; Bogaerts, Ria

Health Physics, Volume 114 (5) – Jan 1, 2018

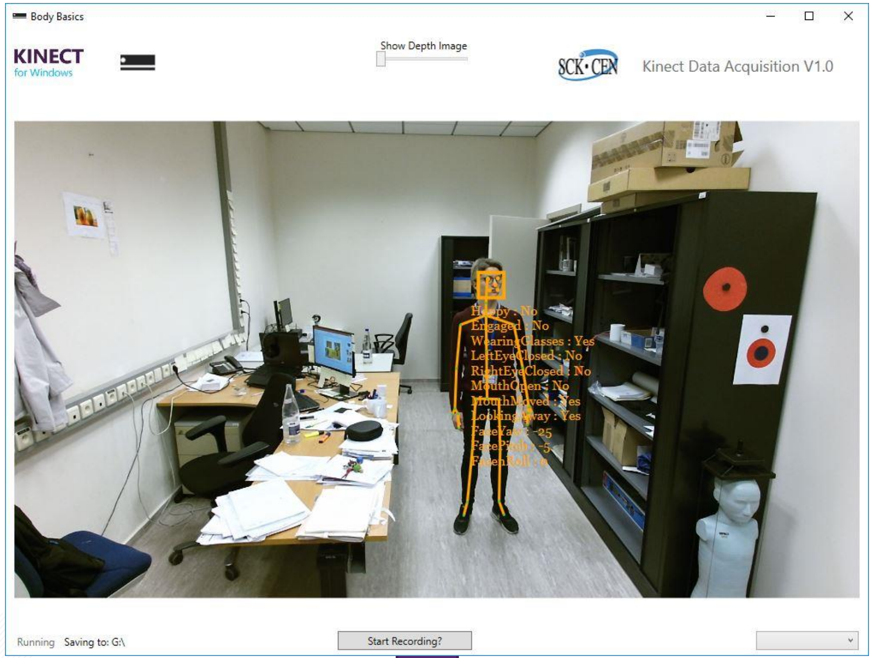
Staff Motion Tracking

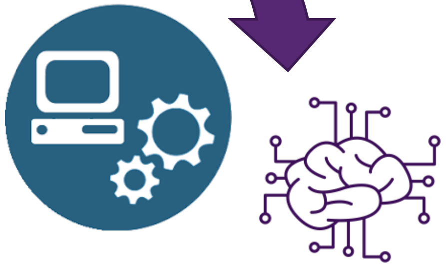
Tracking system based on single depth camera

