Personal Dose Computation Using Monitoring Systems and 3D Cameras

19th EAN Workshop: "Innovative ALARA Tools“

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Framework for individual monitoring: why is dosimetry needed

- Routine monitoring of the individual exposure of workers is an integral part of any radiation protection program

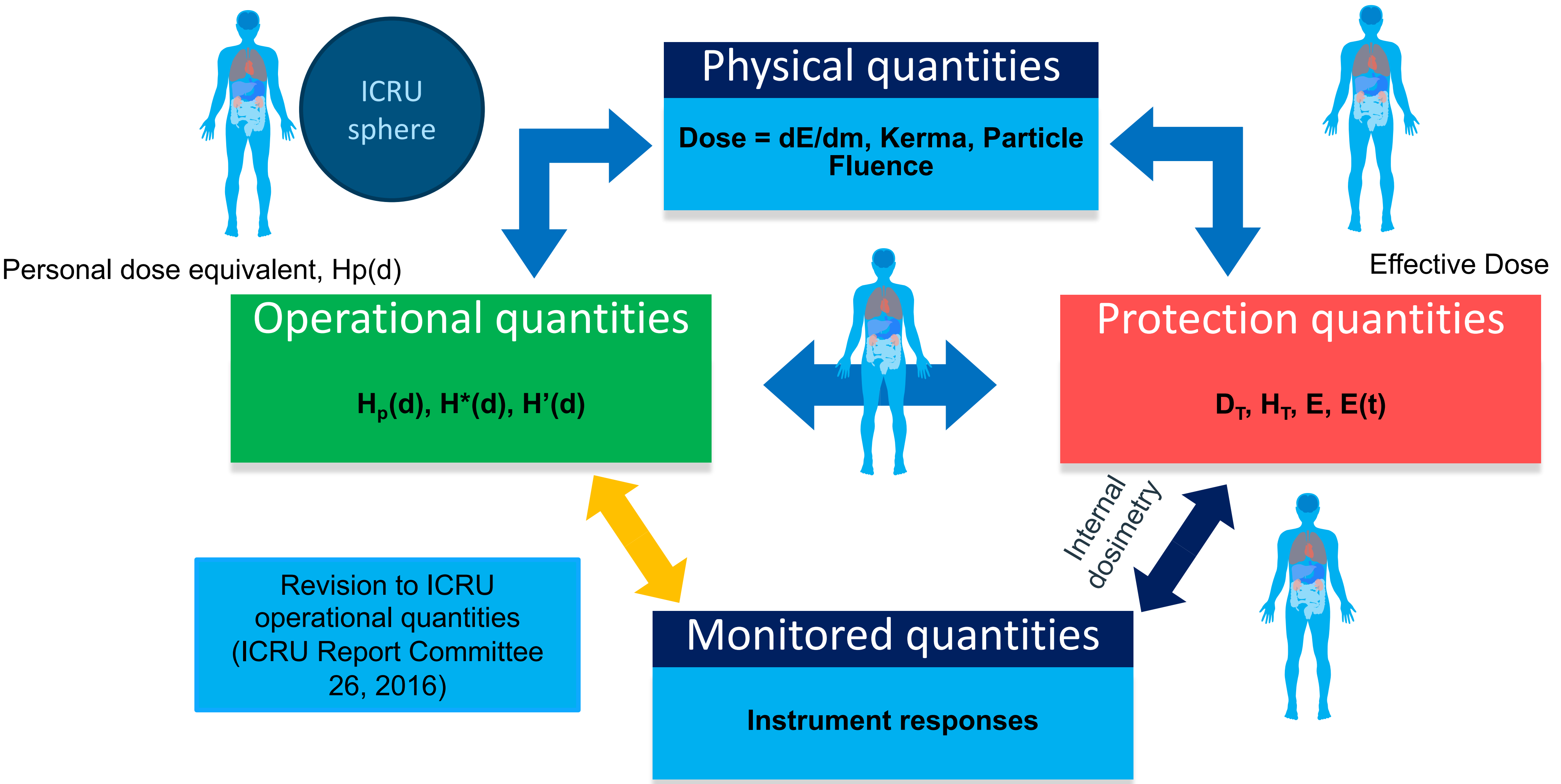
Individual monitoring of workers

Control occupational exposure

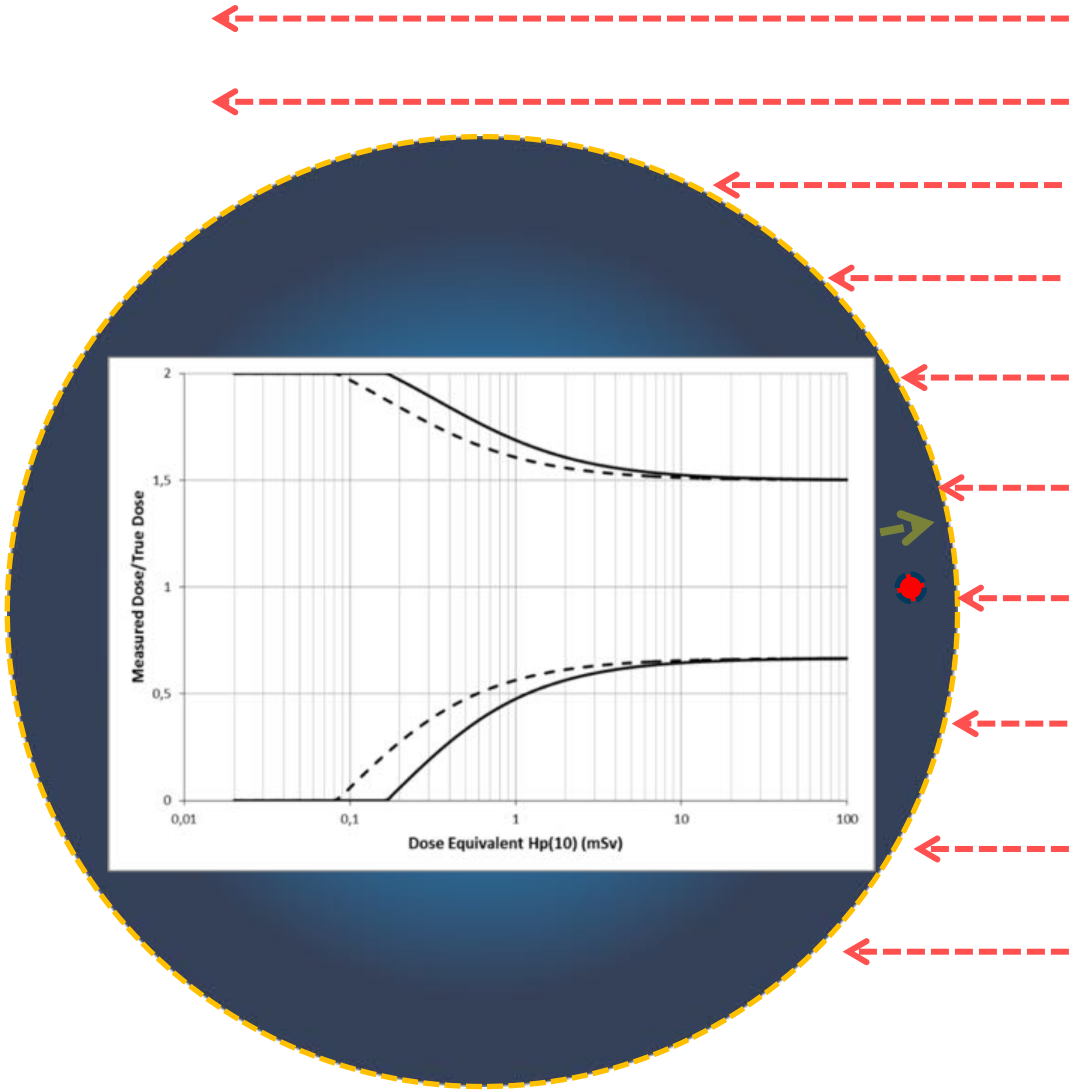
Dose limits and ALARA principle

Inform workers of their exposure

Quantities in dosimetry and RP



Limitations of Personal Dosimetry: **Safety** Aspects

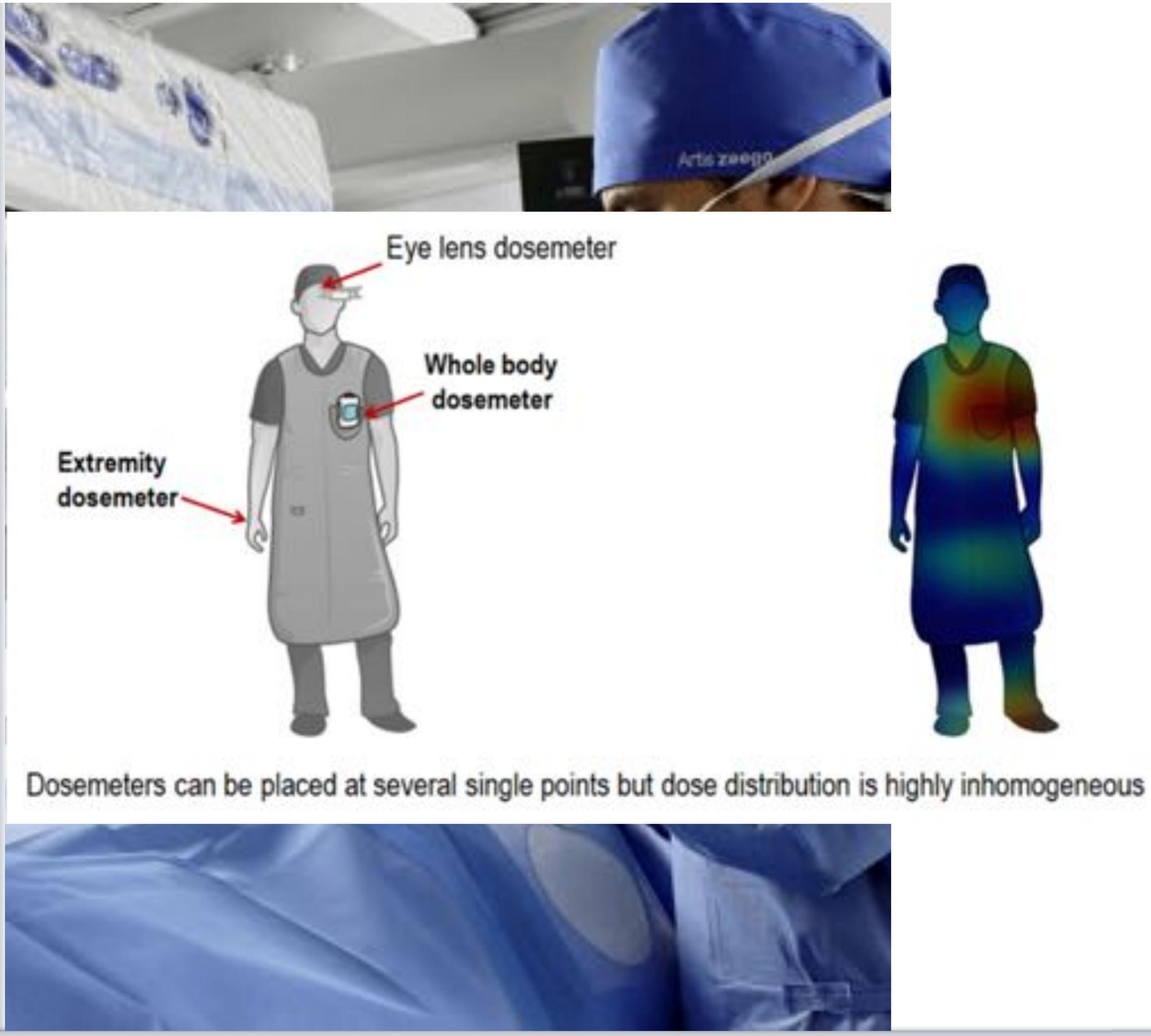


- Risk of health effect is given by tissue doses and effective dose. However, **tissue doses are not measurable**
- **Personal dose equivalents** are supposed to be **conservative estimation** of tissue doses and effective dose.
- No dosimeter is perfect for $H_p(10)$
  - Non-linearity, fading,…
  - Energy and angular dependences,…

Dosimeters are subject to high uncertainties (up to 50%), especially in highly inhomogeneous fields.

