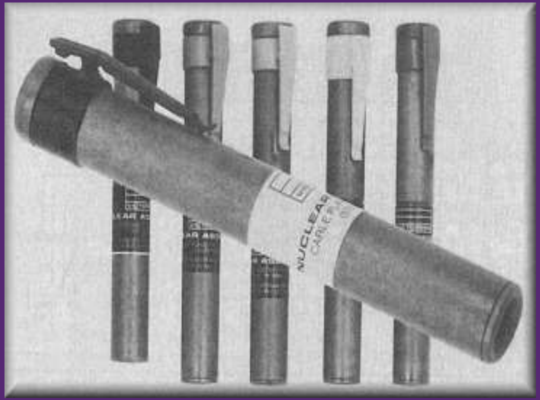
Personal online dosimetry using flexible computational phantoms

P. Lombardo, M. Abdelrahman, D. S. Rondon, L. Struelens,
N. Bergans, F. Vanhavere

sck cen
Belgian Nuclear Research Centre

EURADOS

How do we measure doses?



Individual monitoring techniques **have not really changed** in the last 70 year. While dosemeter technology has evolved (slowly), the basic principles are still the same, such as the limitations:

- They provide only point measurements; often when multiple dosemeters are used, doses have low to none correlation.
- None likes wearing dosemeter: they are often forgotten or placed improperly;
- For the great part, they are passive, and they need to be read-out, with potentially large delay between exposure and positive dose assessment;
- They still have high uncertainty

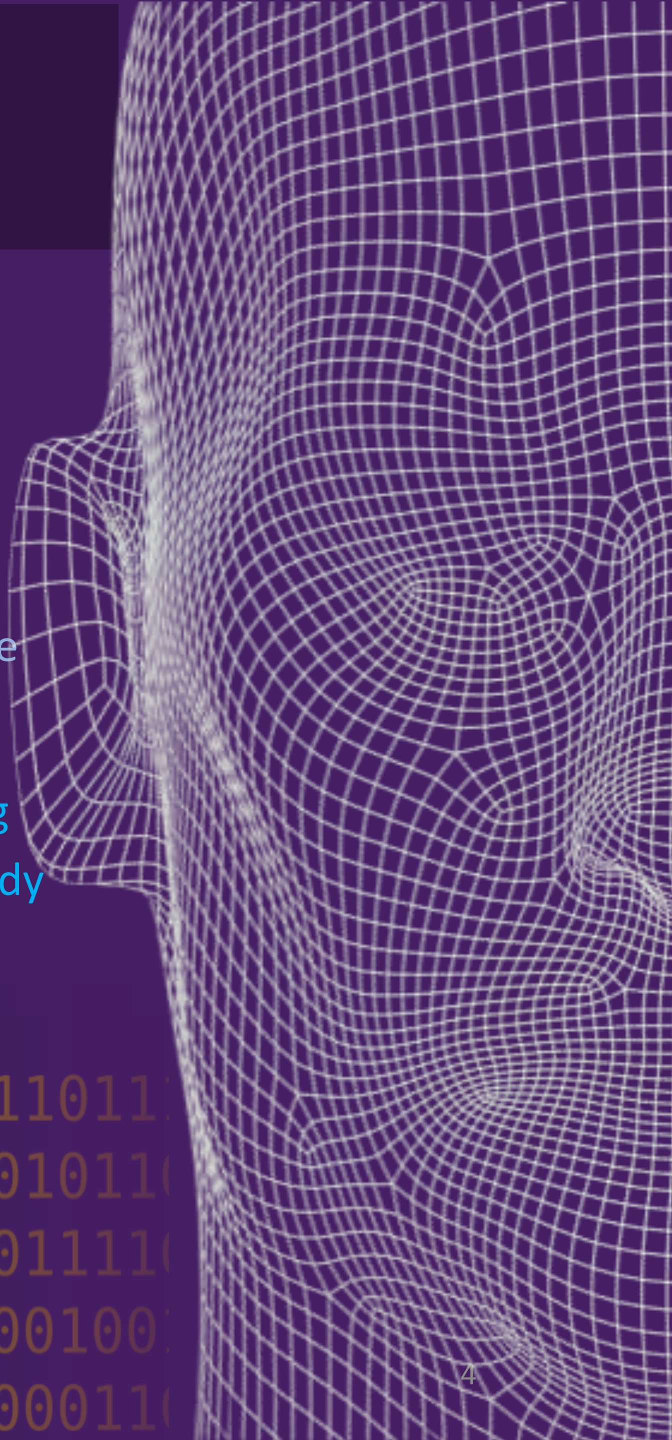
Dose quantities: misconceptions and misuse

- The quantities that can be assessed by physical dosemeters are only the sex averaged operational dose equivalents, and **not individualized tissue/effective doses** for estimation of risk
- Operational quantities are not a good representative metric for absorbed dose in inhomogenous radiation fields
- Operational and protection dose definition, dose conversion coefficients, and dose limits are **often changing** -> **new ICRU operational quantities**

New computational capabilities

In the last 10 years, several new technologies have become available:

- Flexible computational human phantoms
- Faster and more capable Monte Carlo particle transport codes (Geant4)
- Depth sensing cameras and machine learning based algorithms for performing accurate body tracking



Flexible computational human phantoms

RAF phantom family (2022)

RAF Adult Male (AM)

RAF Adult Female (AF)

RAF 1 Year Old Female (1yoF)

RAF Adult Male (AM)

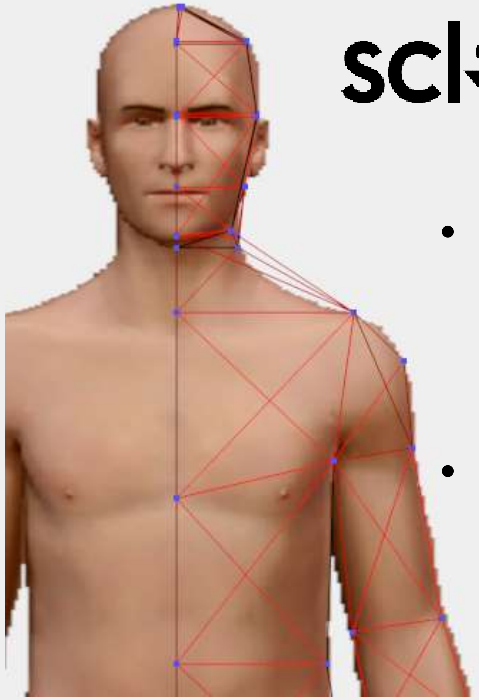
- 177 cm, 75 kg
- 7.7 million polygons
- 71 organs, 142 tissues
- About 2900 IDs with sub-segmentation

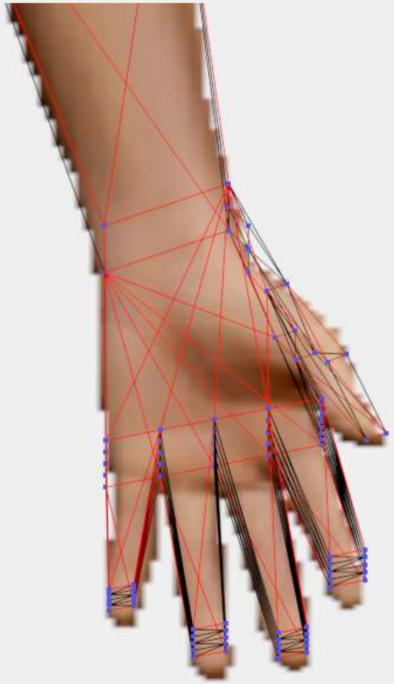
RAF Adult Female (AF)

- 167 cm, 62 kg
- 3.6 million polygons
- 69 organs, 129 tissues
- About 250 IDs with sub-segmentation

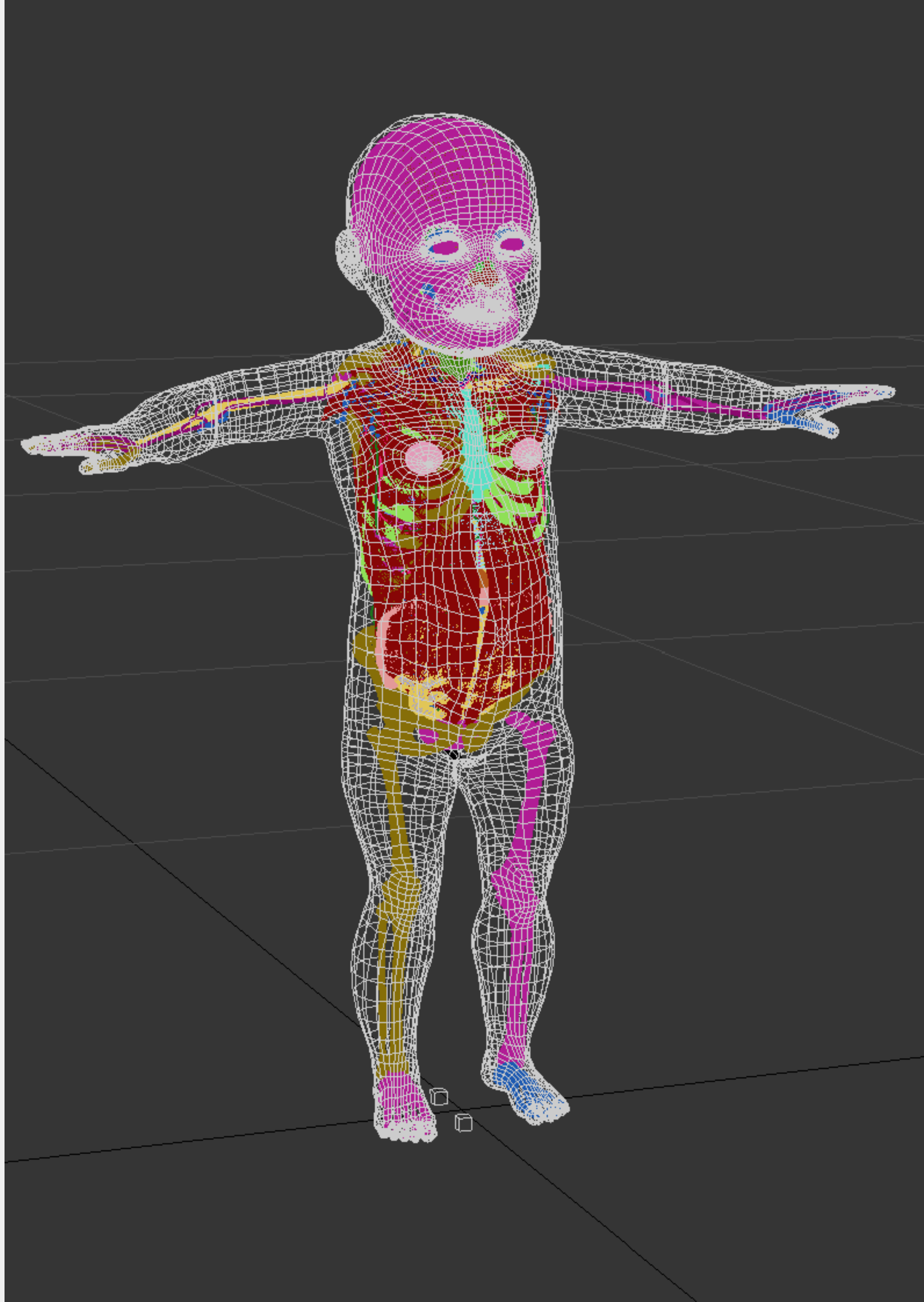
RAF 1 Year Old Female (1yoF)