Depth Image

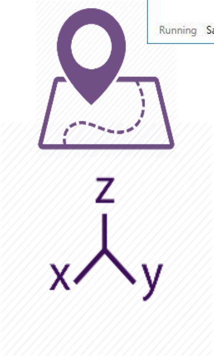


Skeleton Tracking



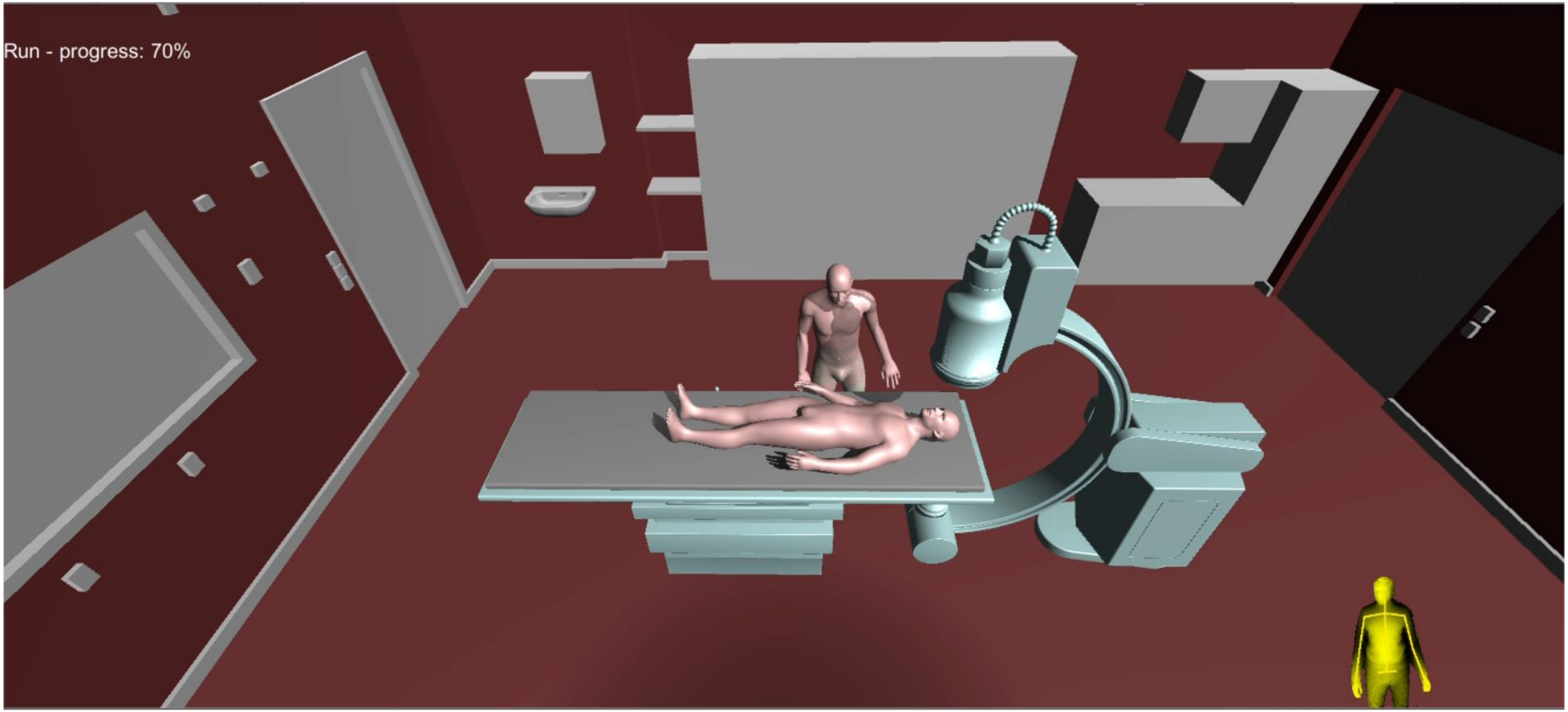


Real-time processing

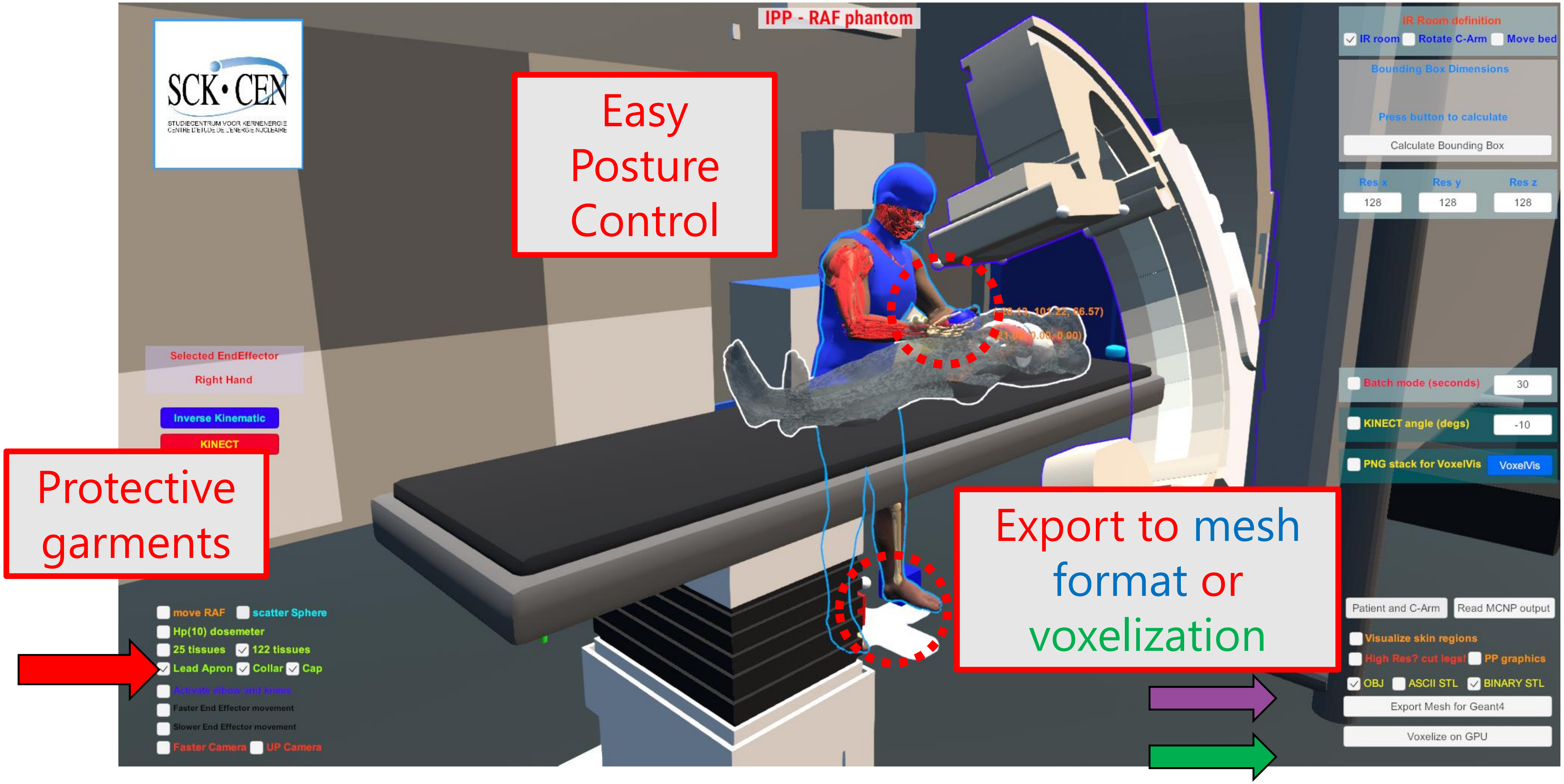


Storing XYZ coordinates or send to a cloud

Animation of RAF phantom



Dose Simulations



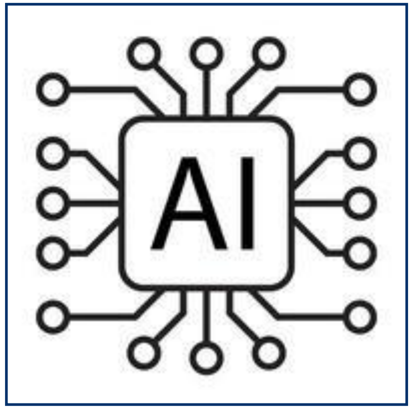

IPP - RAF phantom
SCK • CEN
STUDIECENTRUM VOOR KERNENERGIE
CENTRE D'ETUDE DE L'ENERGIE NUCLEAIRE
Standard position
No room
Selected EndEffector
Head
Inverse Kinematic
KINECT
zoom Face
zoom Chest
rescale RAF
move RAF
scatter Sphere
Hp(10) dosemeter
25 tissues
122 tissues
Lead Apron
Collar
Cap
Faster End Effector movement
Slower End Effector movement
Faster Camera
UP Camera
C-Arm rotation
rotation of projection
29
LAO
arm angulation
37
CAU
position along bed
-43.0705
position perpend bed
53.51411
IR Room definition
IR room
Rotate C-Arm
Move bed
effective dose [Sv/(Gy DAP)] * (voxel volume)
0.000112357150692318
Calculate Bounding Box
Res x
Res y
Res z
256
512
256
(-43.07, 121.76, 51.51)
load MCNP PTRAC
Batch mode (seconds)
30