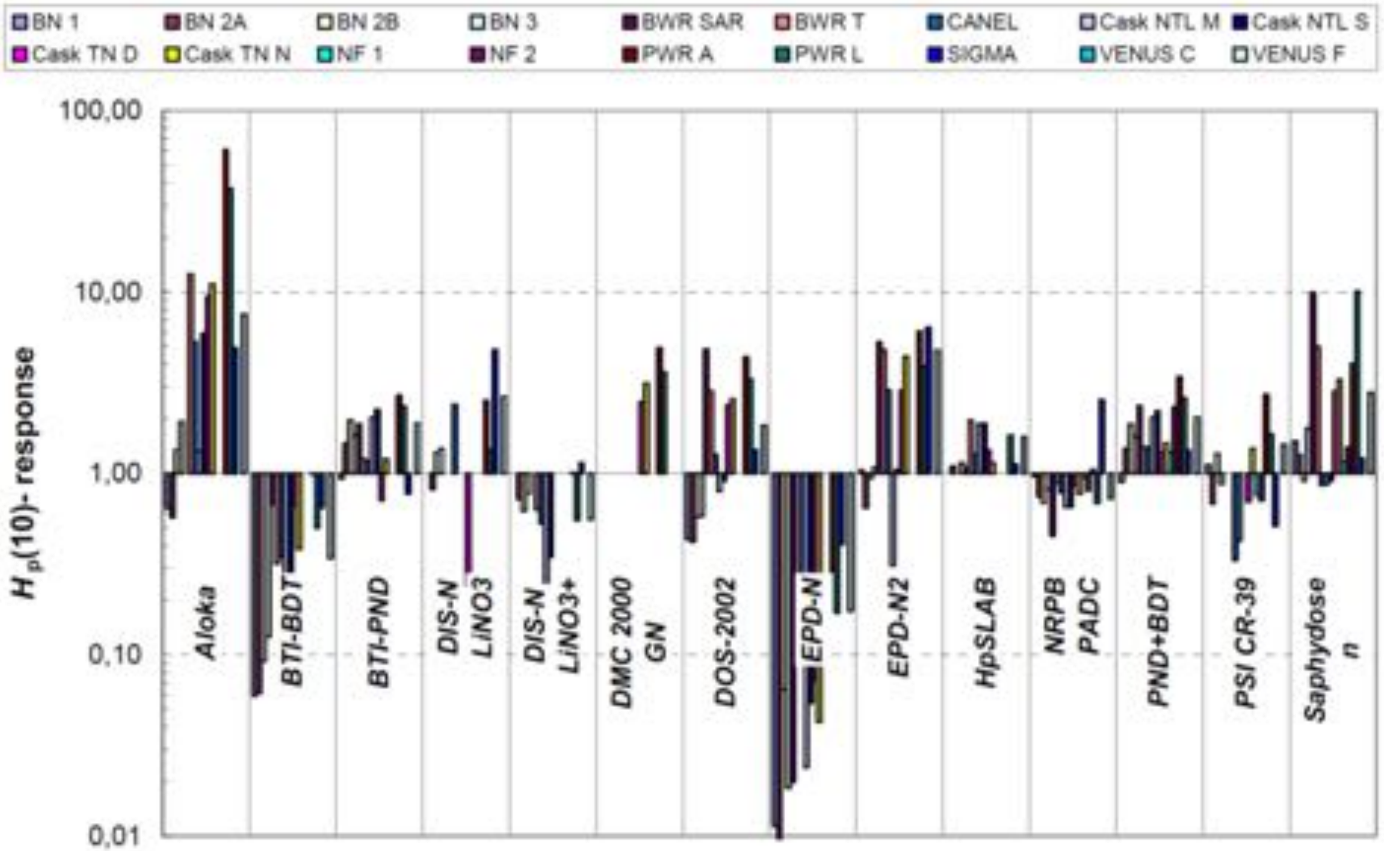
Limitations of Personal Dosimetry: **Safety** Aspects

- The main source of radiation dose to the doctor is the **patient body**
- Highly **inhomogeneous** scatter field
- **Physical dosimeters will measure dose equivalents far from protection quantities**



Limitations of Personal Dosimetry: **Safety** Aspects

Neutrons personal dosemeters have highly energy-dependent responses:



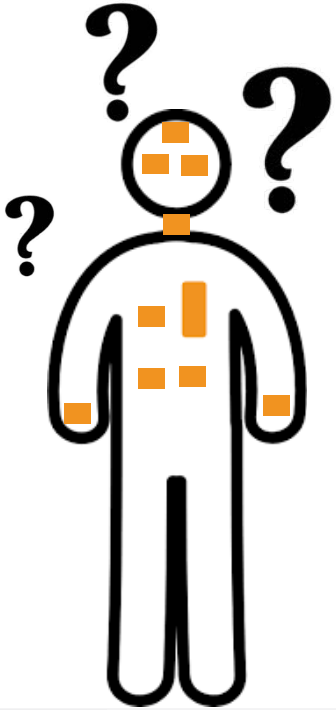
±2 orders of magnitude variation in workplace fields!

Limitations of Personal Dosimetry: **Practical Aspects**



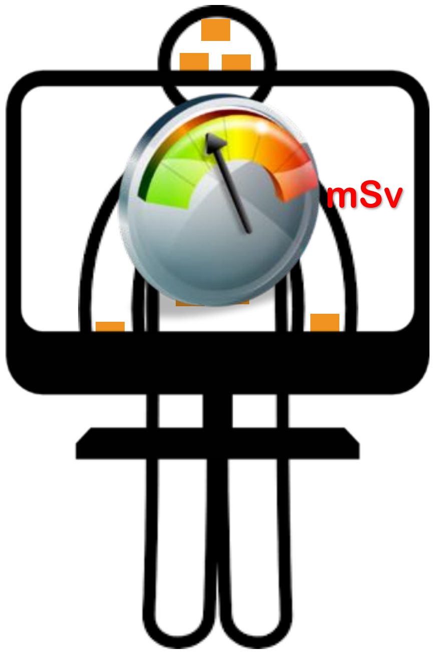

- Workers **do not like** wearing their dosimeter
  - Sometimes they **forget to wear** it…
  - Sometimes they **forget to change** it, or they **lose** it…
  - Sometimes they **place** it in the **wrong** position…

- Workers **really do not enjoy** wearing **more than one dosimeter**
  - Still, **not all body** is covered by dosemeters
  - Depending on the application, the use of dosemeters can **hinder work**
  - Added complexity in handiling and **extra workload** for read-out

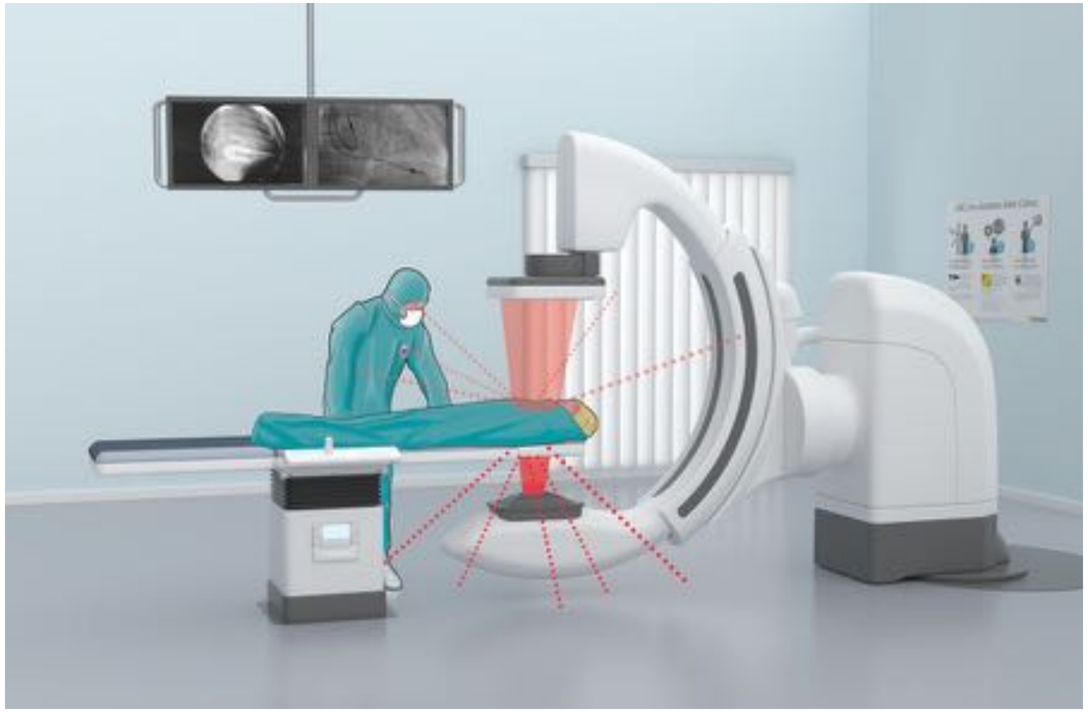


Personal Dosimetry: what brings the future?

- May be no need for physical dosimeters?
- 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
  - ….



Use of computational methods for individual monitoring



PODIUM Objectives

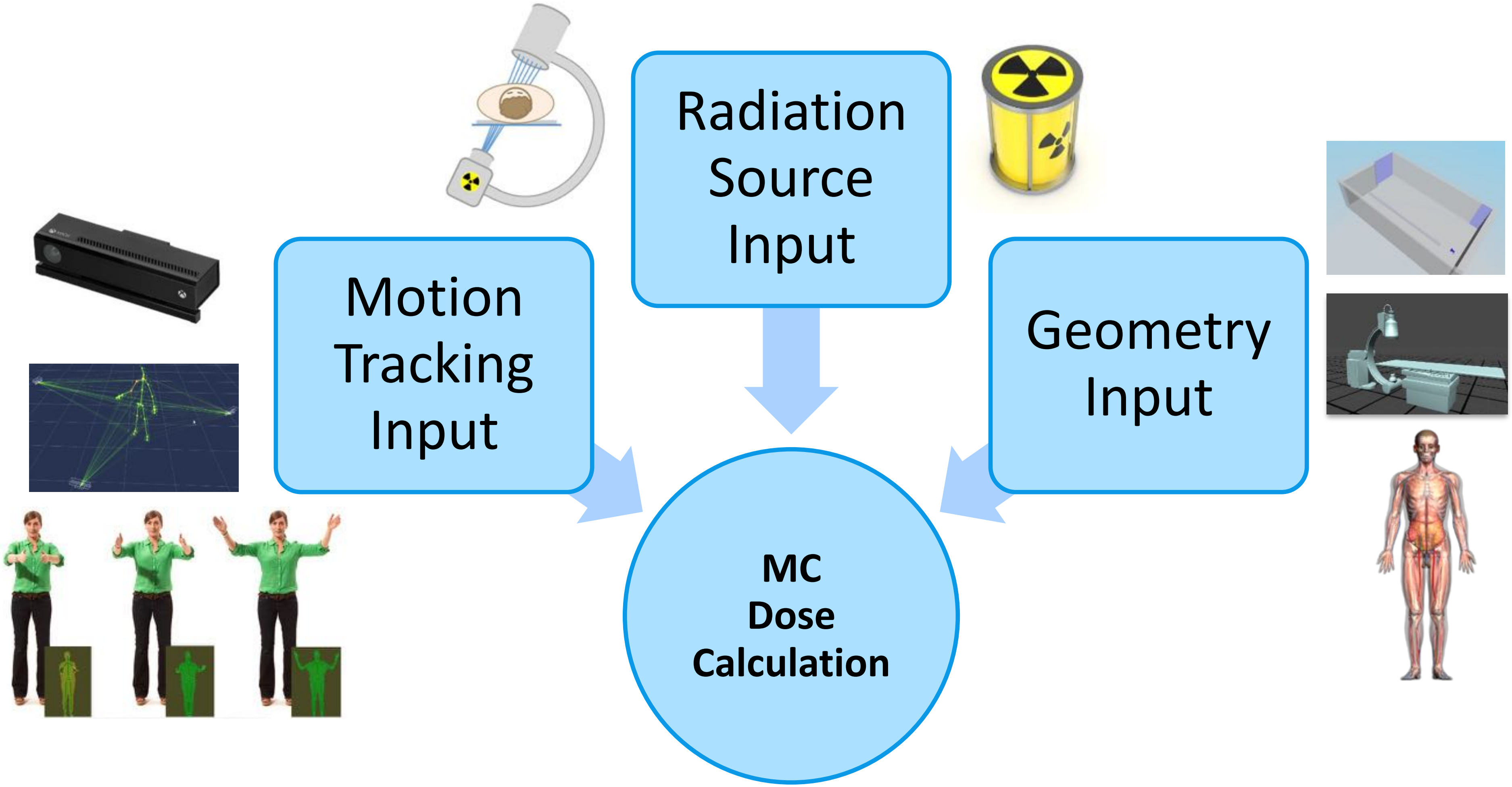
- **Improve occupational dosimetry** via an online dosimetry application using computer simulations: without the use of physical dosemeters
- **Develop an online application** in which we will calculate individual occupational doses
- In a limited time frame, simultaneously use an intermediate approach with **pre-calculated fluence to dose conversion coefficients** for phantoms of different statures and postures
- **Apply and validate** the methodology for two situations where improvements in dosimetry are urgently needed: **neutron workplaces** and **interventional radiology**
- The **legal aspects** to introduce this or similar techniques as an official dosimetry method will also be established

PODIUM Personal Online Dosimetry Using computational Methods

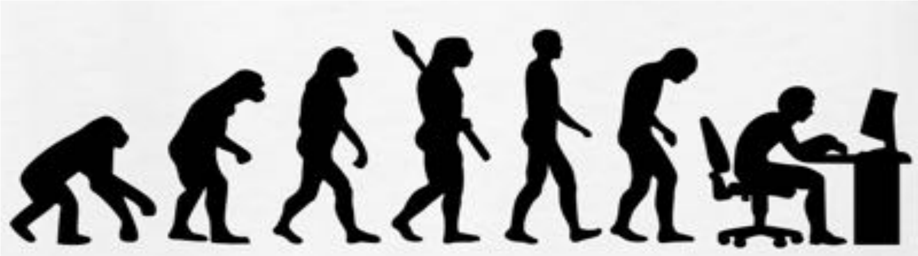
How is our virtual dosimetry system working?