- 76 cm, 10.3 kg
- 2.1 million polygons
- 66 organs, 113 tissues





- **Geometry modeled using 3Ds Max**
  - **Polygonal meshes** (quads for large organs)
- **Main references:**
  - **3 (+ 1) anatomical atlases:** Human Anatomy Atlas by Argosy, BioDigital Human by BioDigital, Complete Anatomy by 3d4 Medical (+ Complete Human Anatomy by Primal Picture)
  - **ICRP Reference Adult Phantoms (Publication 110)**
  - **ICRP Pediatric Phantoms (Publication 145)**
  - **ICRP Publication 89 reference Masses**
  - **DINBelg2005**



The GOOD:

- Simpler (after learning) approach to modeling
- Easy to implement procedural modeling
- Fast evolving software tools
- Flexible deformable geometry:
  - Rigging
  - Anatomical changes to fit different sizes
  - Recycling organ models between different phantoms

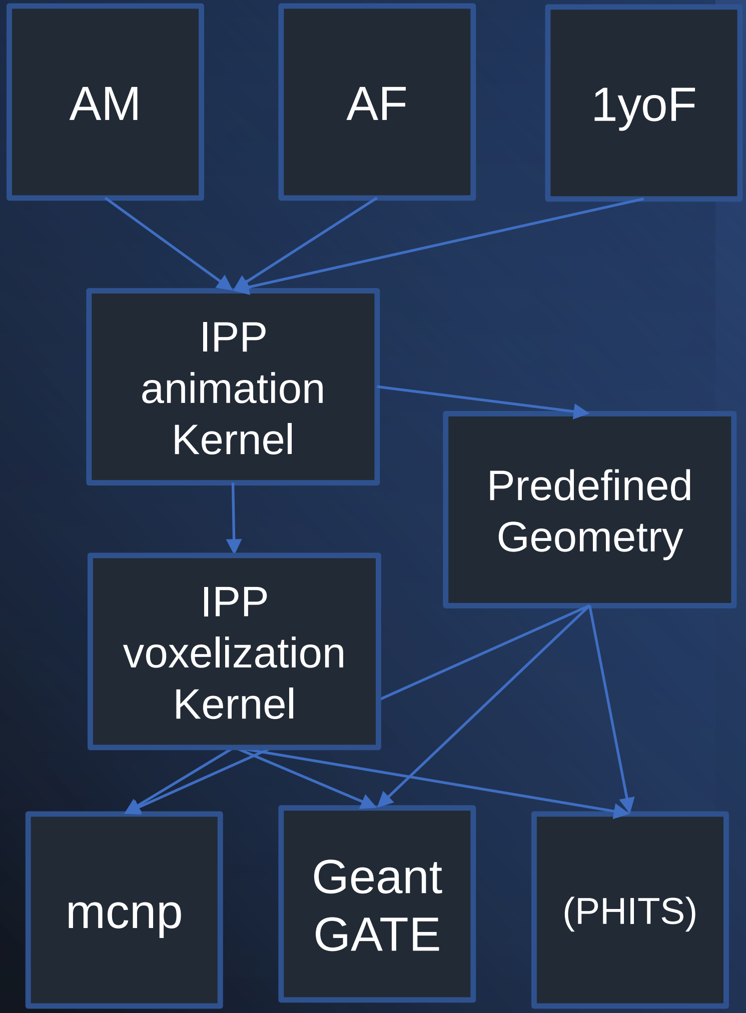
The BAD:

- Organs are defined only by outlining surfaces
- To use the RAF phantoms and their flexibility, 3Ds Max is needed (steeper learning curve, cost)

Interactive Posture Program (2022)

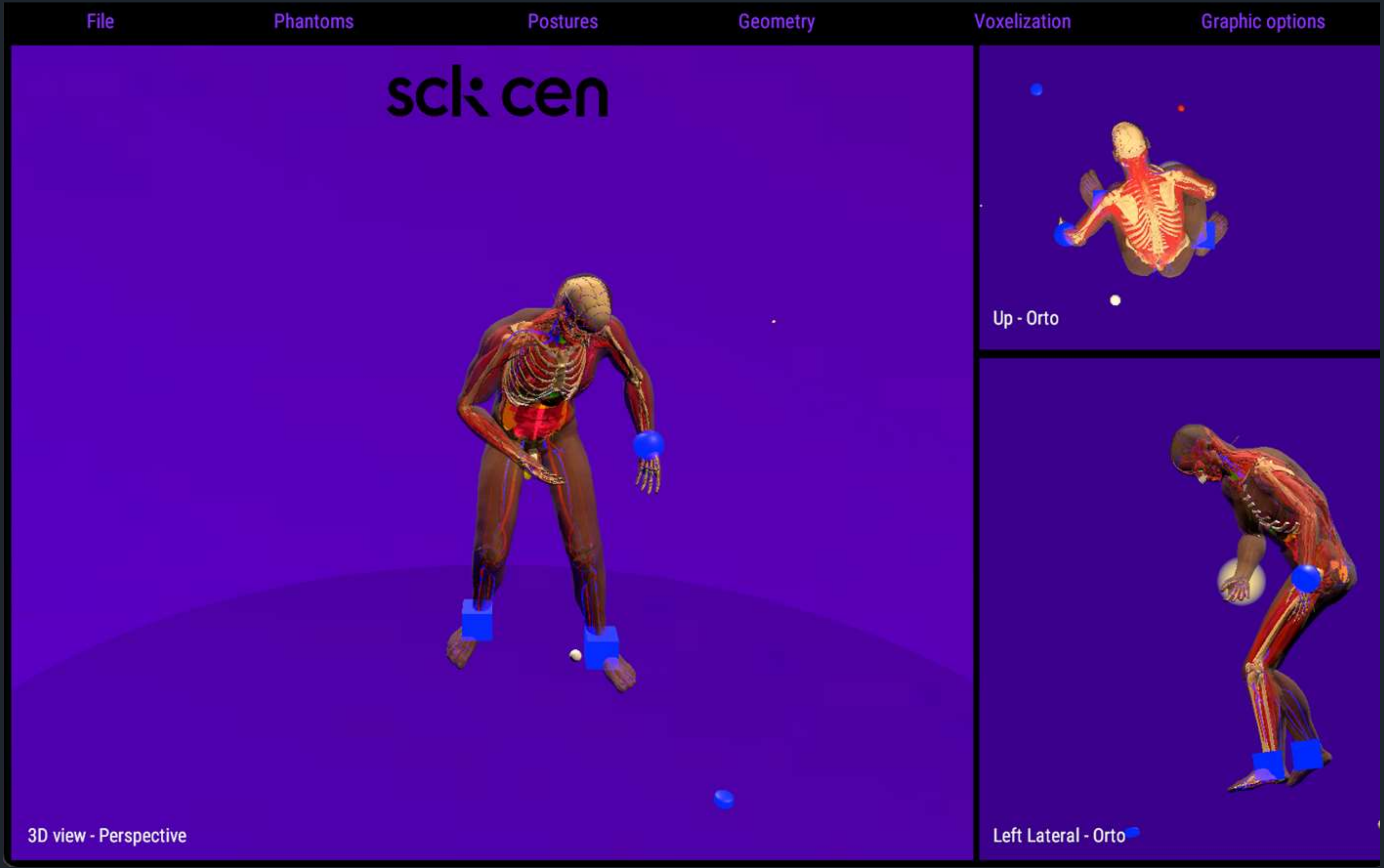
Software developed using Unity, C# (interface) and C++ (compute shaders for voxelization) to allow easy sharing of the phantoms and the creation of simulations input files. IPP can be to be used to:

- Change the posture of the RAF phantoms
- Voxelize and export to MCNP, Gate (Geant) and soon PHITS
- Generate MC geometry of pre-defined exposure scenarios



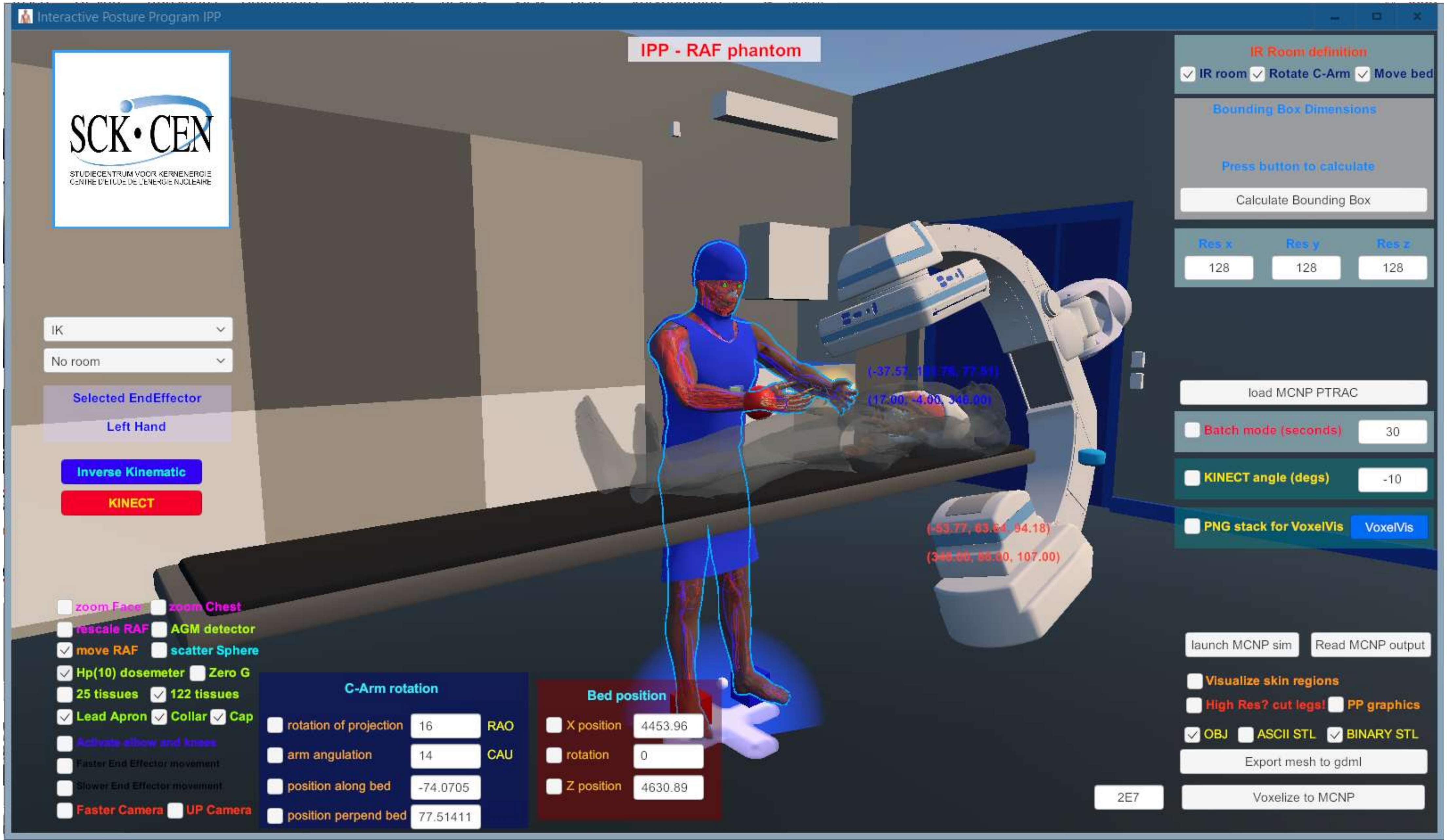

File
Phantoms
Postures
Geometry
Voxelization
Graphic options
sck cen
Up - Orto
3D view - Perspective
Left Lateral - Orto