KINECT angle (degs)
-10
Source position
PNG stack for VoxelVis
VoxelVis
Patient and C-Arm
Read MCNP output
Visualize skin regions
High Res? cut legs!
PP graphics
OBJ
ASCII STL
BINARY STL
Export Mesh for Geant4
Voxelize on GPU
launch MCNP sim

Augmented reality visualization of the 3D distribution of the scattered radiation

Towards real time: how to accelerate the simulations

- Monte Carlo codes are highly parallelizable
- Use of GPU

- Neural Networks
    - Similar input and output as the MC simulations
    - Learns to predict the dose



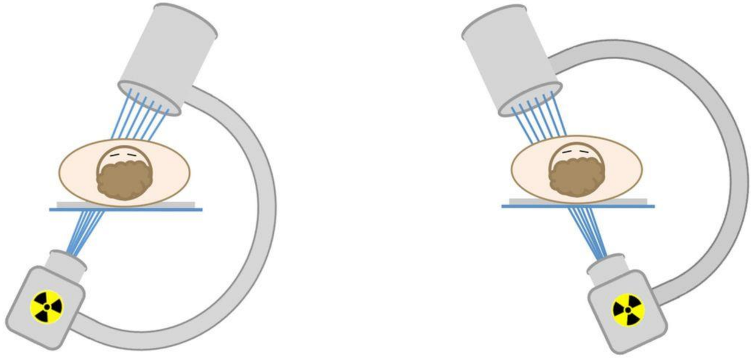
Interventional Radiology Case

X-Ray spectrum

- Tube potential (kVp value)
- Tube current
- Added filtration
- Target material
- Voltage waveform

Tube Angulation

- C-arm projections



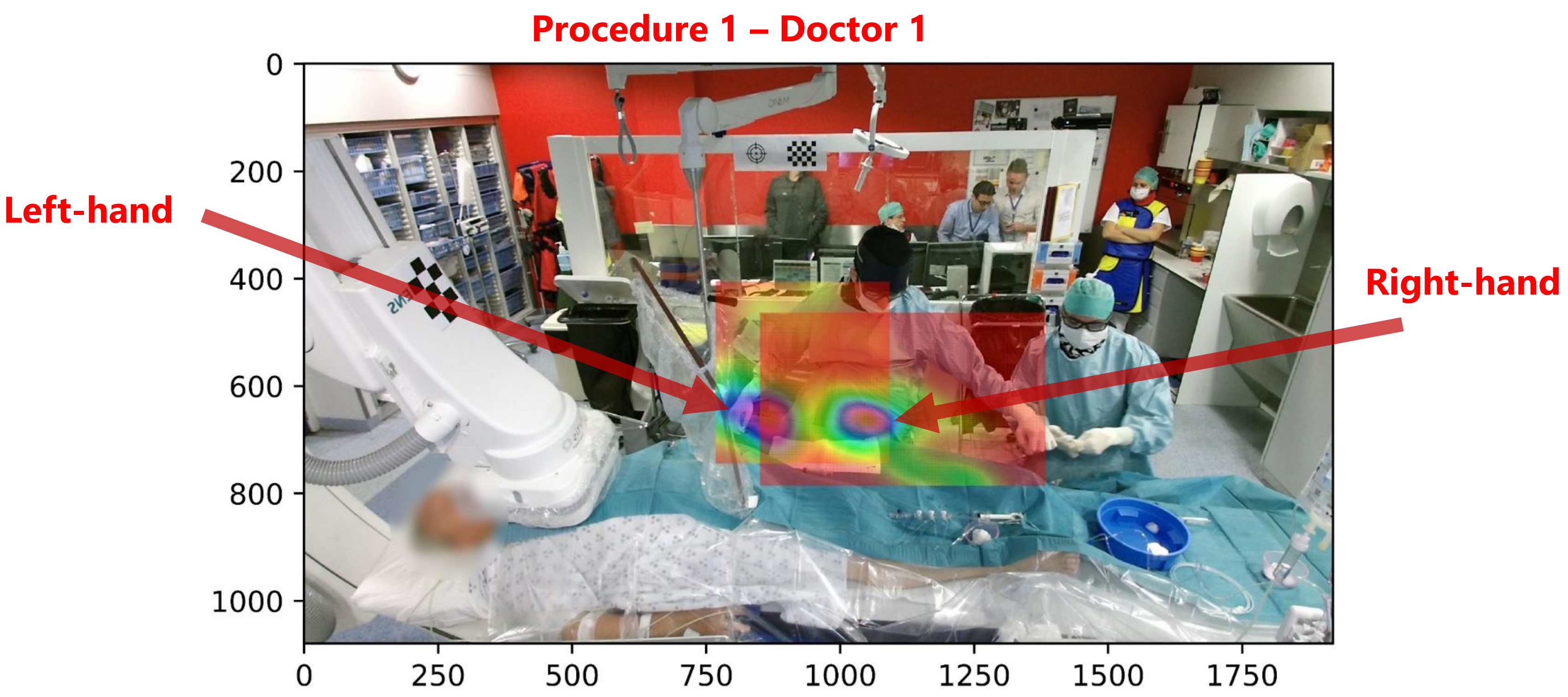
Interventional Radiology and Cardiology Parameters	
Parameter	**Range**
High Voltage	60-120 kVp
Intensity	5-1000 mA
Inherent filtration	3-6 mm Al_{eq}
Additional filtration	0.2-0.9 mm Cu
Energy range of scattered spectra	20 keV – 100 keV