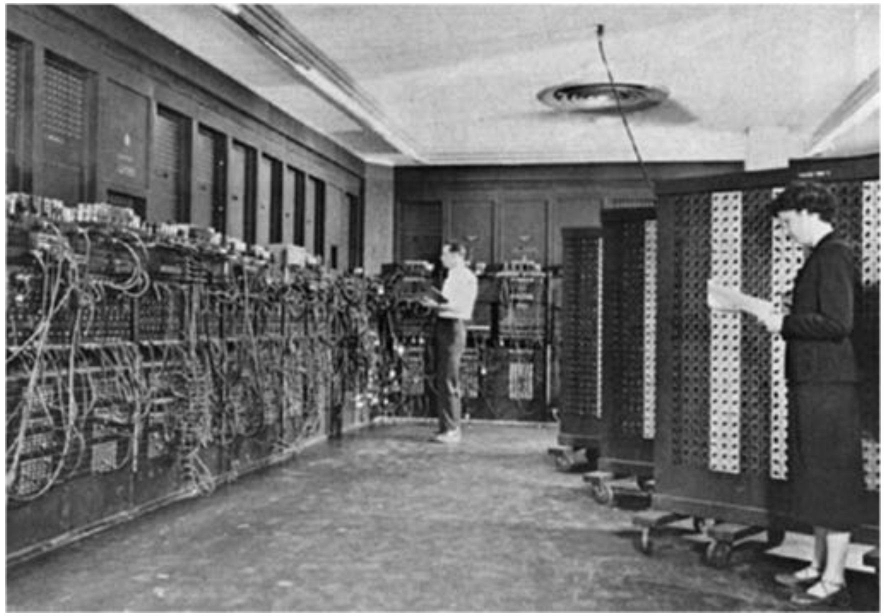
Motion Tracking

Staff movement monitoring and Radiation field mapping



Computational power increases significantly and it is foreseen that the trend will keep up for the next decades

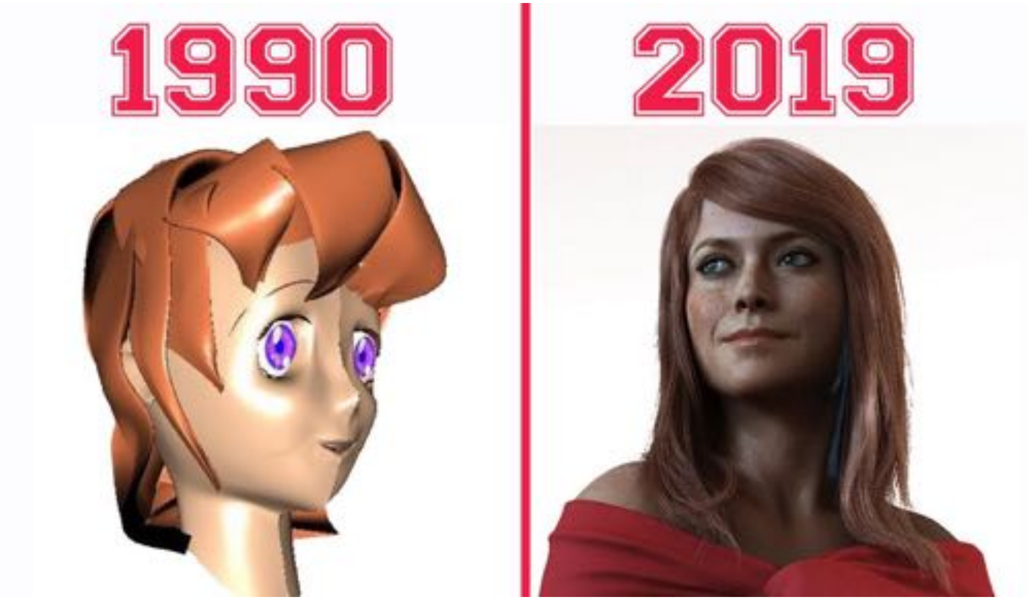




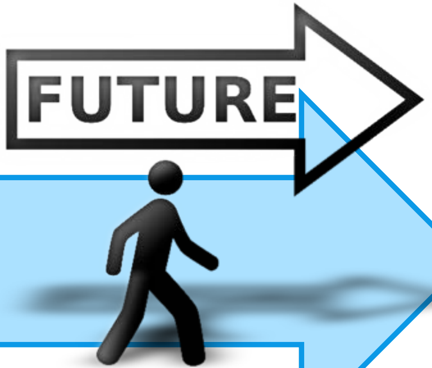
Motivation: 3D modeling

3D modeling and visualization are now widely available and affordable as ever

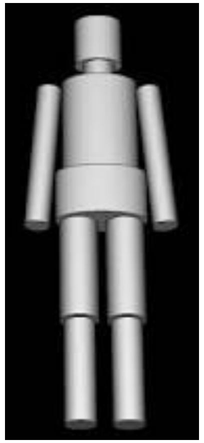
vs.



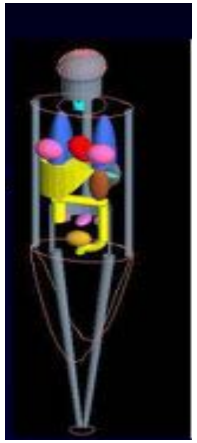
Geometry Input: Human Phantoms



1950's	1960's	1980's	2000's
Simple phantoms	**Stylized phantoms**	**Voxel phantoms**	**B-REB Phantoms**

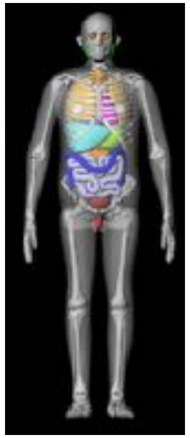


BOMAB Phantom



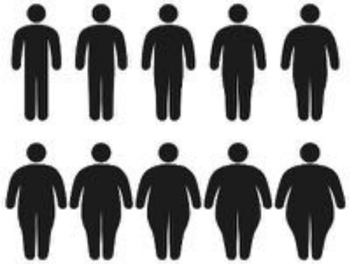
ORNL Phantom

Irene, Baby & Child Voxel Phantoms



UF Adult male Phantom

Realistic Anthropomorphic Flexible Phantom*



Personalized Phantoms

***PhD: P. Lombardo** SCK•CEN

RAF phantom (2018)

- **Polygonal Mesh B-Rep** phantom designed with 3Ds Max
- **Tissue masses** (without blood) were **fit to ICRP 89**, with differences within ±10%.
- The phantom has about **2900 segmented tissues** forming 78 (+ 1) organs, grouped in ≈ **500 clusters.**
- We performed a **dosimetric validation** for idealized external irradiation by comparing with **ICRP 116**. For most of the organs and energies, **differences were within ± 30%.**

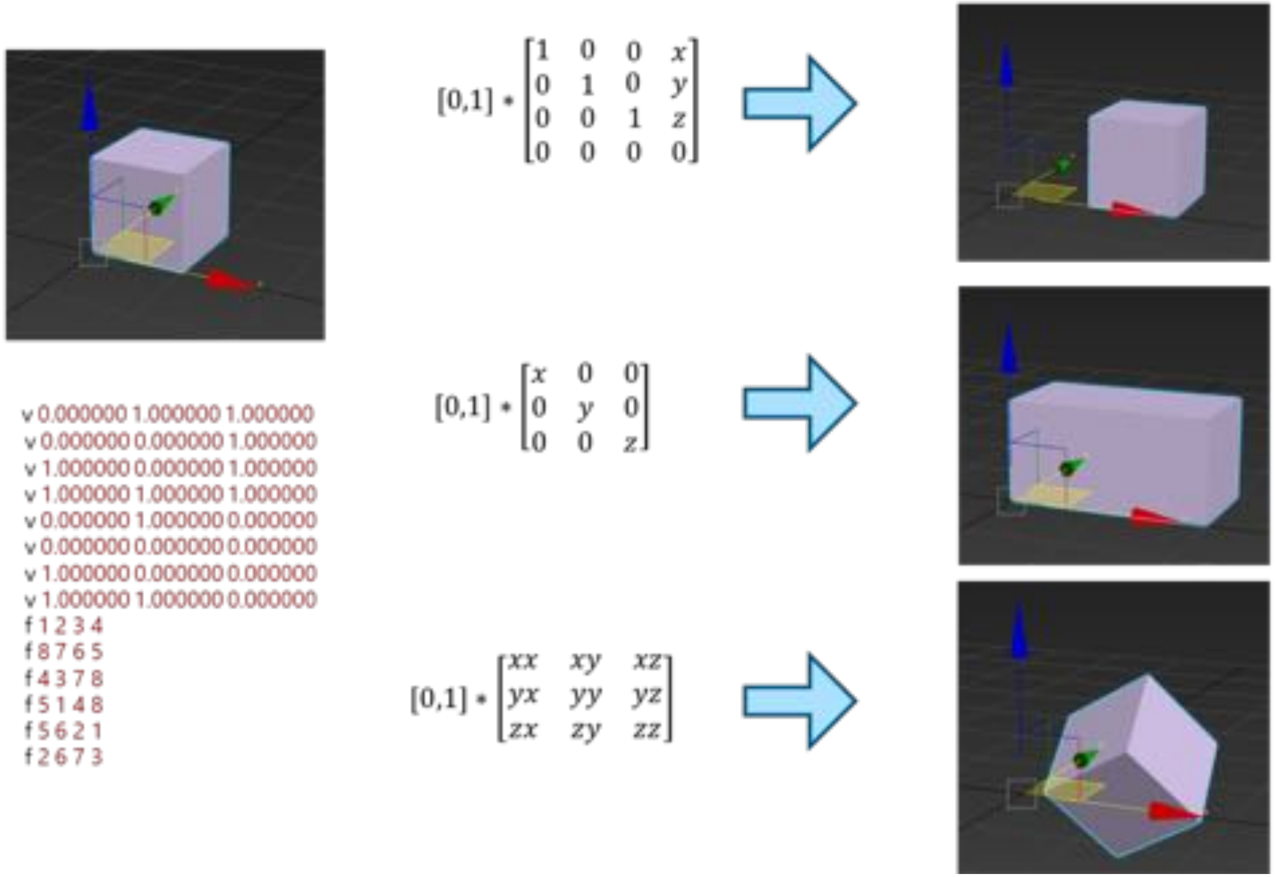
*P A. Lombardo, F Vanhavere, A L. Lebacq, L Struelens, and R Bogaerts. "Development and Validation of the Realistic Anthropomorphic Flexible (RAF) Phantom" Health Phys., 114(5), pp 486-499, 2018.