File
Phantoms
Postures
Geometry
Voxelization
Graphic options
sck cen
Up - Orto
3D view - Perspective
Left Lateral - Orto


File
Phantoms
Postures
Geometry
Voxelization
Graphic options
sck cen
Up - Orto
3D view - Perspective
Left Lateral - Orto

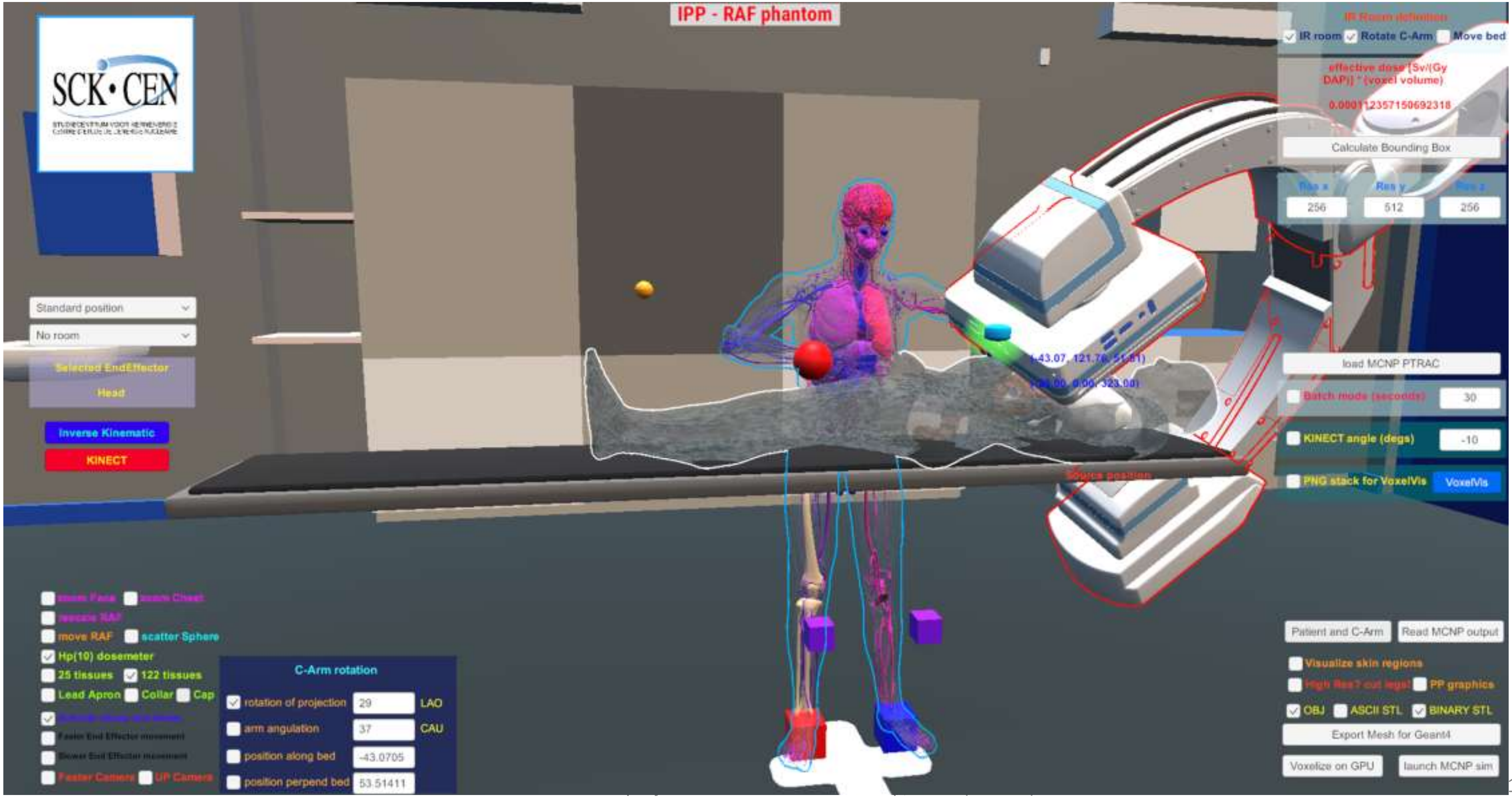

File
Phantoms
Postures
Geometry
Voxelization
Graphic options
sck cen
Up - Orto
Distances between phantoms
Distances
RAF rotation about z: 0.00
draw calculated distances (in red closest distance)
3D view - Perspective
Left Lateral - Orto

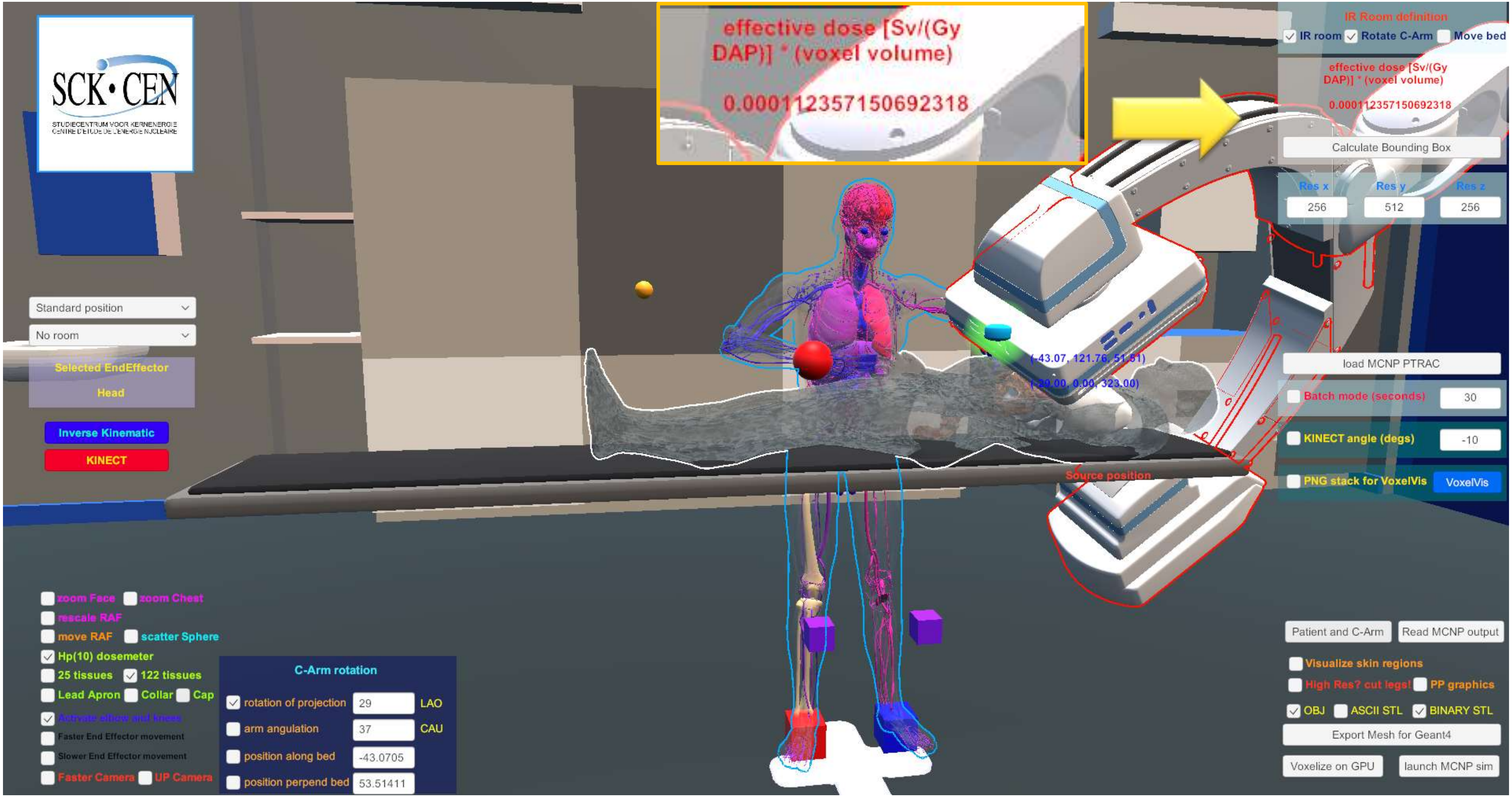
Virtual reality environment: Interventional Radiology




outp 4/17/2019 9:59 AM File 82,502 KB
runtpe 4/17/2019 9:59 AM File 542,388 KB
ptrac 4/17/2019 9:53 AM File 3,803 KB
SCK•CEN
STUDIECENTRUM VOOR KERNENERGIE
CENTRE D'ETUDE DE L'ENERGIE NUCLEAIRE
Standard position
No room
Selected EndEffector
Head
Inverse Kinematic
KINECT
Move bed
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
PNG stack for VoxelVis
VoxelVis
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
Patient and C-Arm
Read MCNP output
Visualize skin regions
PP graphics
OBJ
ASCII STL
BINARY STL
Export Mesh for Geant4
Voxelize on GPU
launch MCNP sim