Input

- Radiation dose structured report (RDSR) extracted from the X-ray machine
- **Time synchronization with tracking**
- DAP meter for normalization

Test at UZ-VUB - Brussels

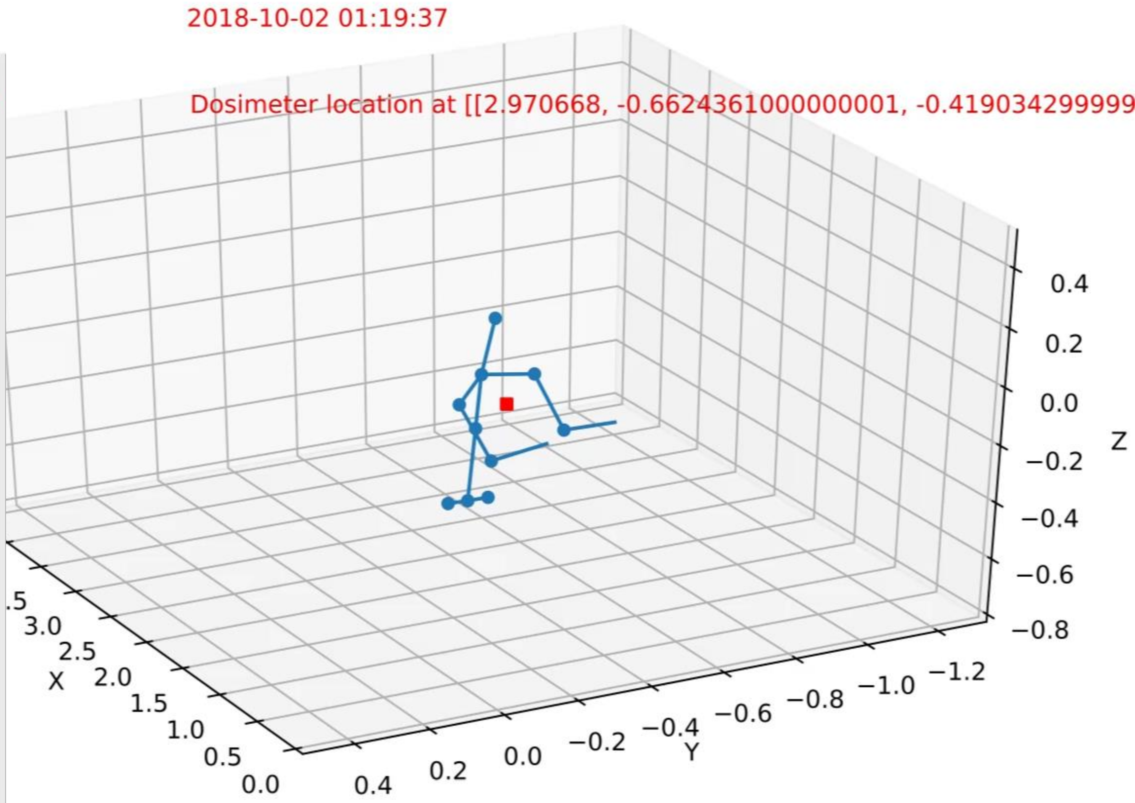
Probability Density Function – Wrist Joints of doctor 1



Test at CHU-Liège

Case: Angioplasty Procedure

- Measurement of accumulated dose $H_p(10)$ of operators with Thermo EPD
- Estimation of dosimeter location by the tracking system



Results from CHU-Liège case 4

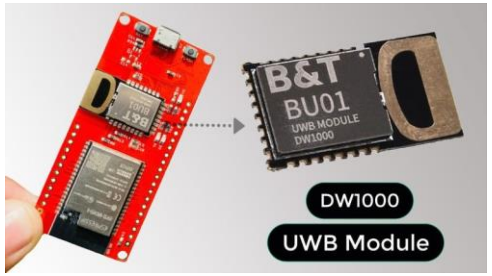
Validation Case	Simulations Accumulated $H_p(10)$	Measured EPD Accumulated $H_p(10)$
EndoVasc CHU-Liège Case 4 (PCI)	39 µSv	23 µSv