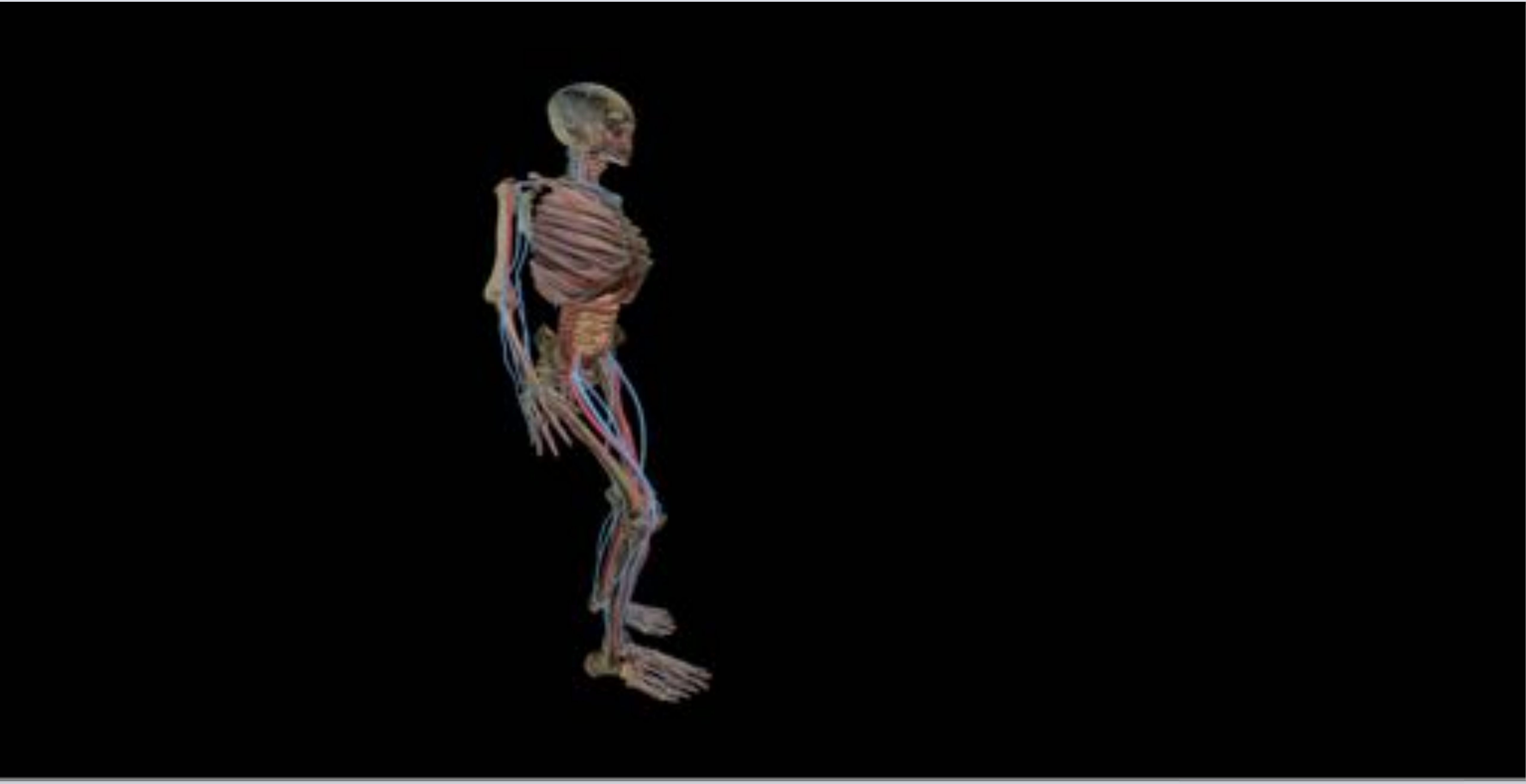
Two approaches are used for posing:

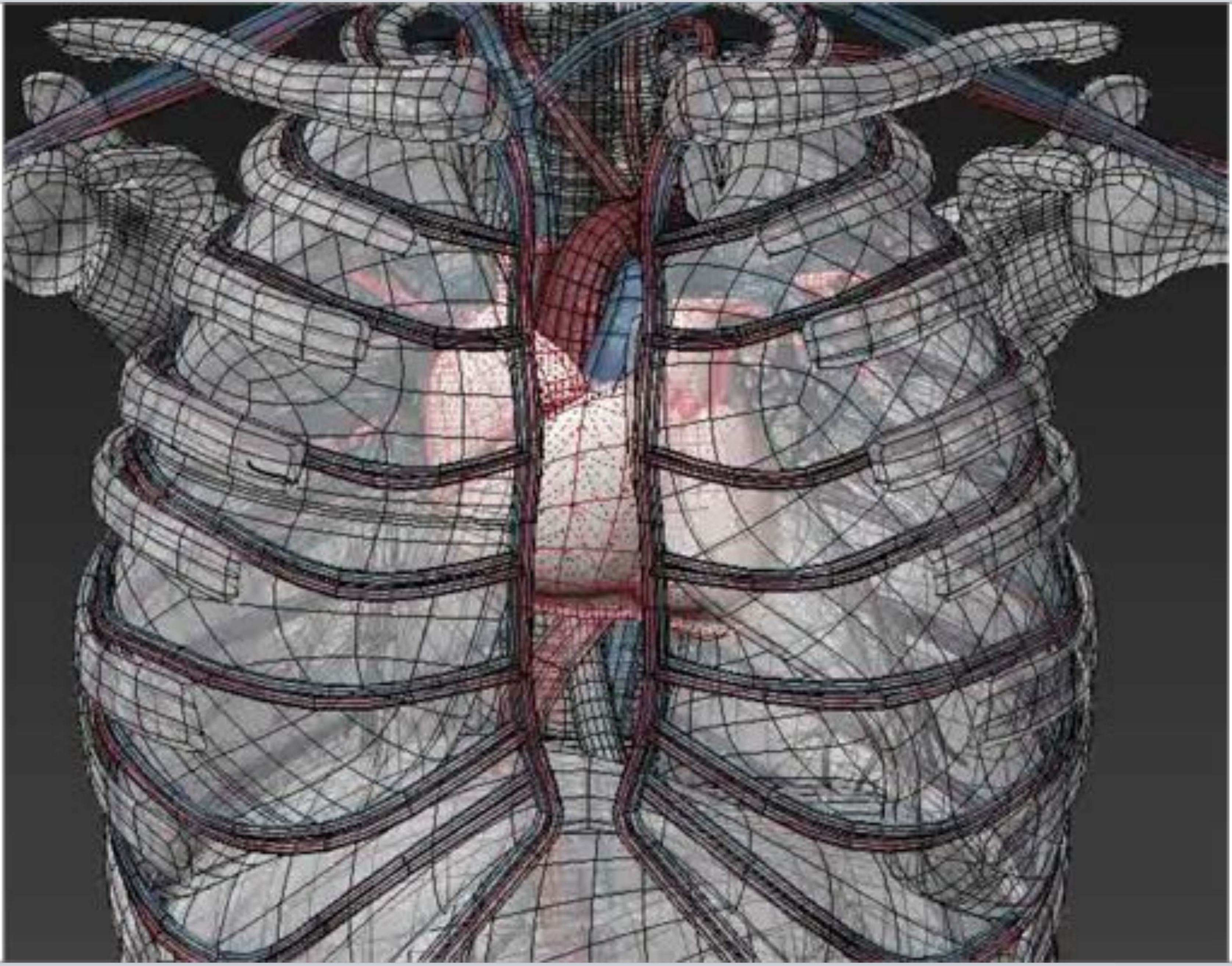
(1) a volume-preserving, skeleton- and influence-region-based approach that allows real-time posing

(2) a physical-simulation-based approach that allows the user to first prescribe the position of bones, then performs a tissue mechanics simulation of the passive deformation of the soft tissues, resulting in more-realistic joint-region geometries

Principles of computer animations

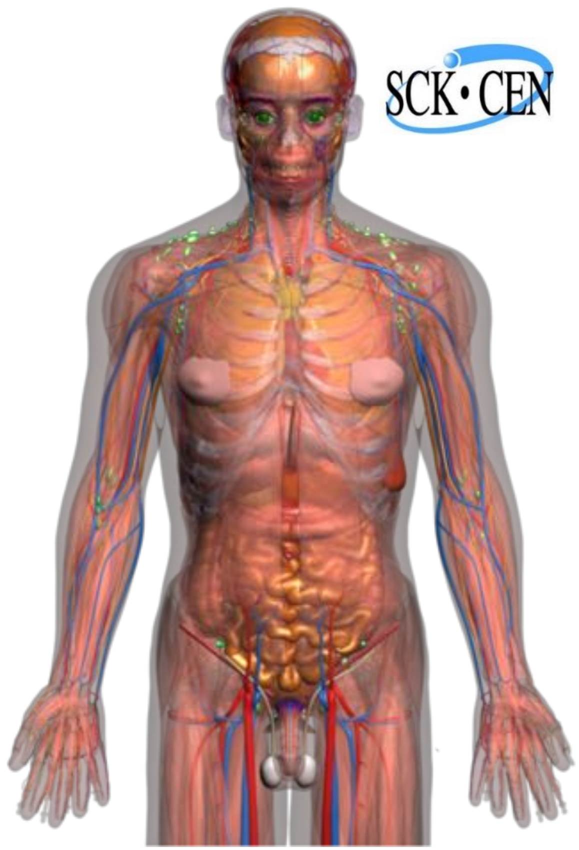


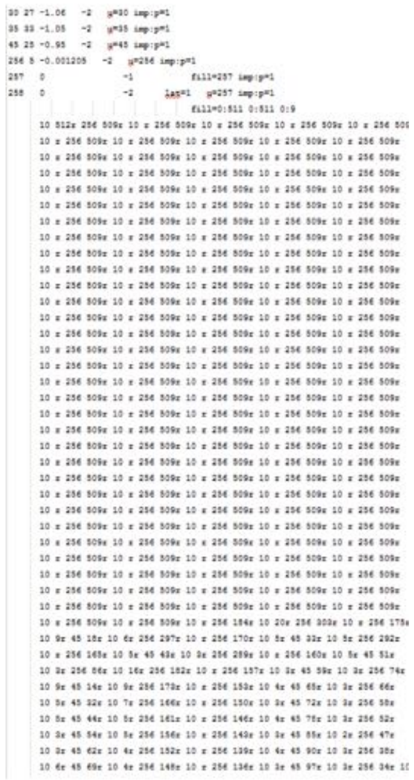


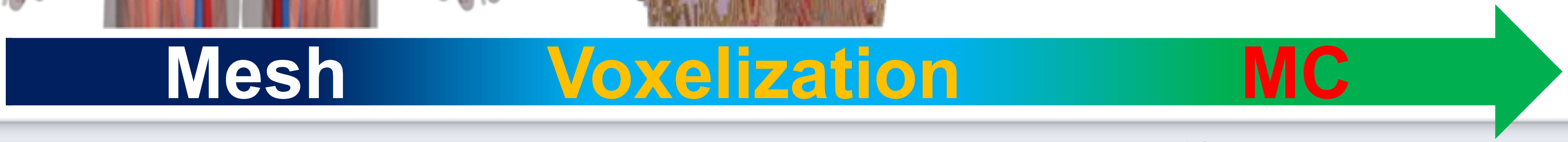


Voxelization of the RAF phantom

- MC codes like MCNP cannot yet load Polygonal Meshes as input geometry

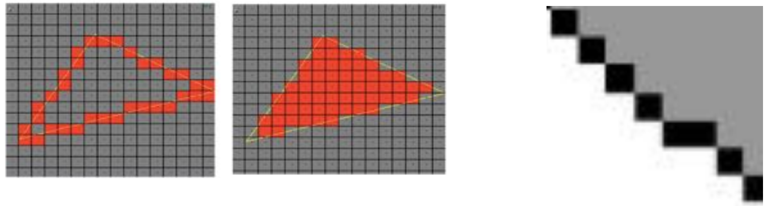




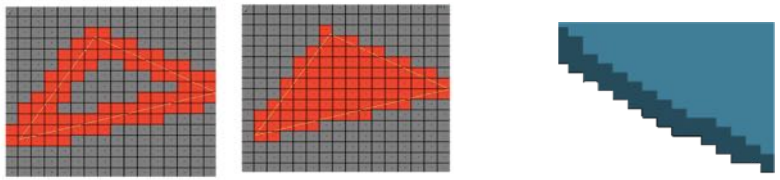


Topological voxelization algorithm

1st objective: Preserve thicknesses of organ walls
2nd objective: Reduce uncertainty in mass of the voxelized organs