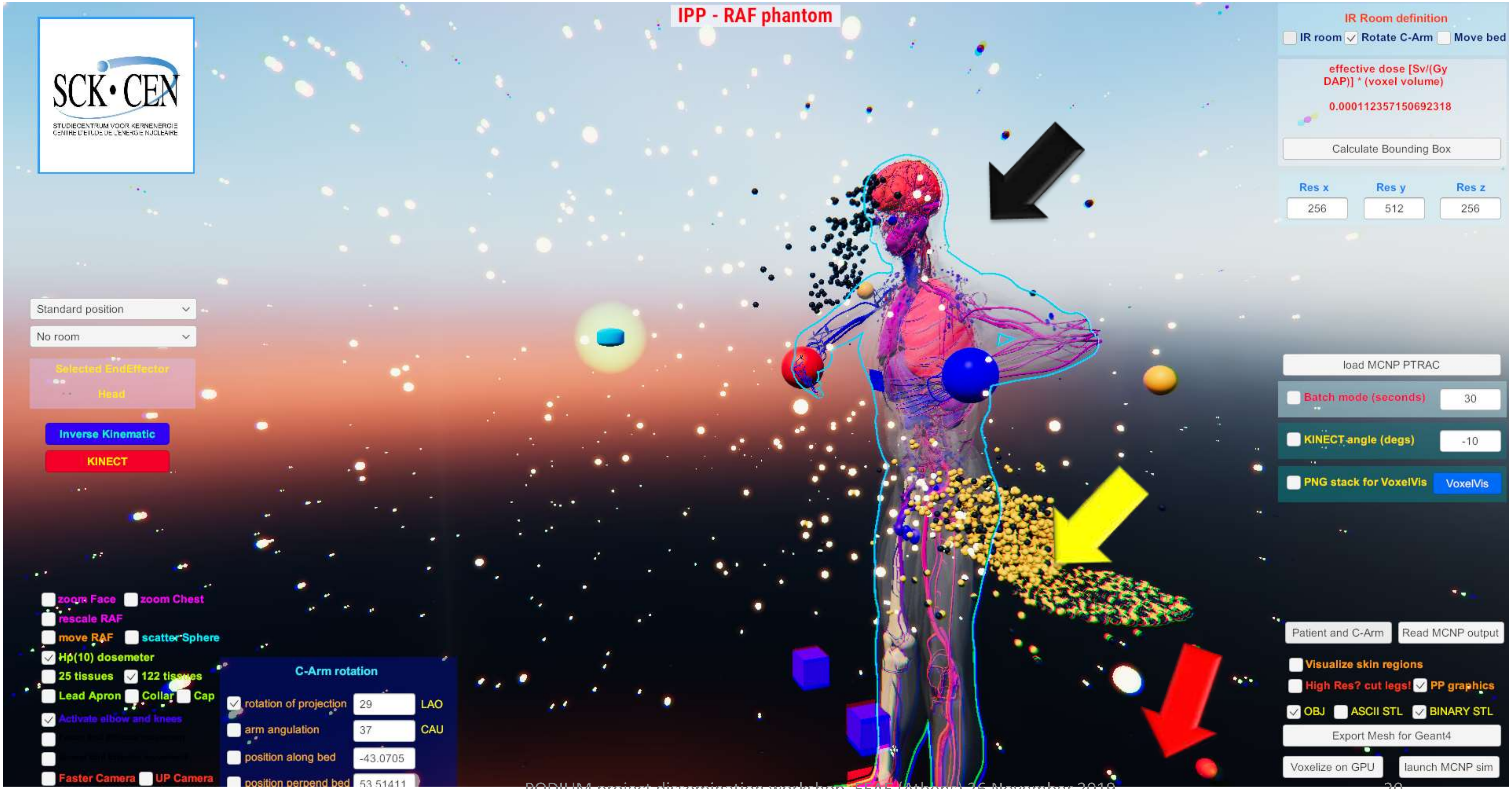
Virtual reality environment: Interventional Radiology





effective dose [Sv/(Gy DAP)] * (voxel volume)
0.000112357150692318
SCK•CEN
STUDIECENTRUM VOOR KERNENERGIE
CENTRE D'ETUDE DE L'ENERGIE NUCLEAIRE
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
Standard position
No room
Selected EndEffector
Head
Inverse Kinematic
KINECT
(-43.07, 121.76, 51.51)
(-20.00, 0.00, 323.00)
load MCNP PTRAC
Batch mode (seconds)
30
KINECT angle (degs)
-10
Source position
PNG stack for VoxelVis
VoxelVis
zoom Face
zoom Chest
rescale RAF
move RAF
scatter Sphere
Hp(10) dosemeter
25 tissues
122 tissues
Lead Apron
Collar
Cap
Activate elbow and knees
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
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


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
(-43.07, 121.76, 51.51)
Source position
IR Room definition
IR room
Rotate C-Arm
Move bed
effective dose [Sv/(Gy DAP)] * (voxel volume)
0.000112357150692318
Calculate Bounding Box
Res x 256
Res y 512
Res z 256
load MCNP PTRAC
Batch mode (seconds) 30
KINECT angle (degs) -10
PNG stack for VoxelVis
VoxelVis
Patient and C-Arm
Read MCNP output
Visualise skin regions
High Res? cut legs!
PP graphics
OBJ
ASCII STL
BINARY STL
Export Mesh for Geant4
Voxelize on GPU
launch MCNP sim


IPP - RAF phantom
SCK•CEN
STUDIECENTRUM VOOR KERNENERGIE
CENTRE D'ETUDE DE L'ENERGIE NUCLEAIRE
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
Standard position
No room
Selected EndEffector
Head
Inverse Kinematic
KINECT
load MCNP PTRAC
Batch mode (seconds)
30
KINECT angle (degs)
-10
PNG stack for VoxelVis
VoxelVis
zoom Face
zoom Chest
rescale RAF
move RAF
scatter Sphere
Hp(10) dosemeter
25 tissues
122 tissues
Lead Apron
Collar
Cap
Activate elbow and knees
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
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

3D Cameras, skeleton and object tracking

3D Cameras

Several Depth cameras are currently available on the market for less than 5k Eur. They make use of different technologies: Structural Light, Time Of Flight, Stereoscopy, Laser ToF, etc..

Orbbec 3D Persee

Intel RealSense L515

Intel RealSense D455

ZED 2i

Matterport Pro2

MS Kinect V2

MS AZURE DK

Person/object recognition and tracking algorithms

Based on segmentation of depth and RGB images, there are hundreds available recognition and tracking algorithms. The most advanced make use of Machine Learning and Deep Learning. The most famous (and the ones we use) are:

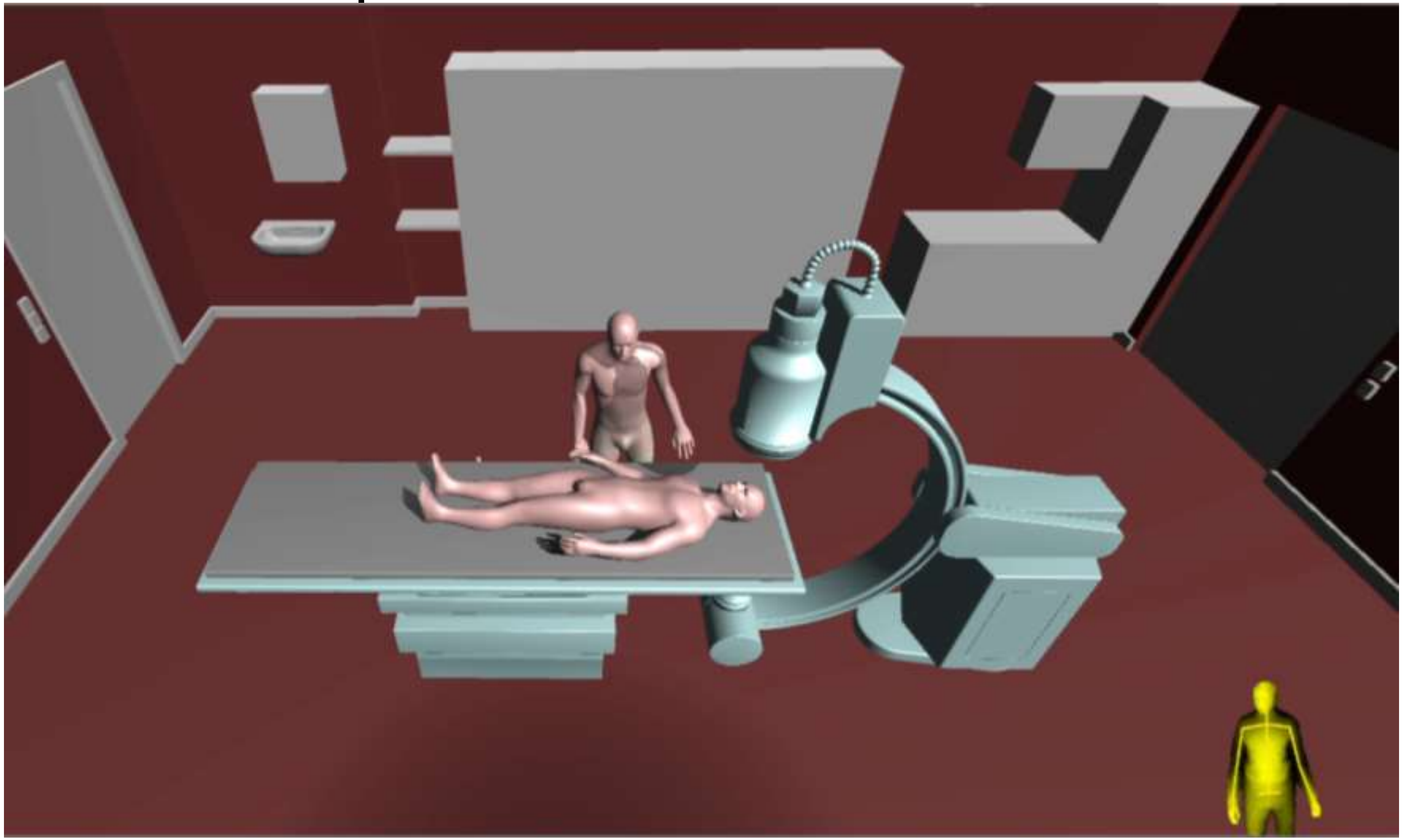
Person tracking & human pose estimation:

- NUItrack
- CubeMos
- Kinect SDK
- Azure DK
- OpenPose
- ZED SDK

Object tracking & object recognition:

- OpenCV: BOOSTING, MIL, KCF, CSRT, MedianFlow, TLD, MOSSE, and GOTURN
- YOLO (v1,v2,v3),
- TensorFlow

Animation of RAF phantom



3D Cameras

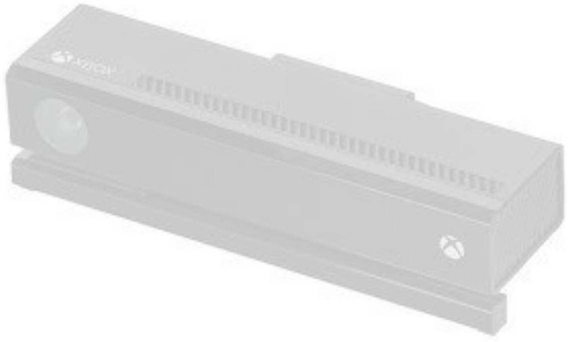
Several Depth cameras are currently available on the market for less than 5k Eur. They make use of different technologies: Structural Light, Time Of Flight, Stereoscopy, Laser ToF, etc..