Event	FL1	FL2	FL3	FL4	FL5
Time (s)	7	6	6	5	6
RDSR DAP (µGy.m^2)	536.5	1655.2	1647.7	1347	1646.9
mGy	47.6	217	216	177	216
F6-REF (MeV/g/#)	6.55E-05	4.85E-05	4.85E-05	4.85E-05	4.85E-05
F6-DOS (MeV/g/#)	3.25E-09	9.27E-10	9.27E-10	9.27E-10	9.27E-10
$H_p(10)$ (µSv)	2.36	4.84	4.81	4.73	4.81
Event	FL6	FL7	FL8	FL9	Total
Time (s)	6	6	5	5	
RDSR DAP (µGy.m^2)	1647.1	1646.7	1496.8	1090.2	
mGy	216	216	196	143	
F6-REF (MeV/g/#)	4.85E-05	4.85E-05	4.85E-05	9.13E-05	
F6-DOS (MeV/g/#)	9.27E-10	9.27E-10	9.27E-10	1.35E-09	
$H_p(10)$ (µSv)	4.81	4.81	5.24	2.46	39

- Difficulties for comparison
  - Low doses
  - Exact dosemeter position is not known
  - Use of protection screens
- Strong dose gradient on the body

Placing a mini tag on the shield

- Transparent shield tracking using tags based on Ultra-Wide-Band (UWB) technology.
- 3D location and orientation could be recorded in real-time (100Hz)

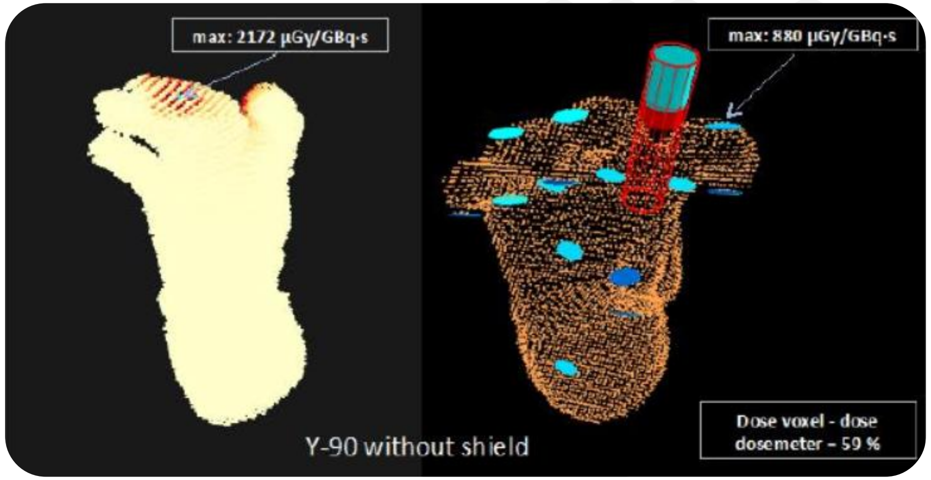


Motion tracking – VUB procedure 1

Complete sequence

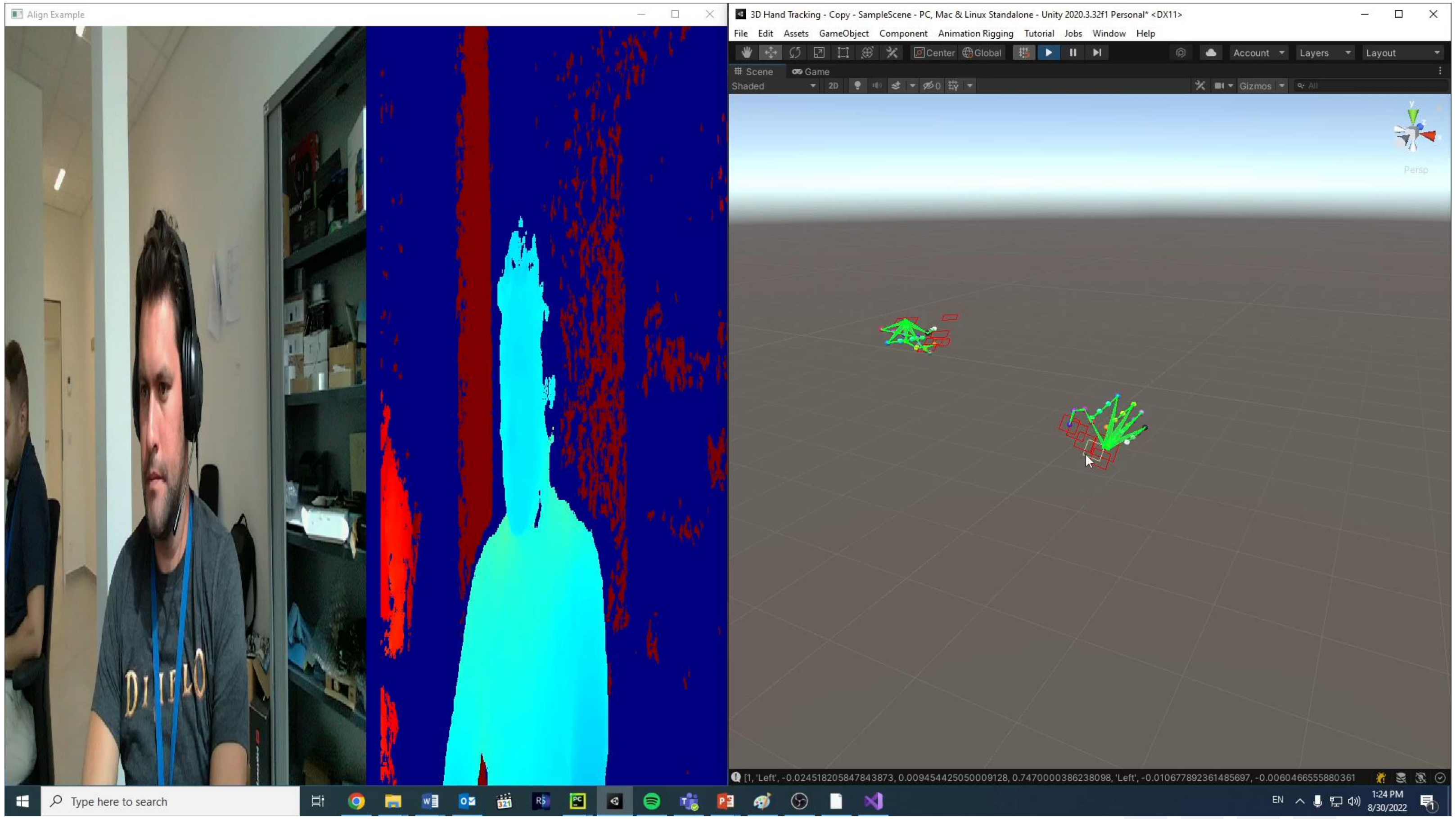
Improve extremity dosimetry in nuclear medicine