Skin layer from ICRP Publication

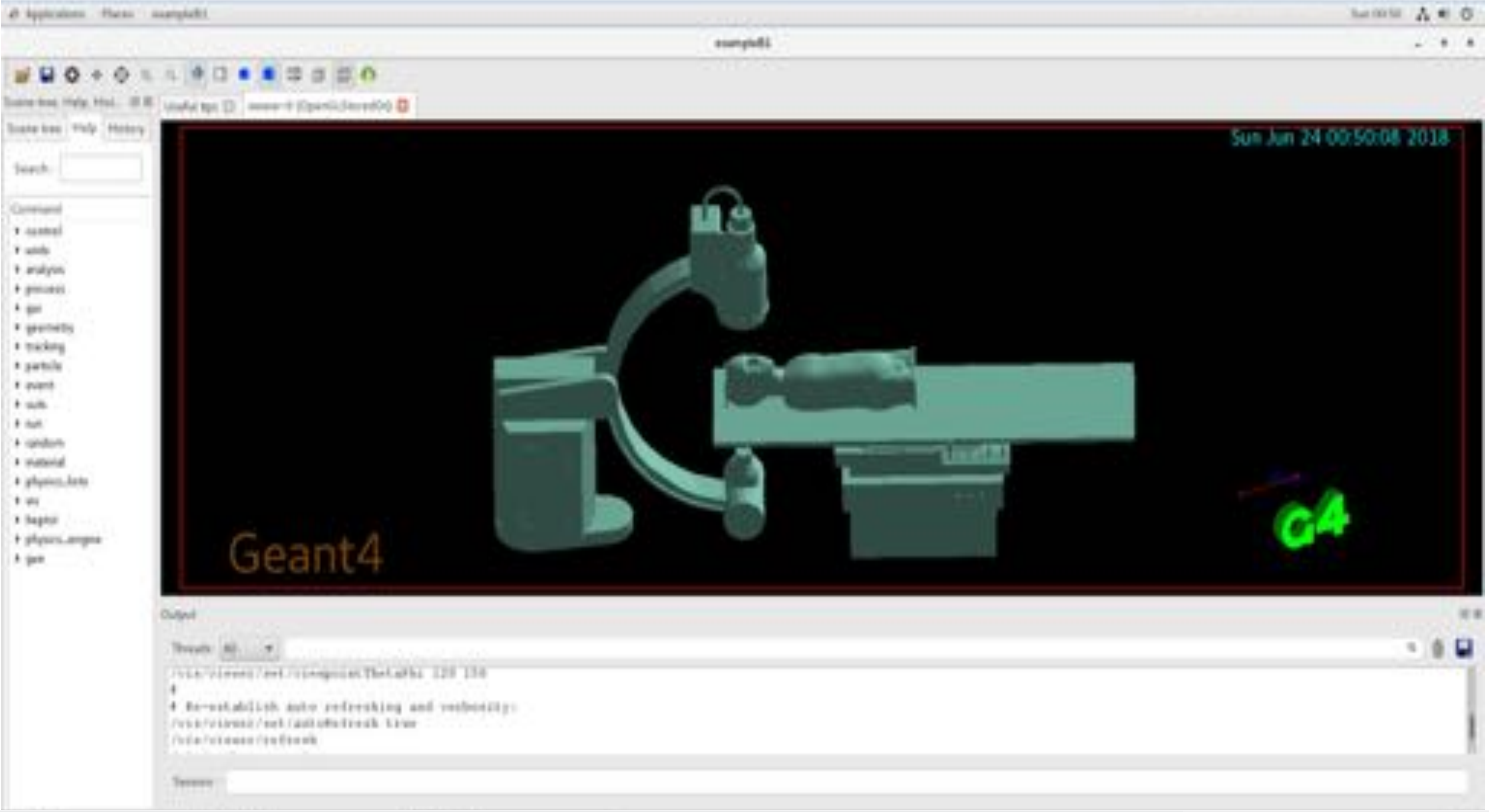


Skin layer from voxelized RAF Phantom

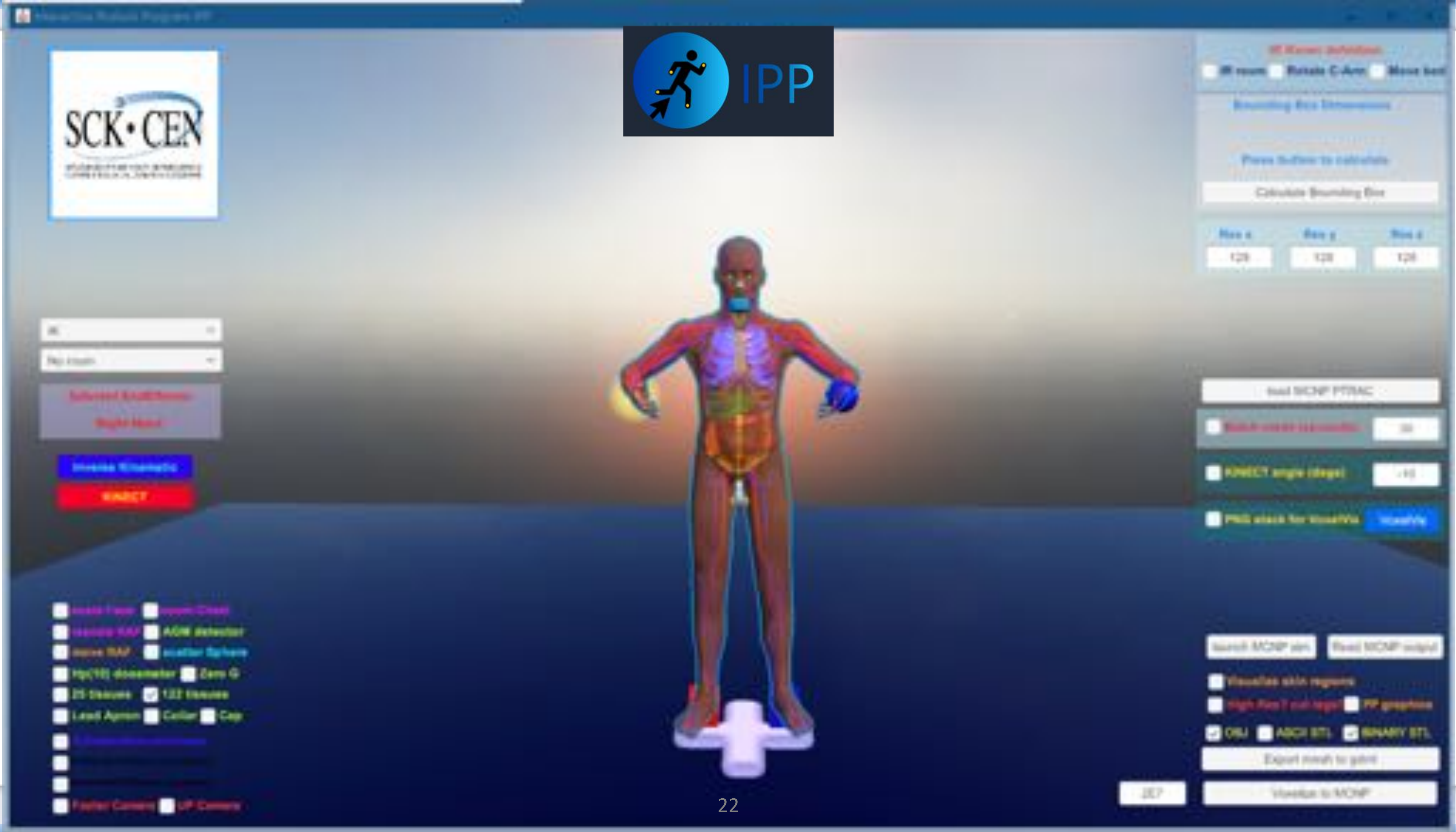
Laine S 2013 A topological approach to voxelization *Comput. Graph. Forum* **32** 77–86

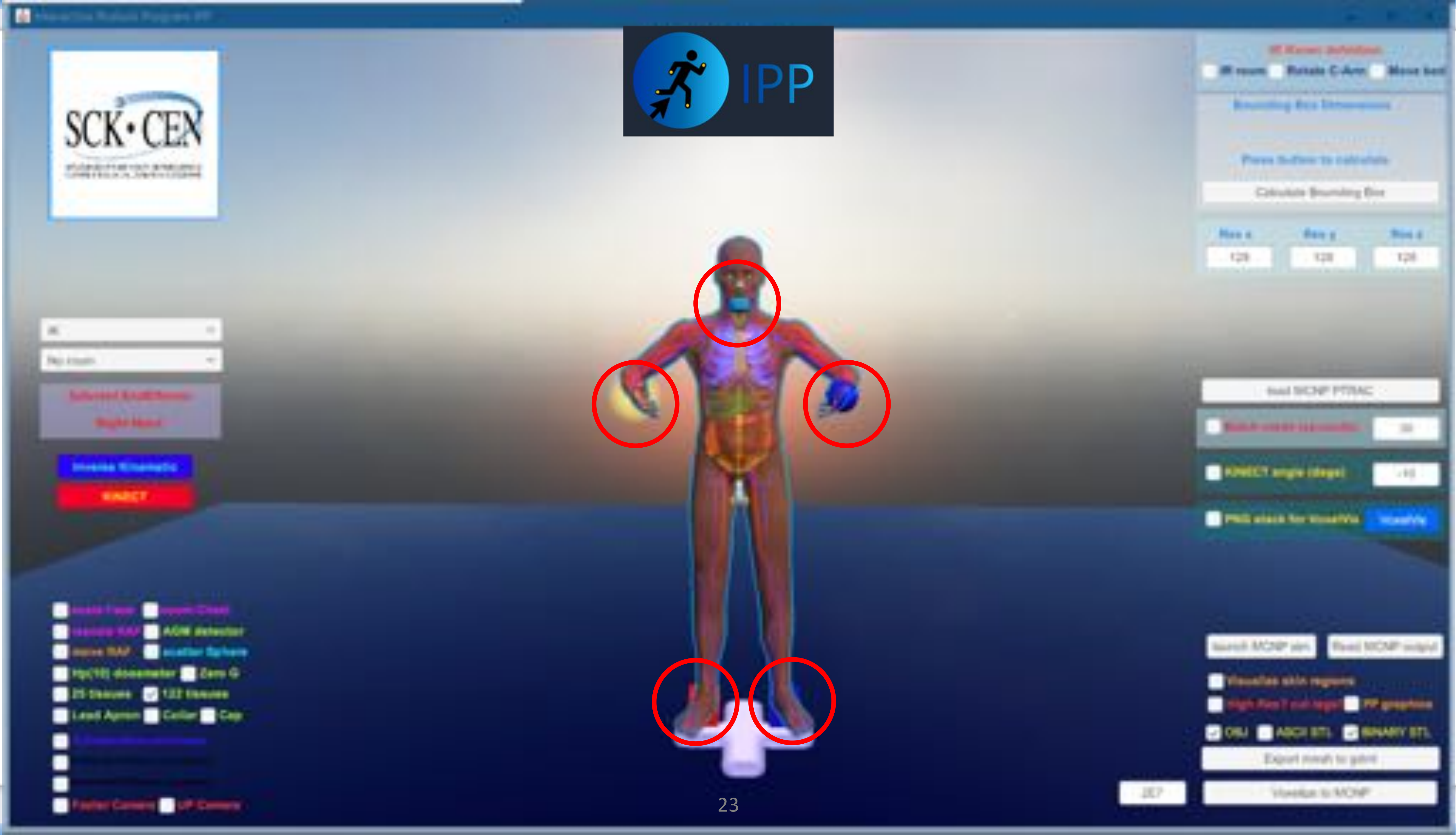
- Few MC codes like Geant-4 adapts Polygonal Meshes as input geometry