Orbbec 3D Persee

Intel RealSense L515

Intel RealSense D455

ZED 2i

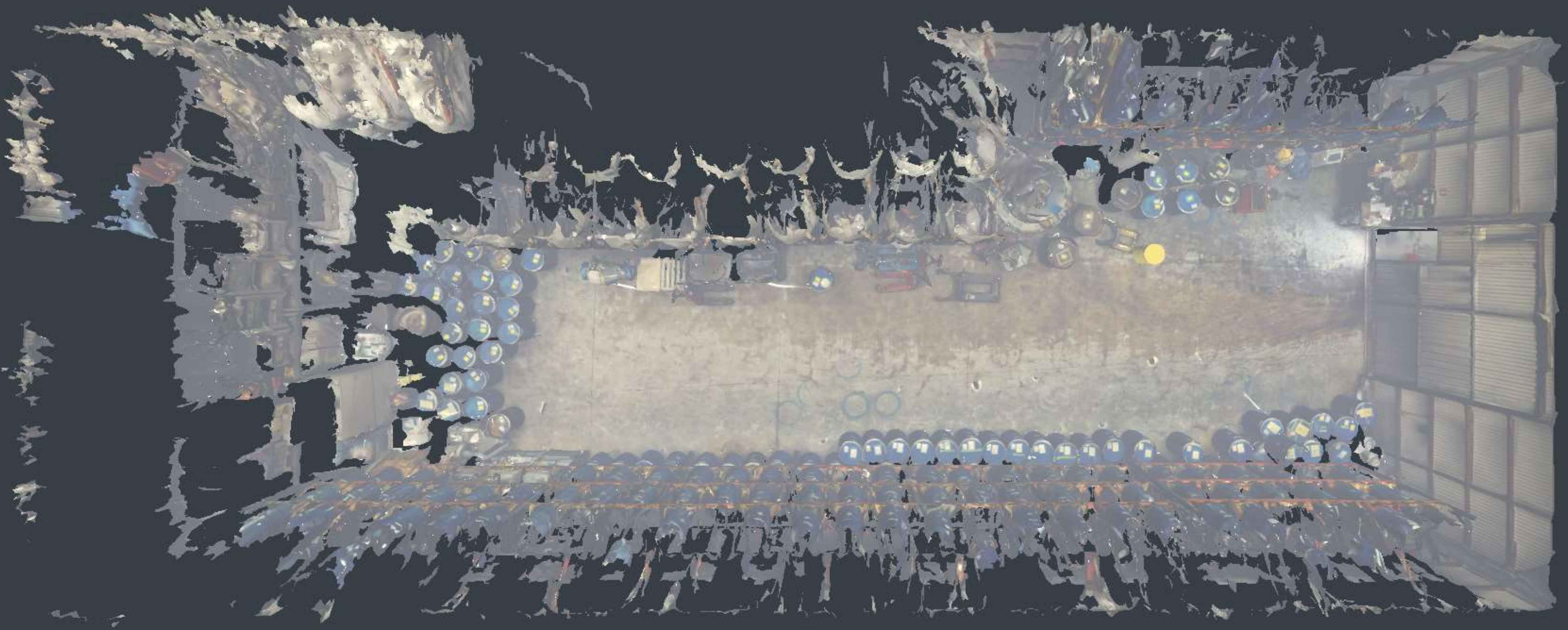


MS Kinect V2

MS AZURE DK

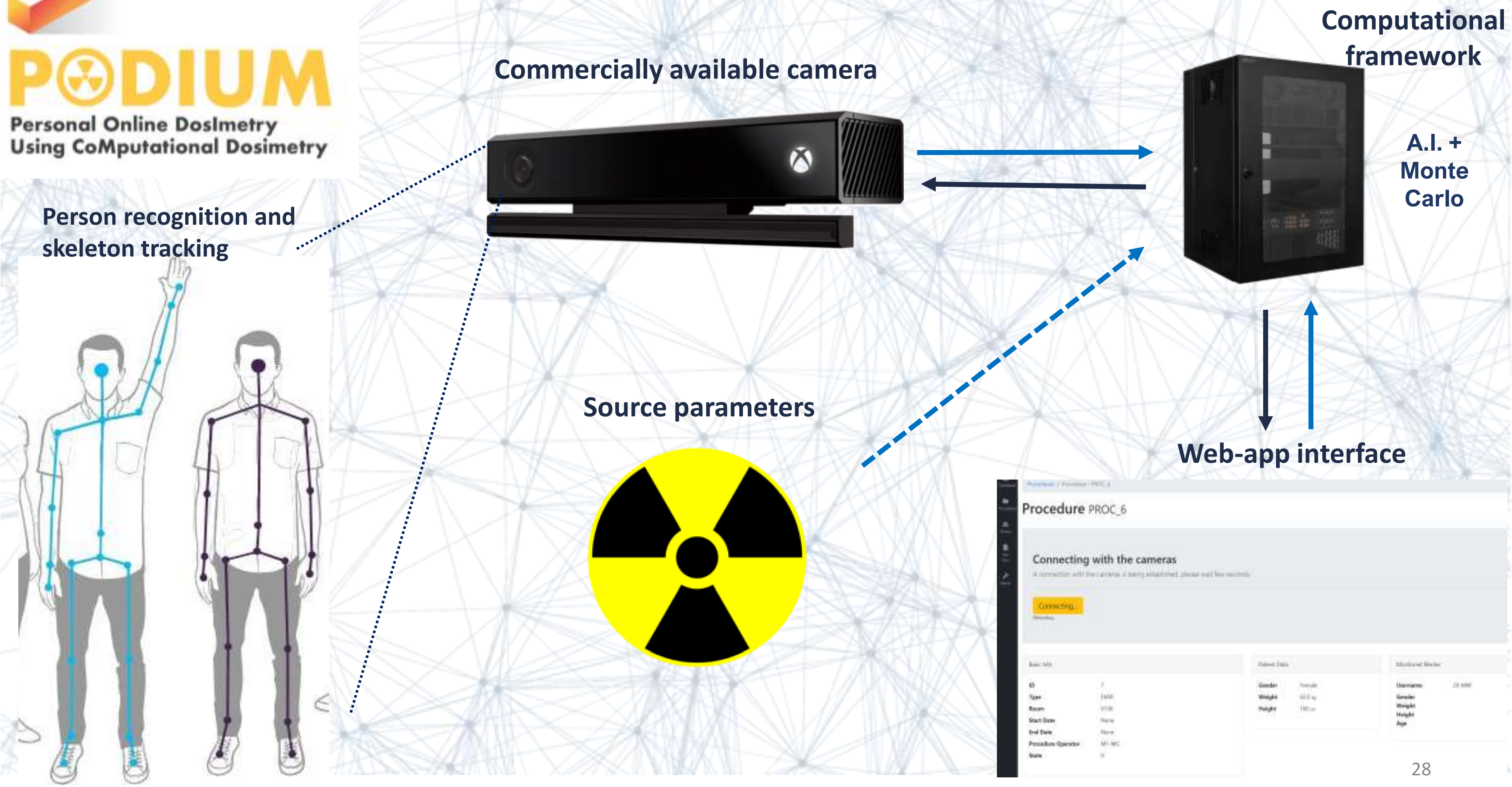
Matterport Pro2

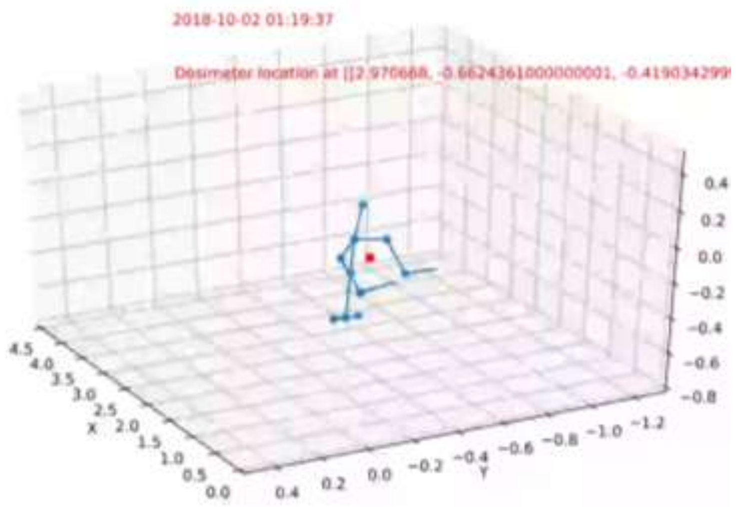
3D Reconstruction



Implementations of computational dosimetry

Online Computational Dosimetry Monitoring System





With PODIUM we proved the feasibility of a purely computational approach to dosimetry, and we applied it to two applications:

- Monitoring of **Interventional Radiology/Fluoroscopy** physicians
- Monitoring of workers in **neutron fields**

PODIUM
Personal Online Dosimetry Using CoMputational Dosimetry

sck cen

Ongoing project: computational dosimetry system for nuclear medicine staff (2020-2024)

The hardware and the software of the dosimetry system is being optimized for the monitoring of nuclear medicine staff

- Agile tracking camera setup based on battery-powered microcomputer

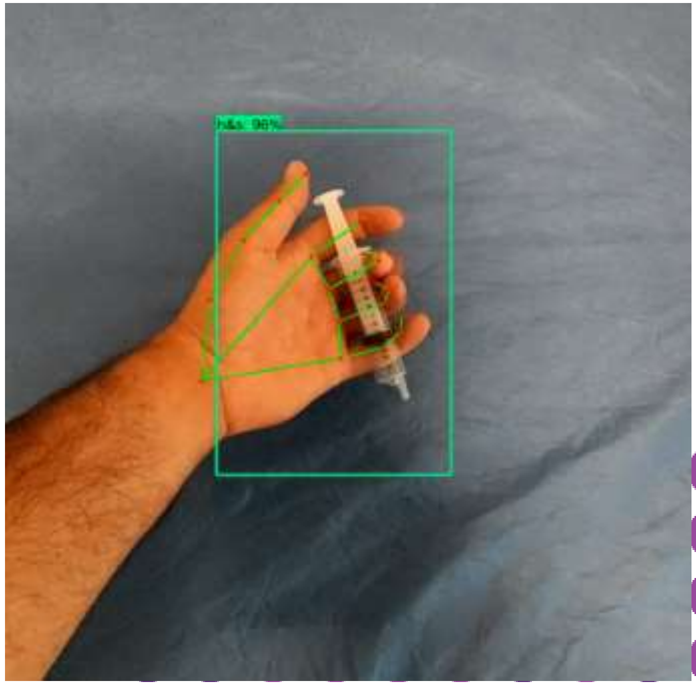
UZ LEUVEN

KU LEUVEN

sck cen

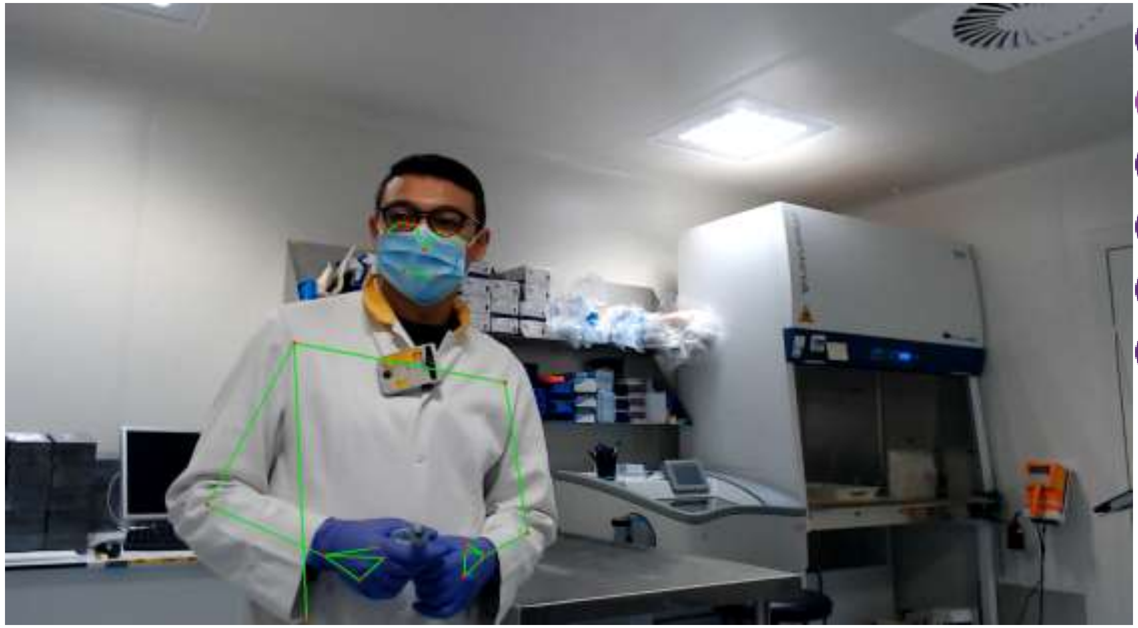
sck cen
Belgian Nuclear Research Centre

Ongoing project: computational dosimetry system for nuclear medicine staff (2020-2024)