- High risk of exceeding legal doses of radiation in the extremities
- Accurate dosimetry is very hard for the hands
  - Higher exposures zones varies from one person to another
  - A single ring dosemeter is not enough to measure the whole hands dose
  - Wearing many ring dosimeters is uncomfortable
  - Multiple dosemeters will make dosimetry service more complex and expensive
- Solution: computational dosimetry?
  - Some specific challenges….



3D hand representation

- Animation techniques: Animation Rigging
  - Only the wrist uses the calculated position as a ground truth
  - Added restrictions to bone size and finger movements
  - The finger moves as a whole chain in the direction of the calculated position for the tips



Source tracking

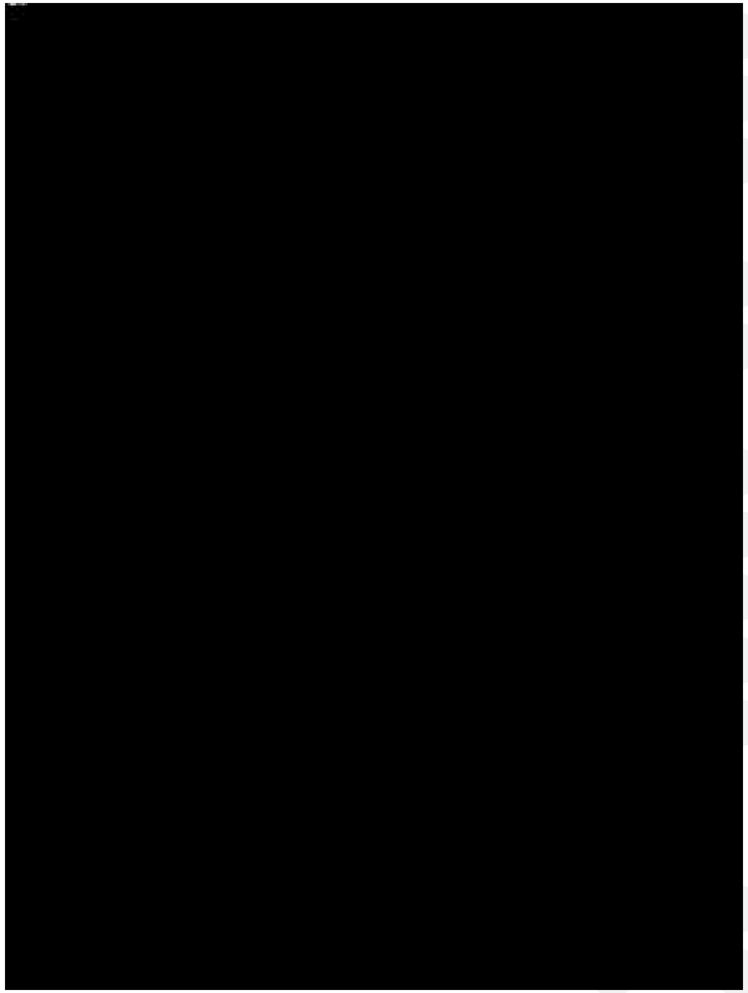
- Syringe detection

Representing the phantom

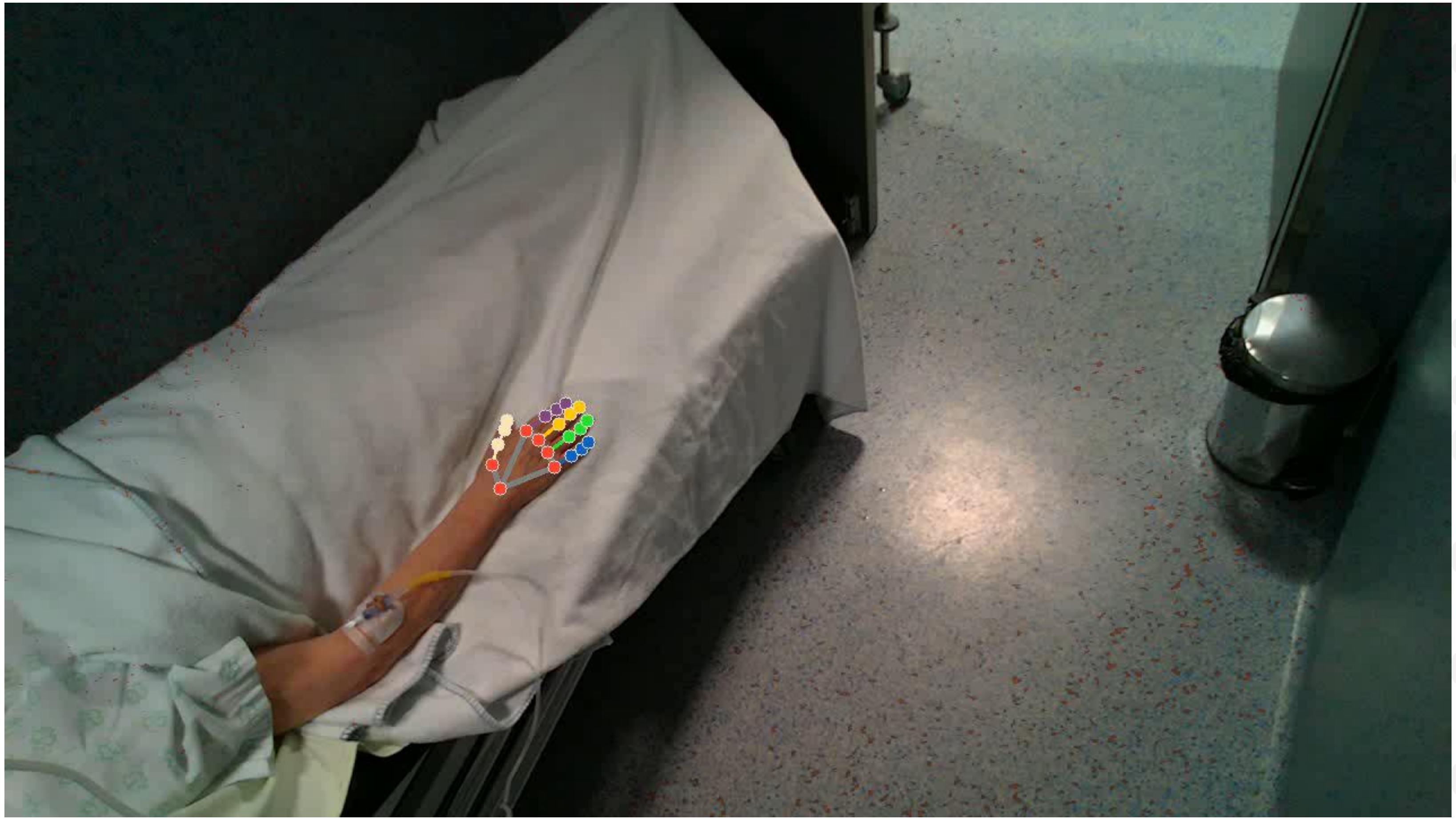
- Mesh:
  - Set of 3D vertexes and edges that shapes different objects
  - Each object has a material attached
  - Easier to export from Unity to Gate
  - Less heavy on memory and hence faster loading times

Voxelized source and phantom

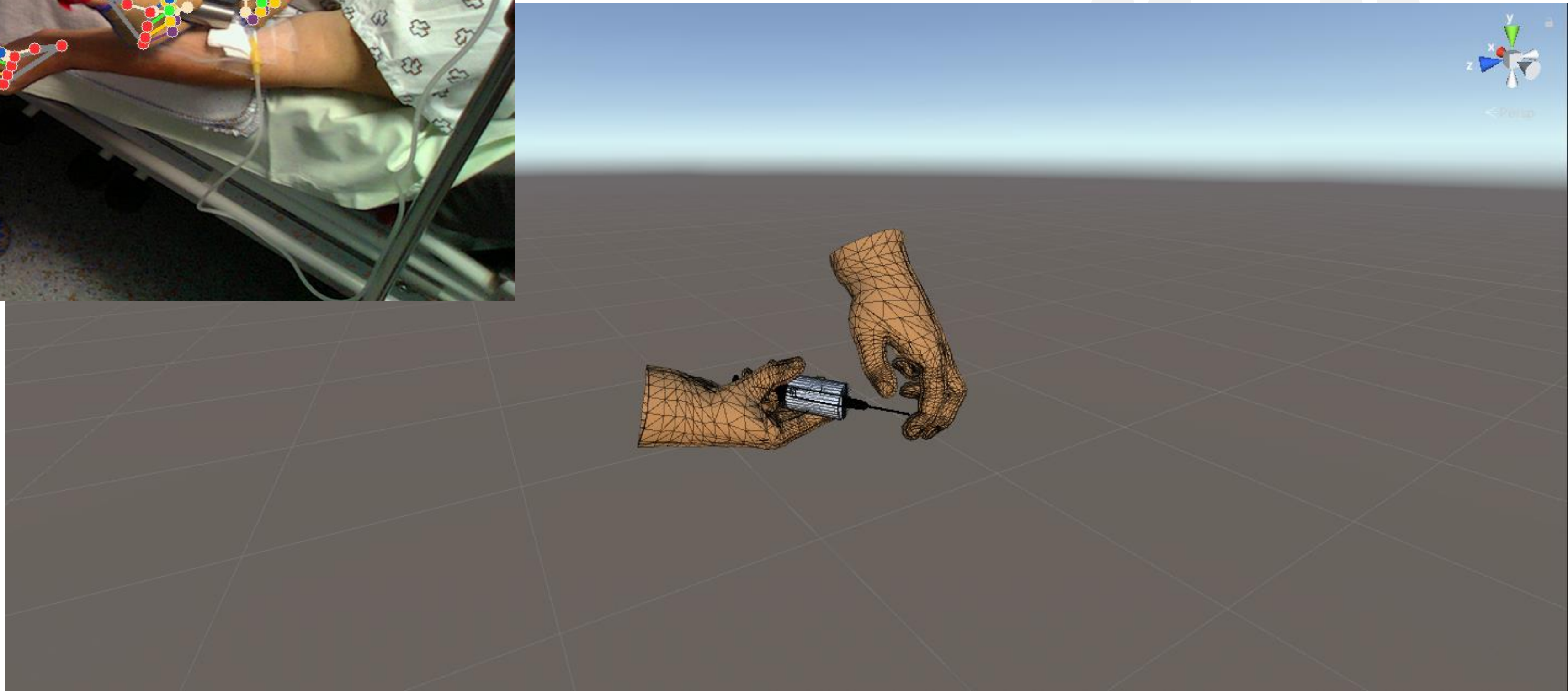
- Optimized IPP voxelization code for the hands
- GPU computing allows faster calculations
- Voxelization time < 1 second