Polygonal mesh geometry in Geant-4

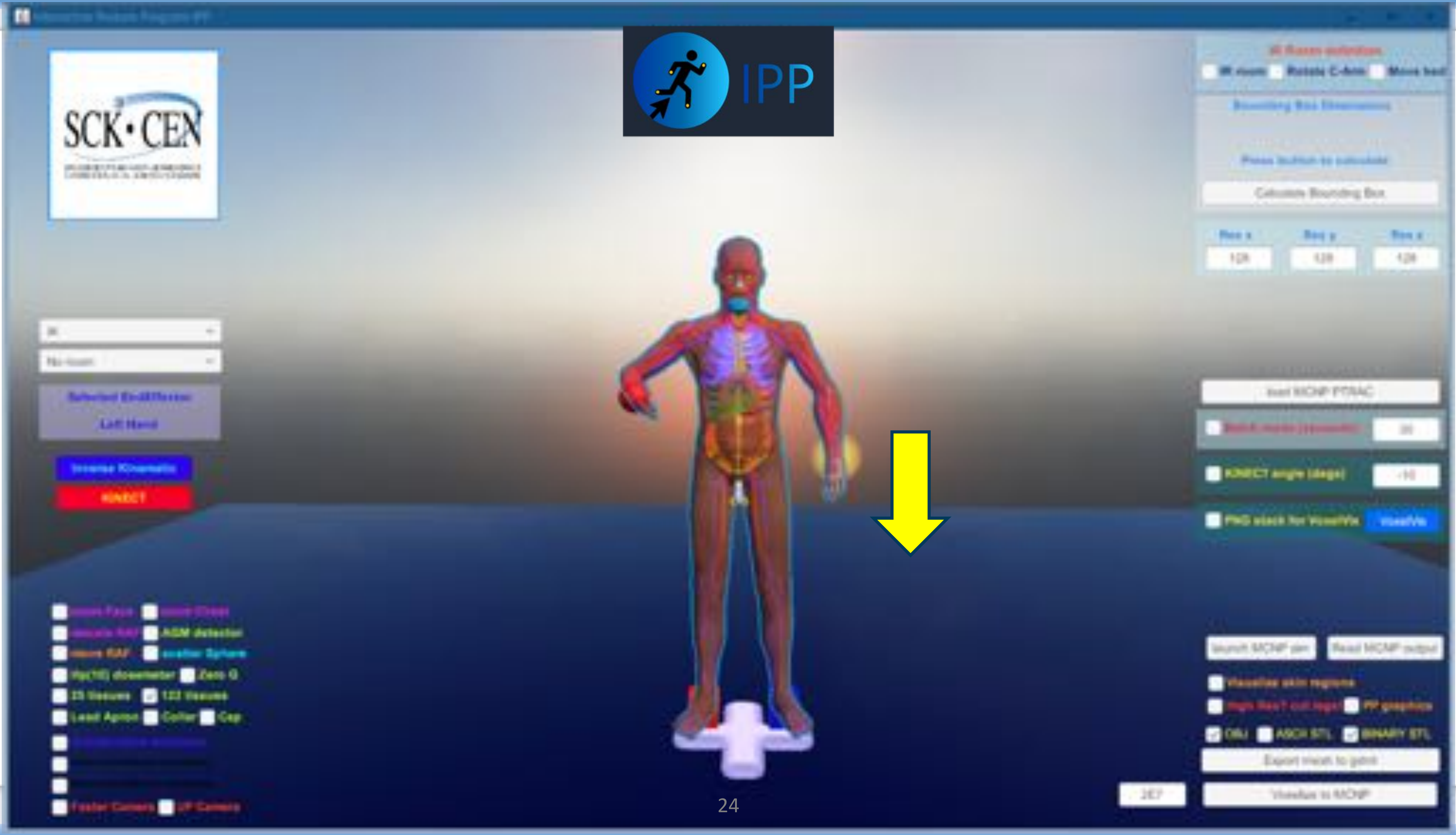


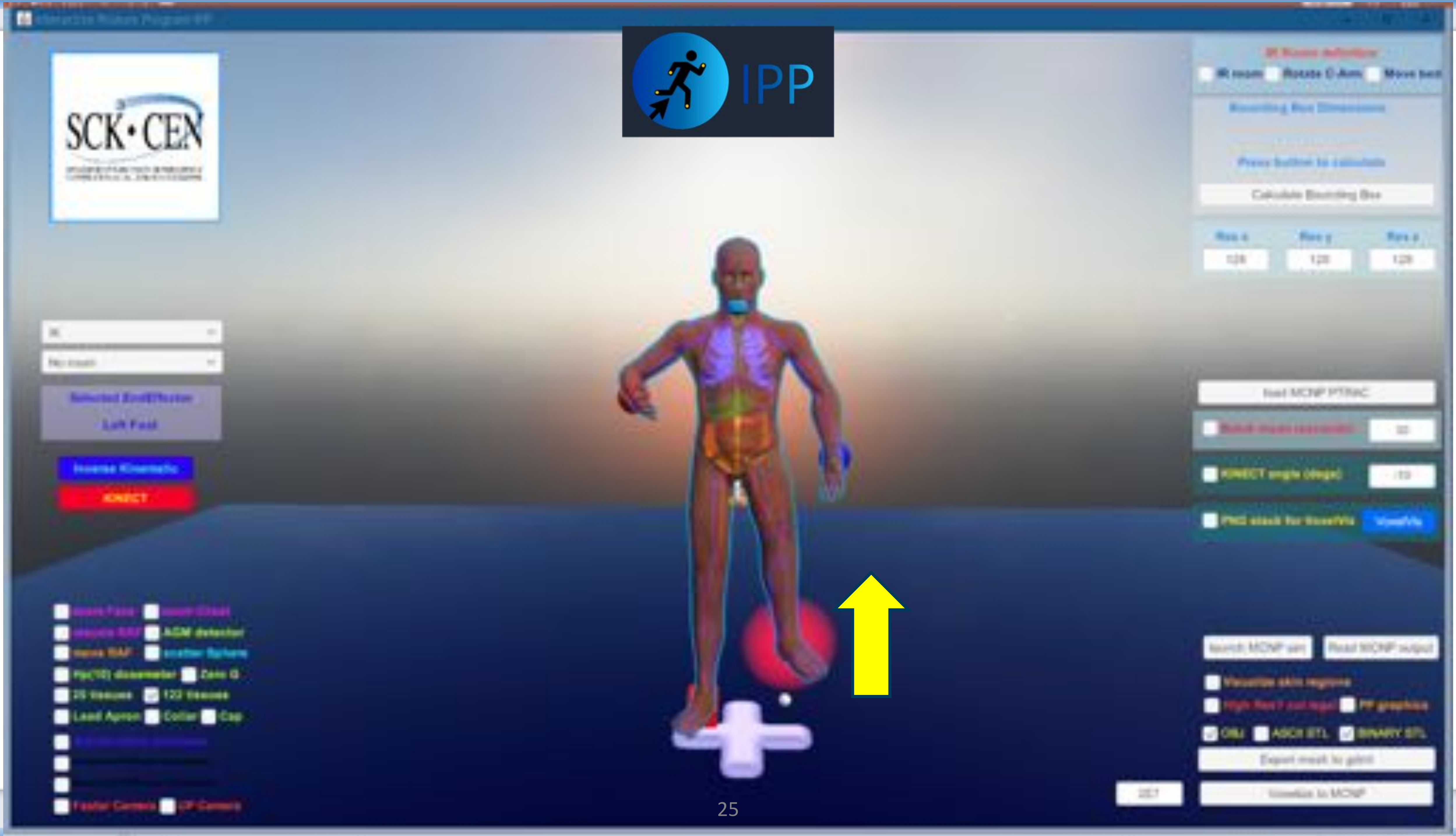
Function 1: change posture

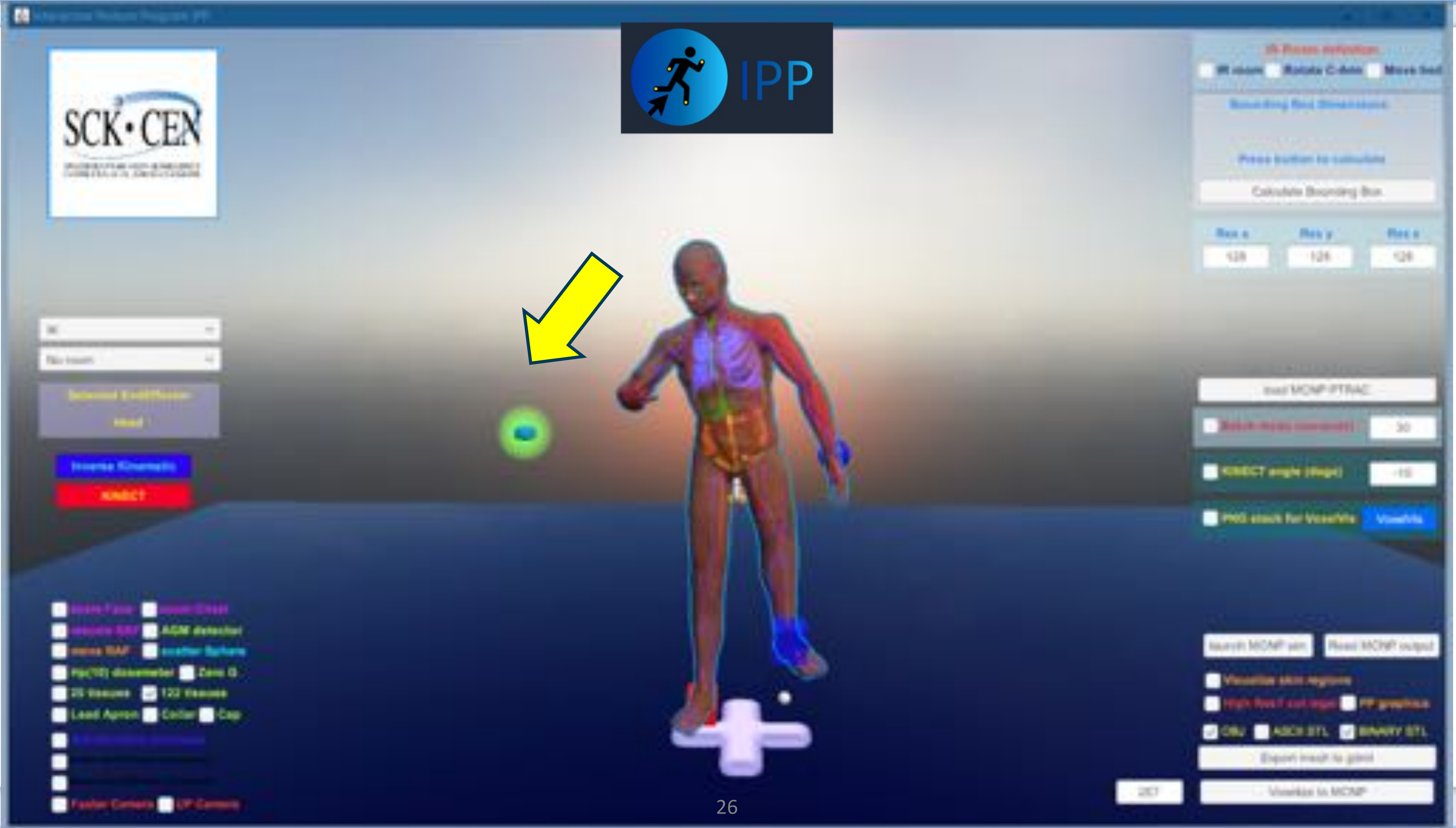

SCK•CEN
IPP

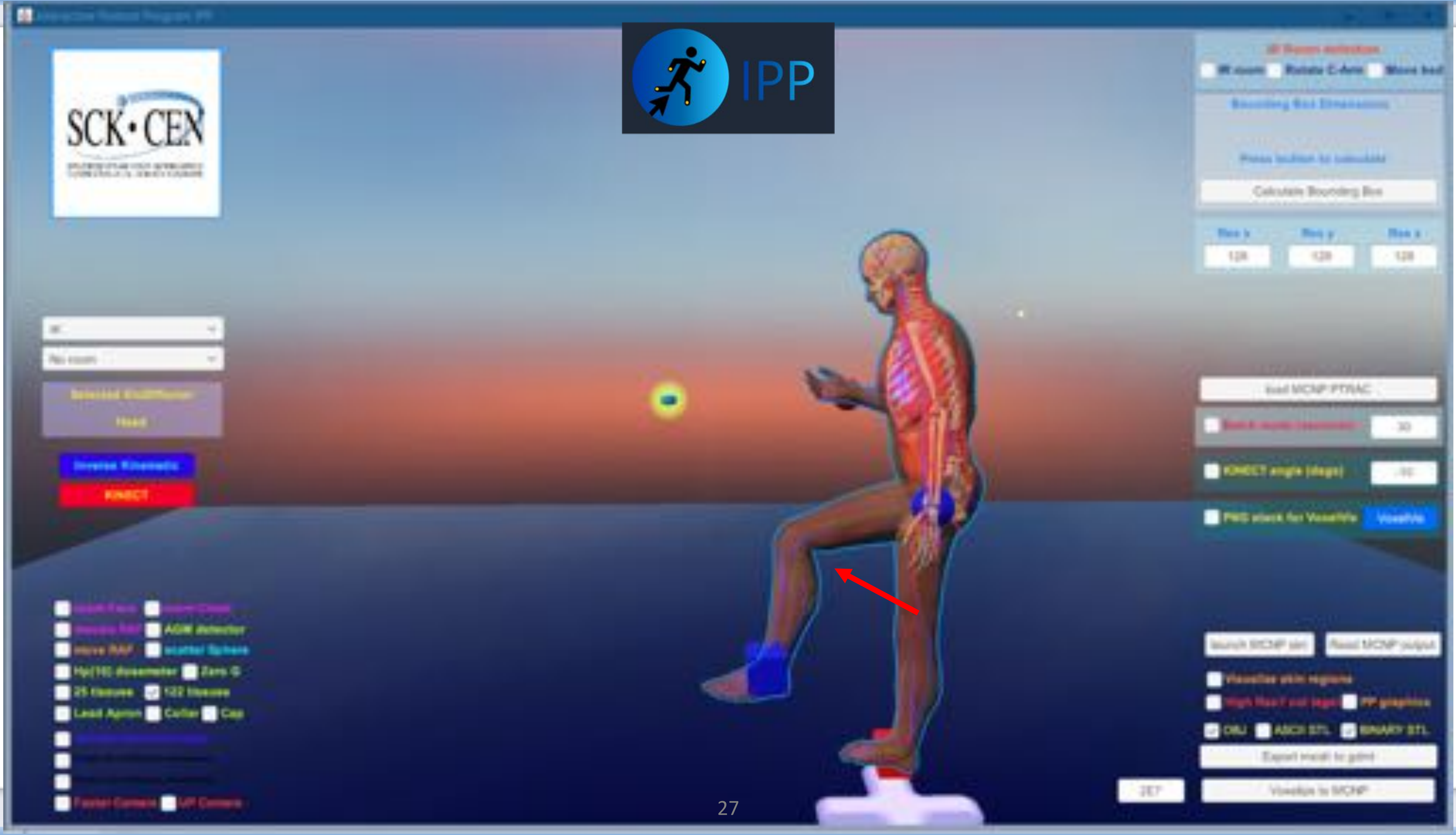