The hardware and the software of the dosimetry system is being optimized for the monitoring of nuclear medicine staff

- New Machine Learning models for finger and syringe tracking

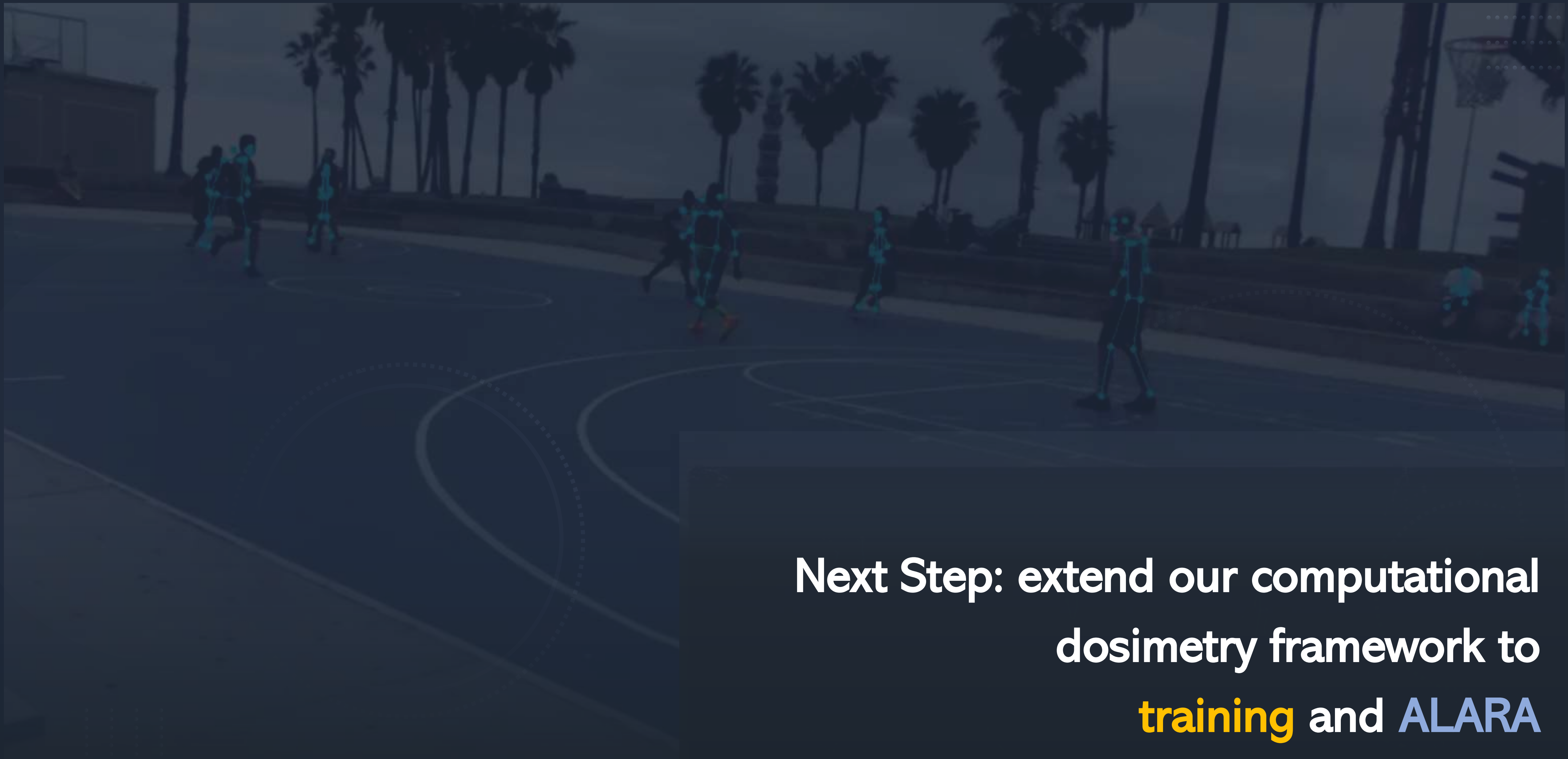


UZ LEUVEN

KU LEUVEN

sck cen

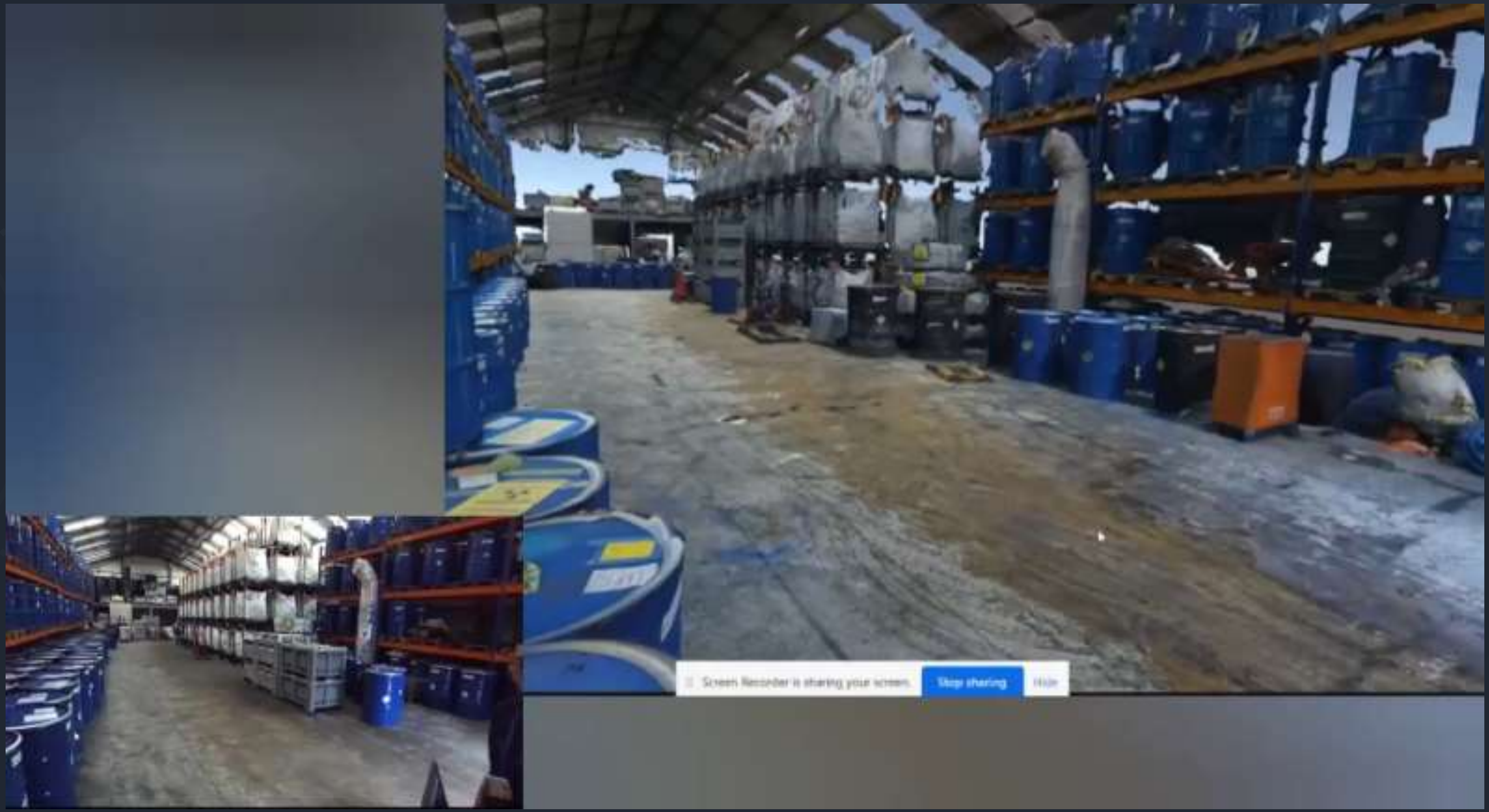
Belgian Nuclear Research Centre



Next Step: extend our computational dosimetry framework to training and ALARA

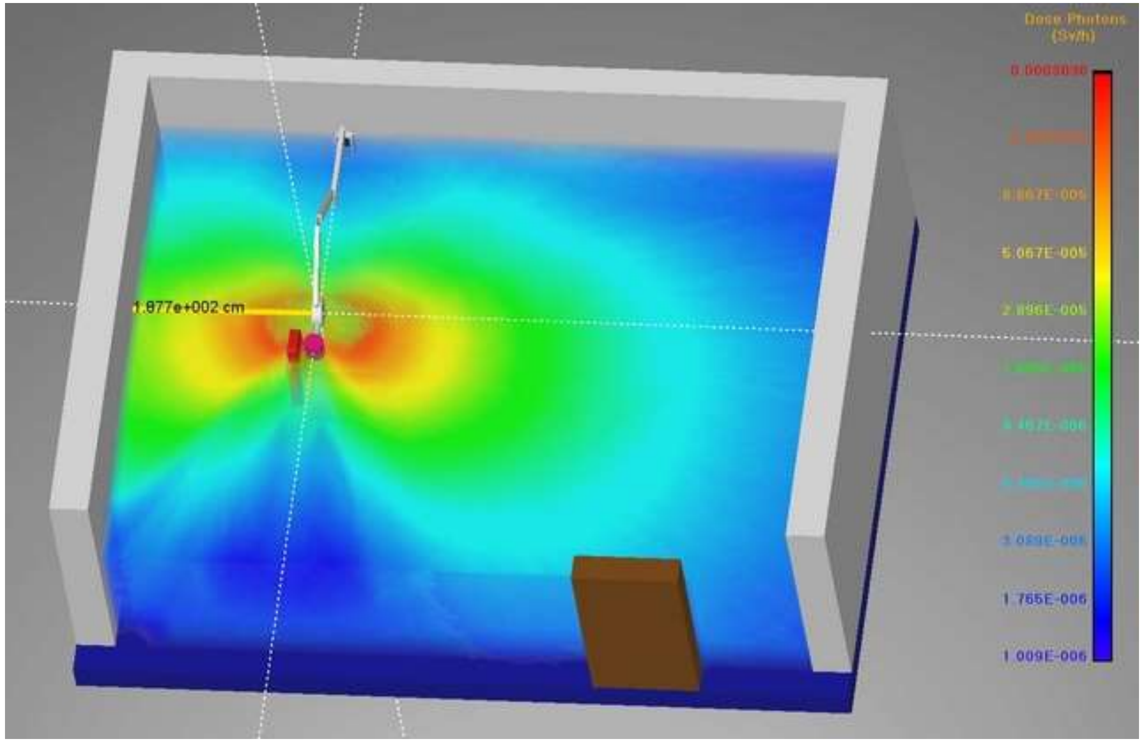
ALARA and training tool for dosimetry in Dismantling and Disposal

By means of a long-range stereo 3D camera, we can track and monitor workers within an area larger than 200 m^2



Objectives of the tool:

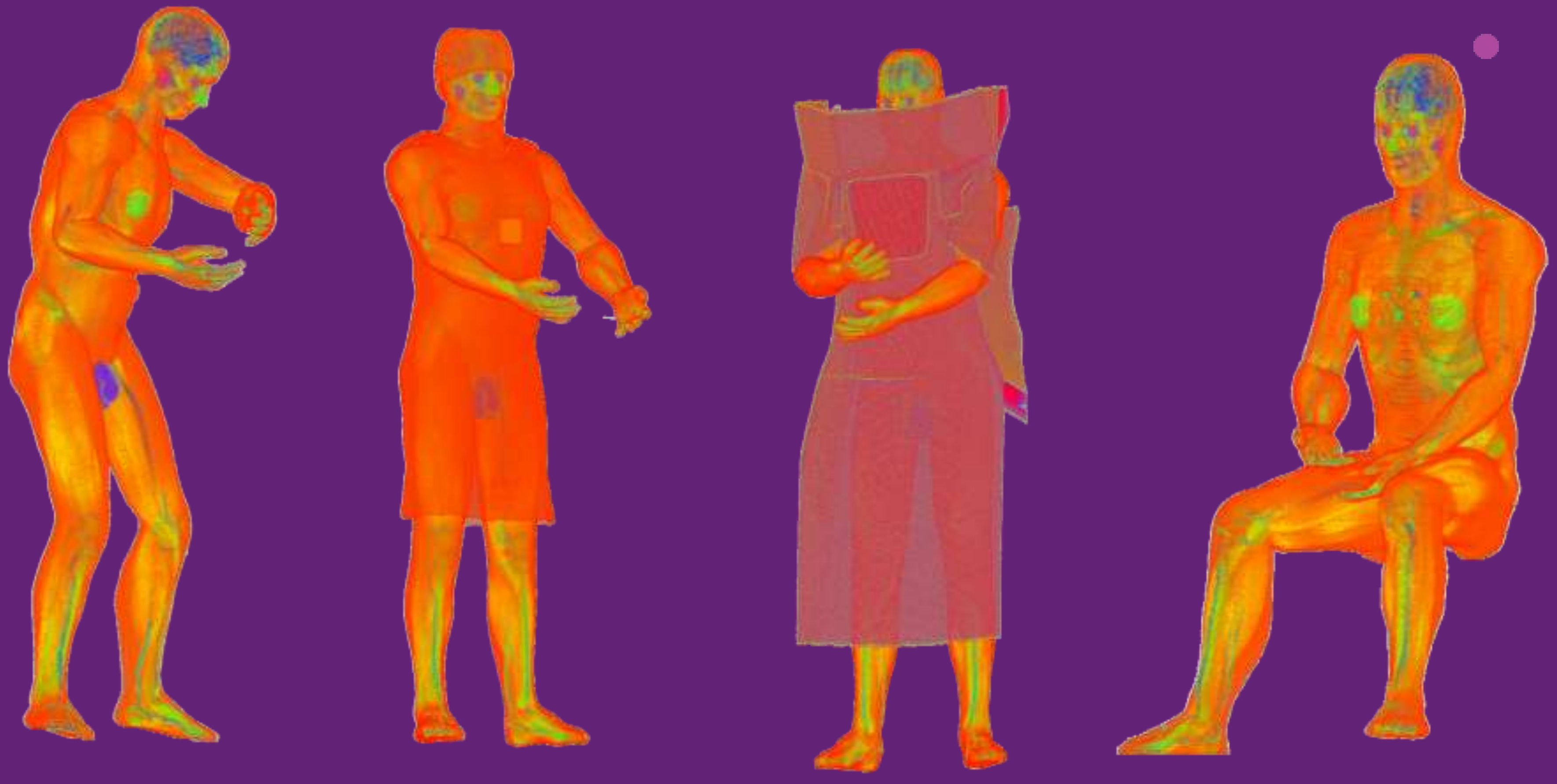
- Training and improve radiation awareness
- Optimization of the workflow based on both Monte Carlo and Machine Learning based calculations
- Support decision making



Live Demo phantoms

Live Demo 3D tracking

Thanks for your attention!



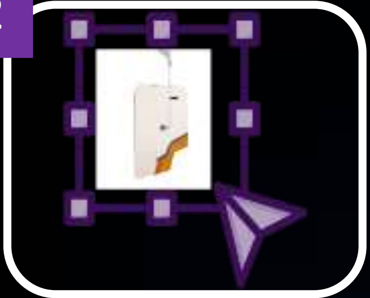
https://www.sckcen.be/en/diensten/medische-toepassingen/persoonlijke-omgevingsdosimetrie

sck cen

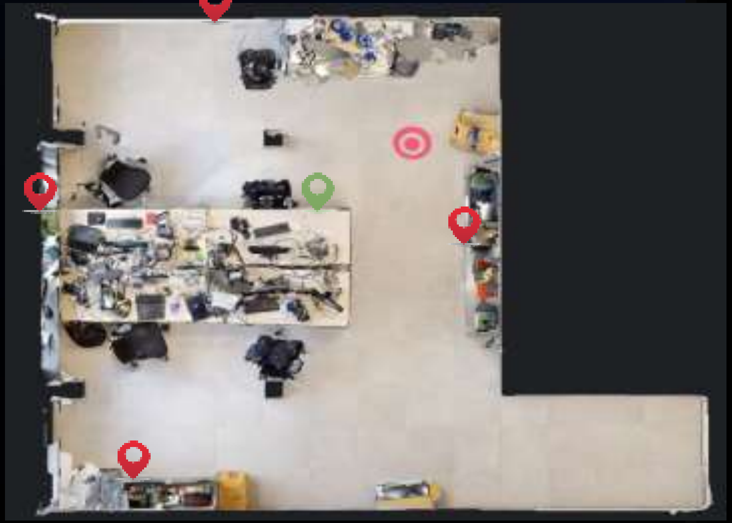
sck cen
CompuDos

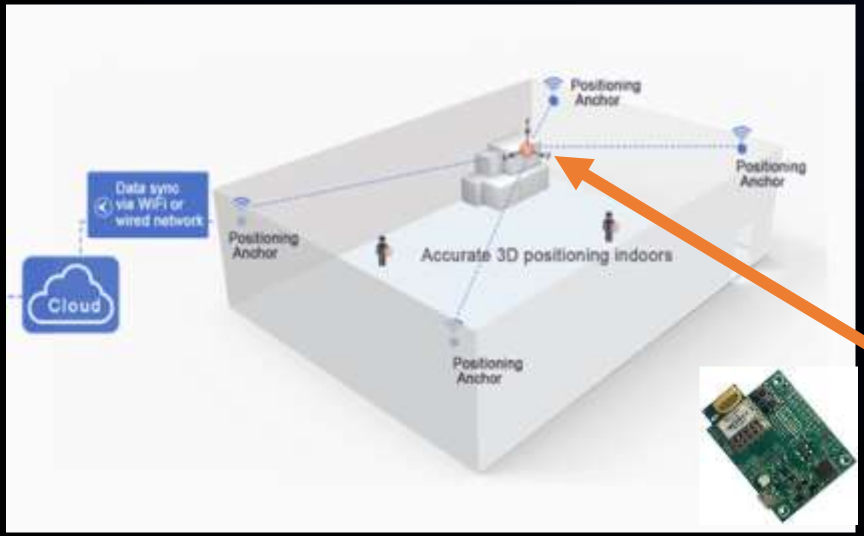
Shield Tracking

2



- 3D tracking of Ceiling-suspended shield position
- Tracking the 3D orientation of the shield
- UWB-IMU sensor based solution