Real case scenario: simulations of different steps during administration



Real case scenario: simulations of different steps during administration



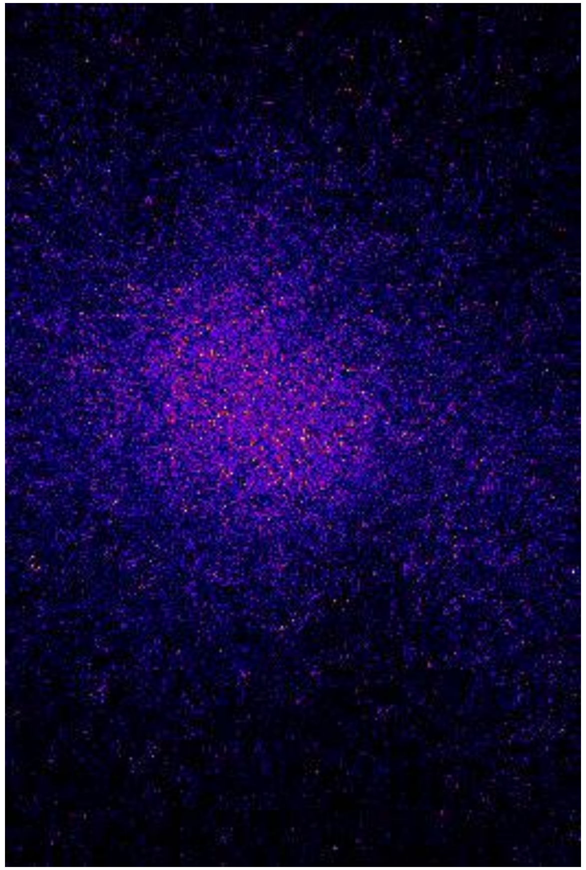
Visualisation of Monte Carlo output

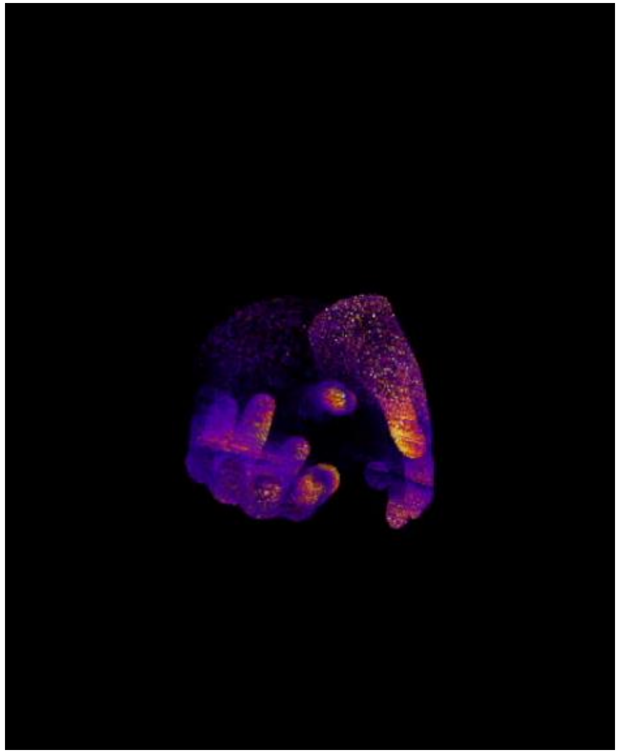
- Dose output should be normalized to activity and branching ratio
- The output can be obtained for each individual region

- To be used for dosimetry purposes

- But also…

- To be used in an ALARA and training application!





Computational dosimetry can help in ALARA applications

- Also for medical applications
- Part of the future will be dosimetry without physical dosemeters
  - Although dosimeters still will exist for many applications
- Increasing contribution from AI and ML
- Important aspect of visualisation of radiation
  - Digital twin creation
  - ALARA and training tool

SCK CEN
Belgian Nuclear Research Centre

Foundation of Public Utility

Registered Office: Avenue Herrmann-Debrouxlaan 40 – BE-1160 BRUSSELS
Operational Office: Boeretang 200 – BE-2400 MOL