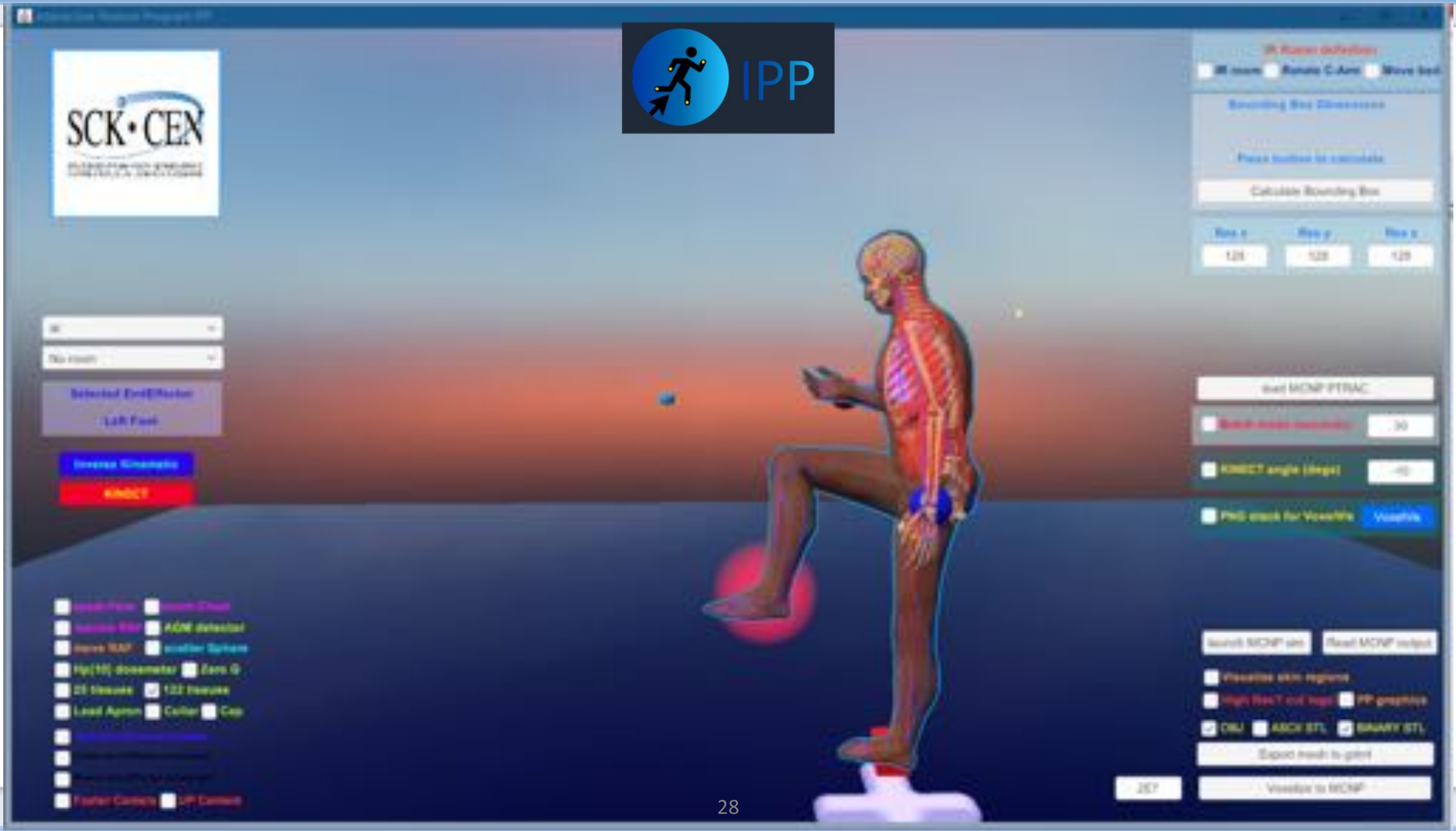
IPP
SCK•CEN


SCK•CEN
IPP
KINECT

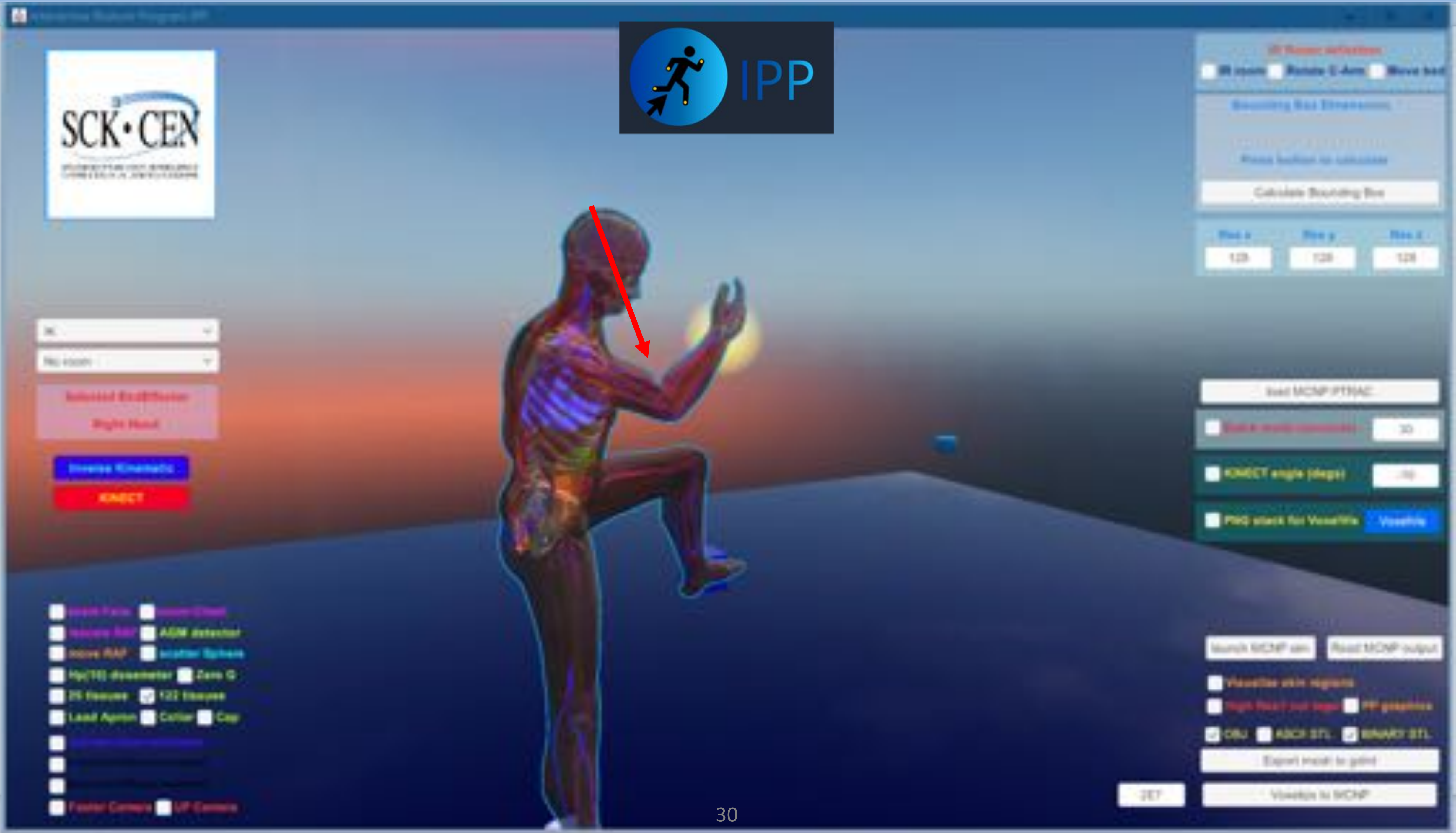

IPP
SCK•CEN
Calculate Bounding Box
Inverse Kinematic
KINECT
Left Foot
Lead Apron
Collar
Cap
OBJ
ASCII STL
BINARY STL