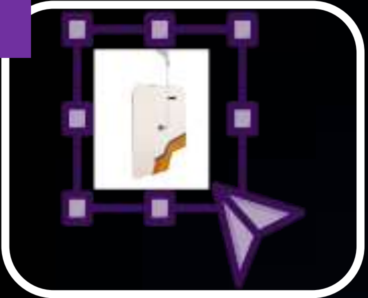


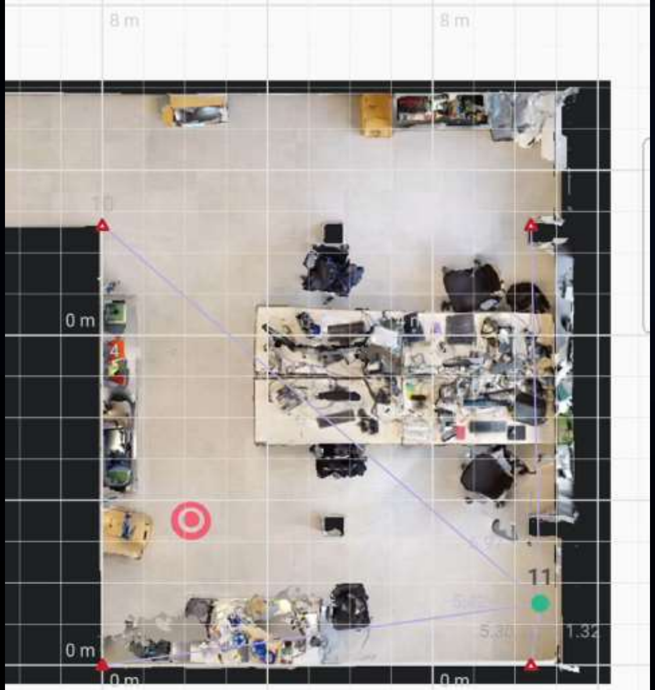


sck cen
CompuDos

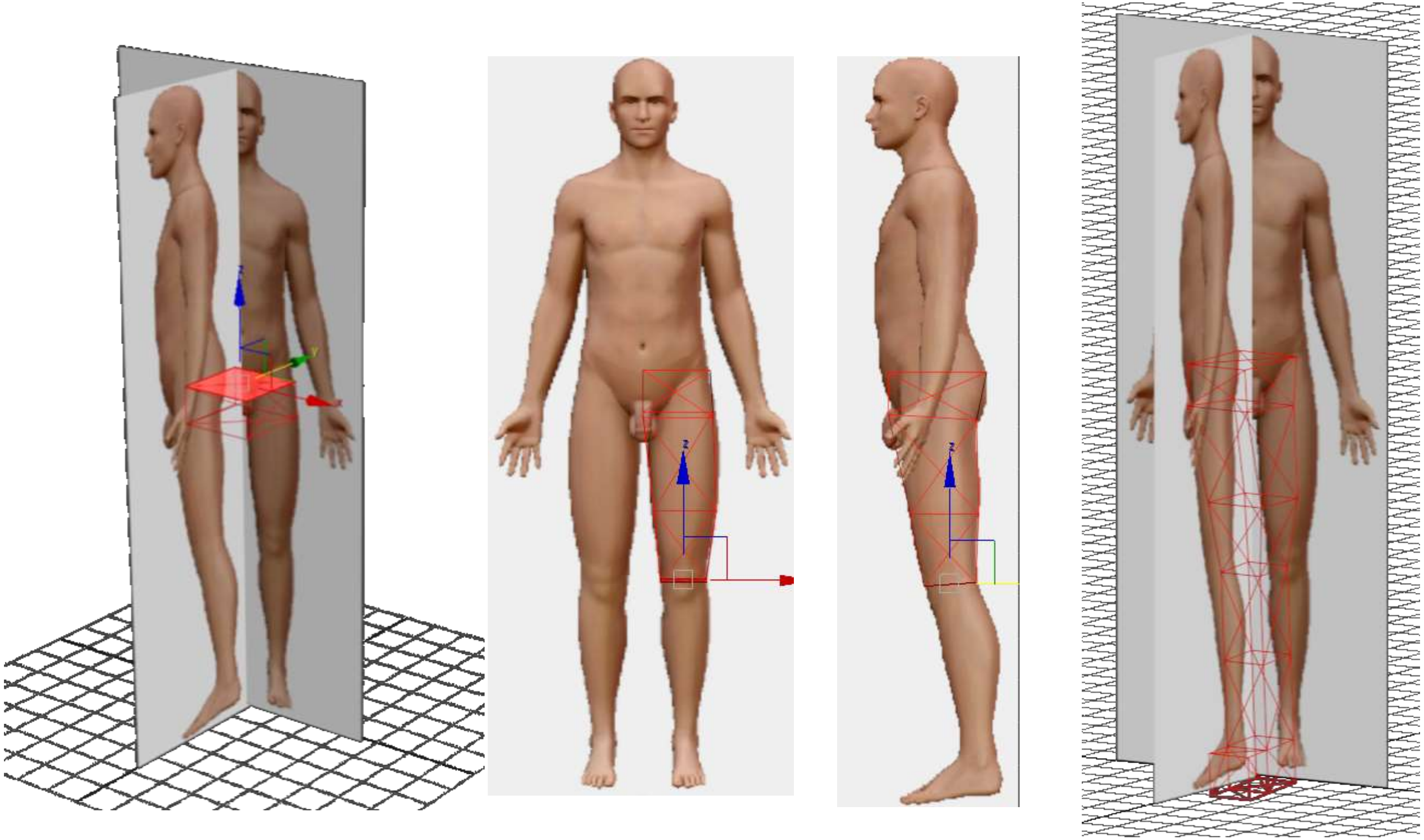
Shield Tracking

2

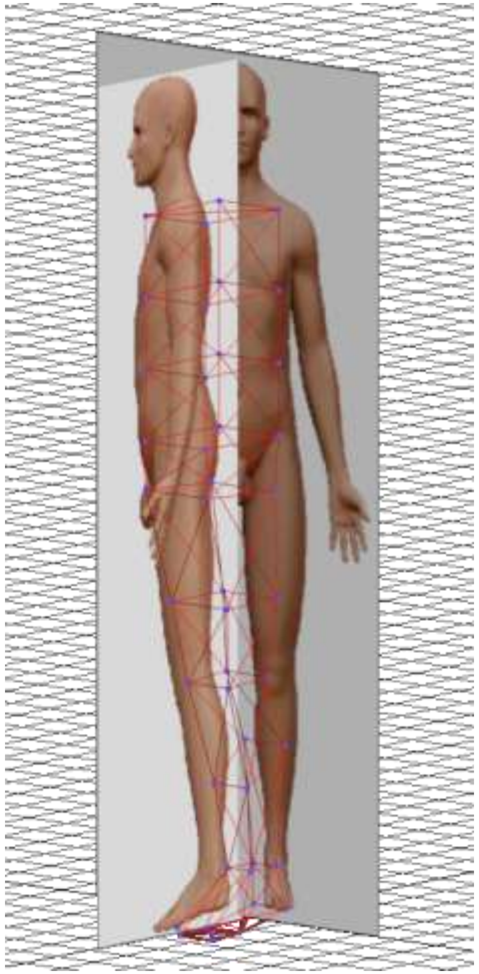


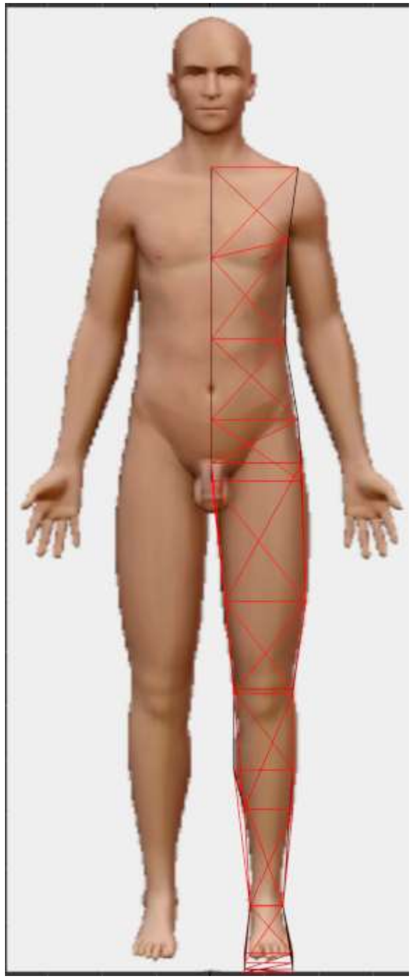


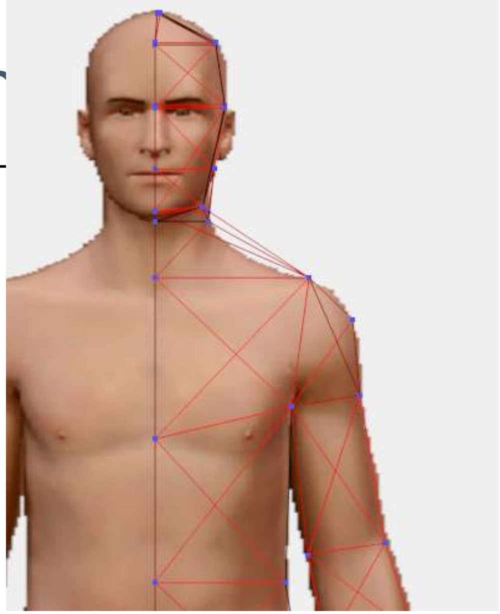
Example of modeling: the skin

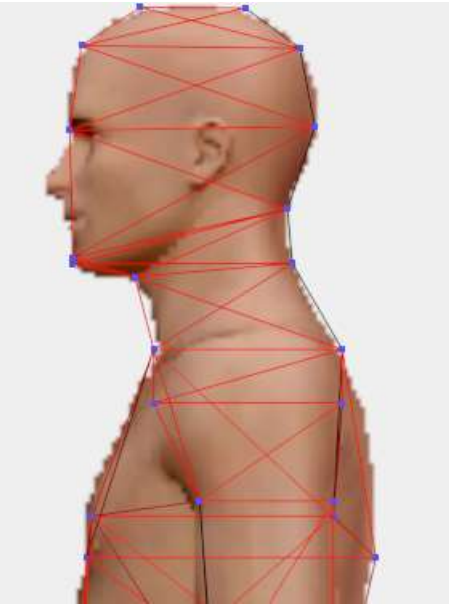


Example of modeling: the skin

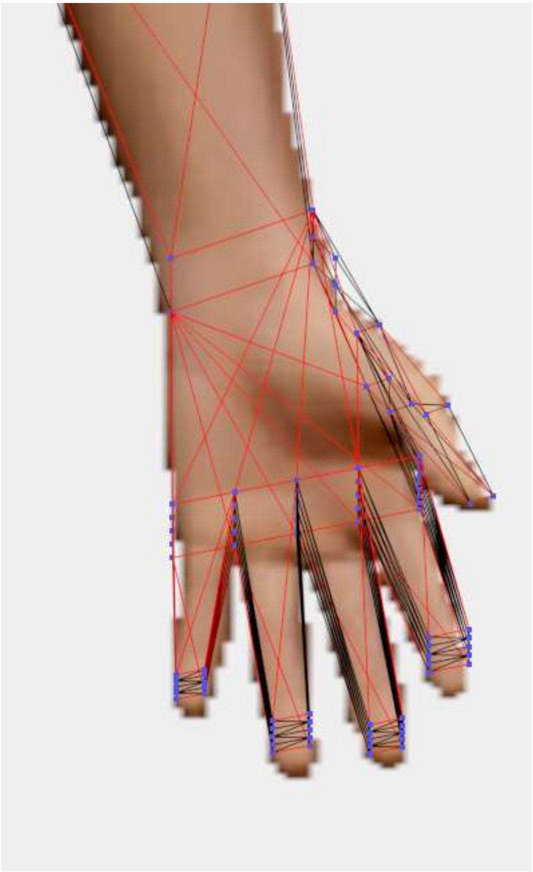


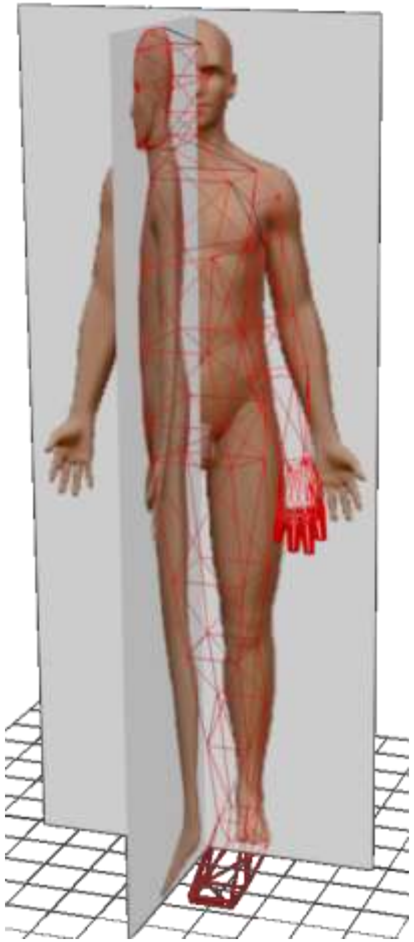


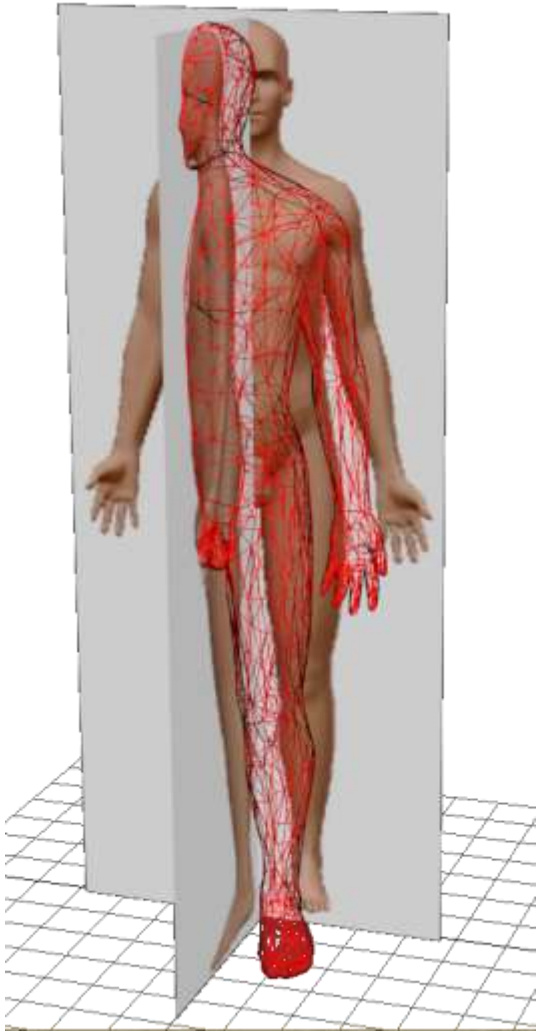




Example of modeling: the skin (3)







Modelling of **shallow organs** with the **shell** operator