SCK•CEN
IPP
KINECT

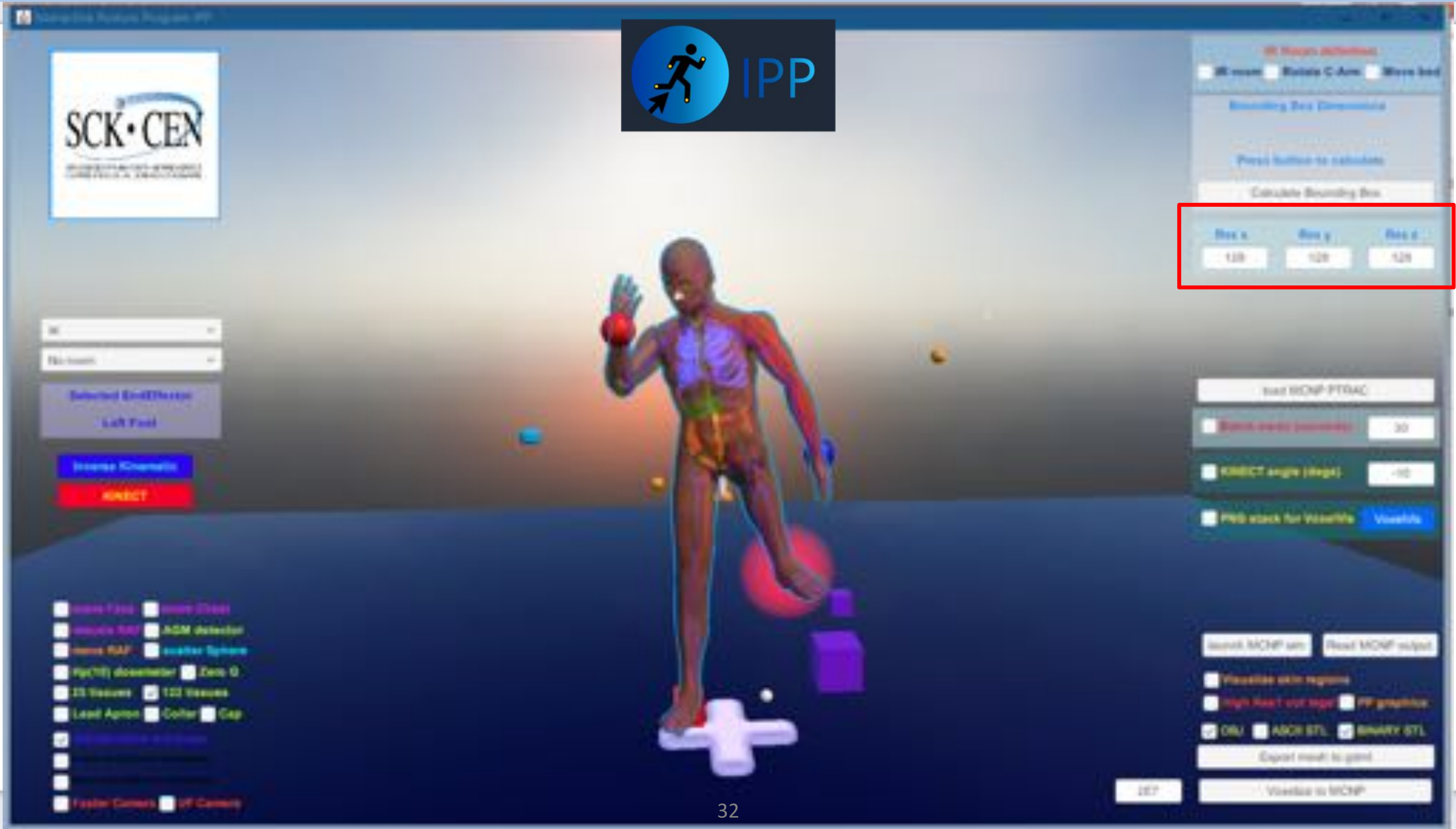

IPP
SCK•CEN
Inverse Kinematic
KINECT
Calculate Bounding Box

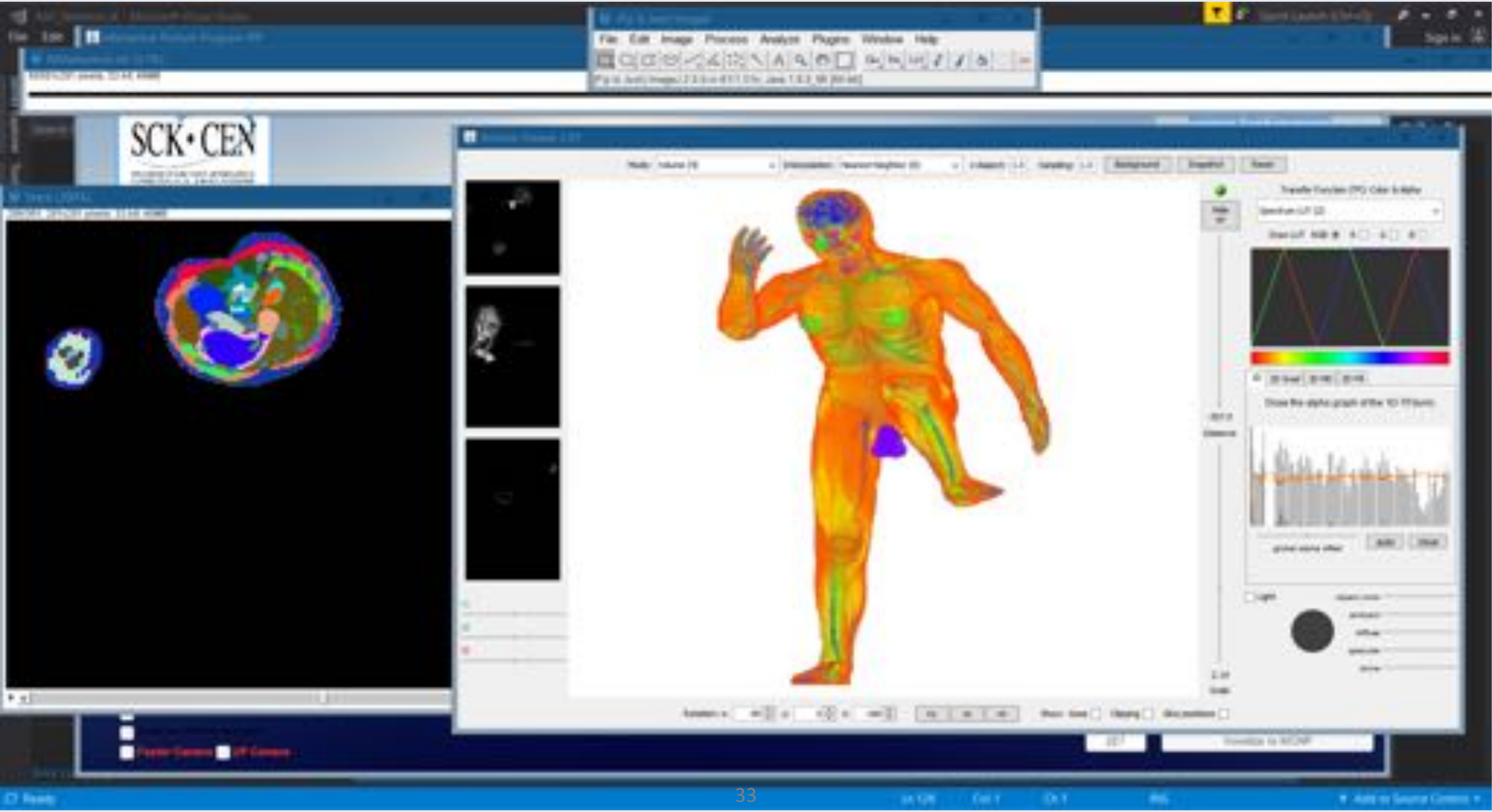

SCK•CEN
IPP
Inverse Kinematic
KINECT
128
128
128


IPP
SCK • CEN
KINECT
AGM detector
Calculate Bounding Box

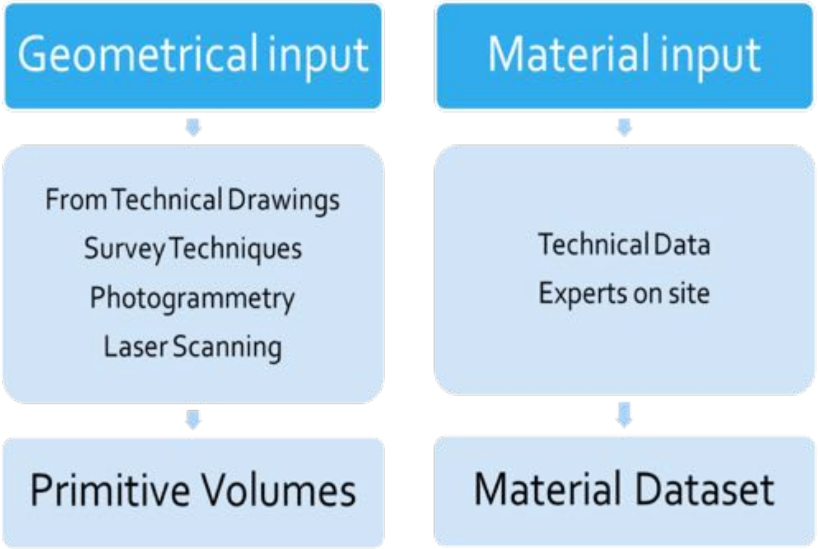

SCK•CEN
IPP
Inverse Kinematic
KINECT

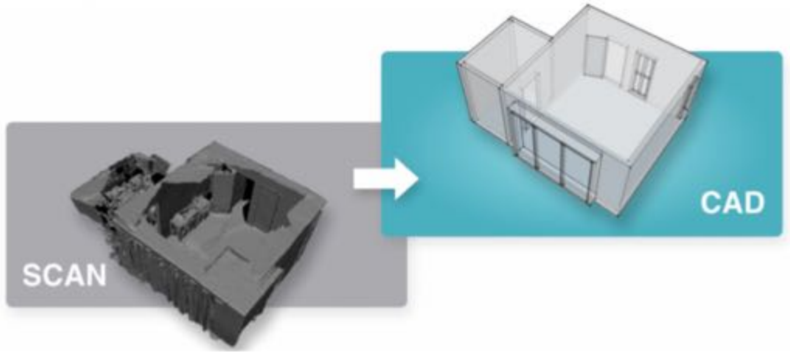
Function 2: voxelization

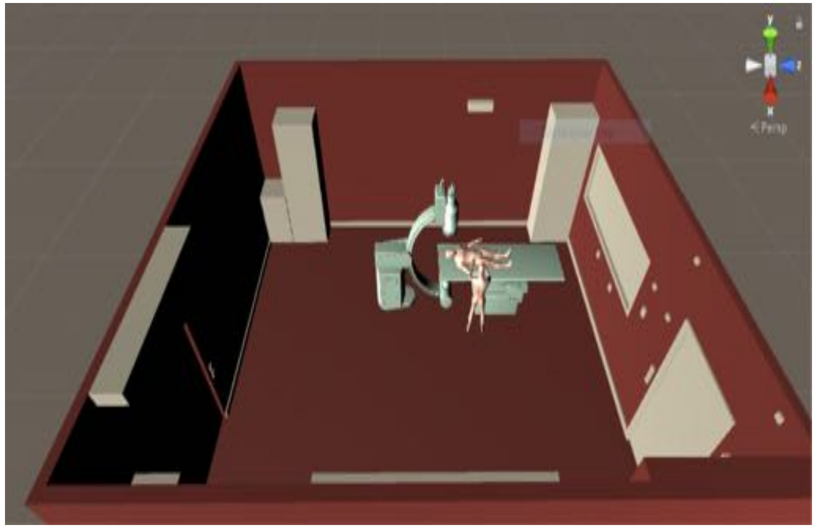

SCK•CEN
KINECT


SCK•CEN
File Edit Image Process Analyze Plugins Window Help

- Define of the workplace geometry for the calculations



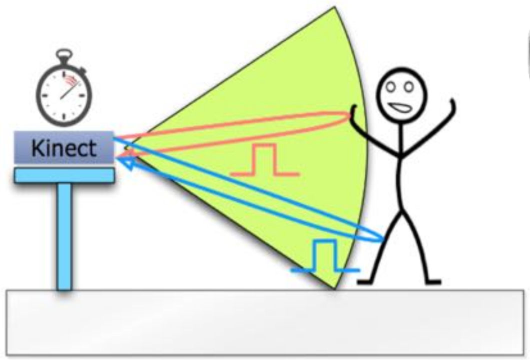




- Simple geometries can be easily modeled
- Complex geometries can be prepare by:
    - converting CAD files to different formats
    - by scanning of the workplace
- Modeling and tracking of important moving objects (shielding) is also needed

Staff Motion Tracking

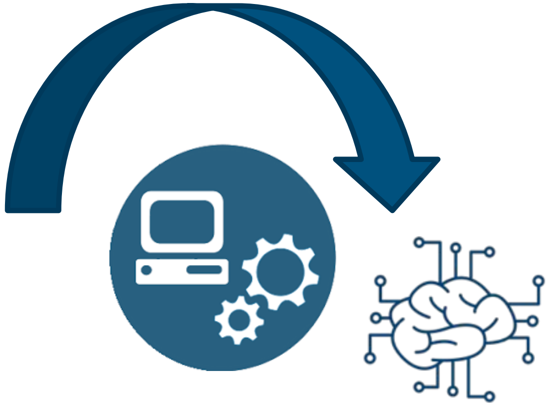
- Markerless tracking based on computer vision
- **RGB-D** cameras: combine color information with per-pixel **depth** information
- Existed for years for high prices (~ $10k to $30k), **very cheap nowadays…**
- **Two technologies**: Structrued light & Time-of-Flight (ToF)
- **Microsoft® Kinect V2 .0**



Staff Motion Tracking

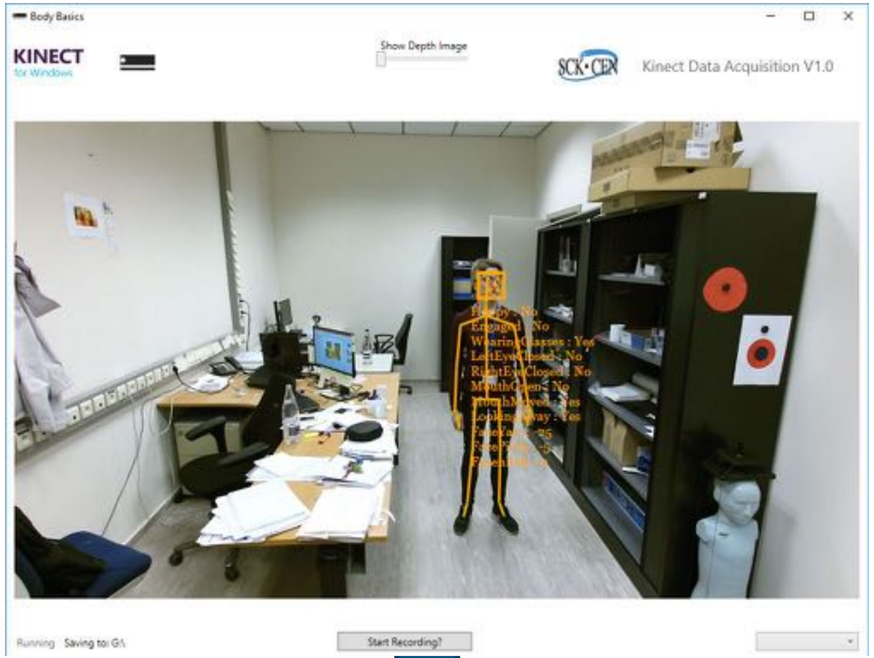
Tracking system based on single depth camera

Depth Image



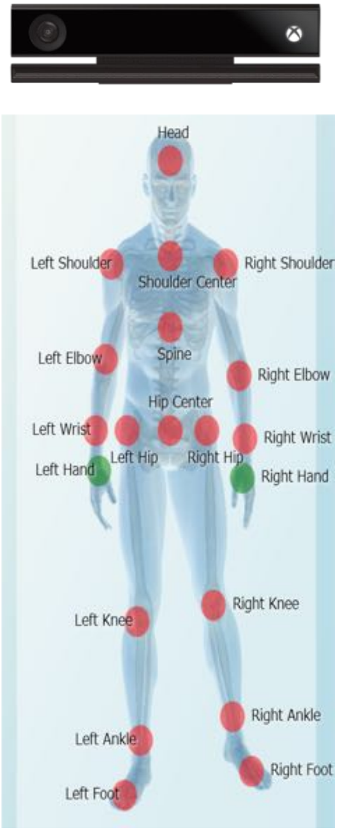
Real-time processing

Skeleton Tracking



Storing XYZ coordinates or send to a cloud

From Motion Tracking to Computational Phantom



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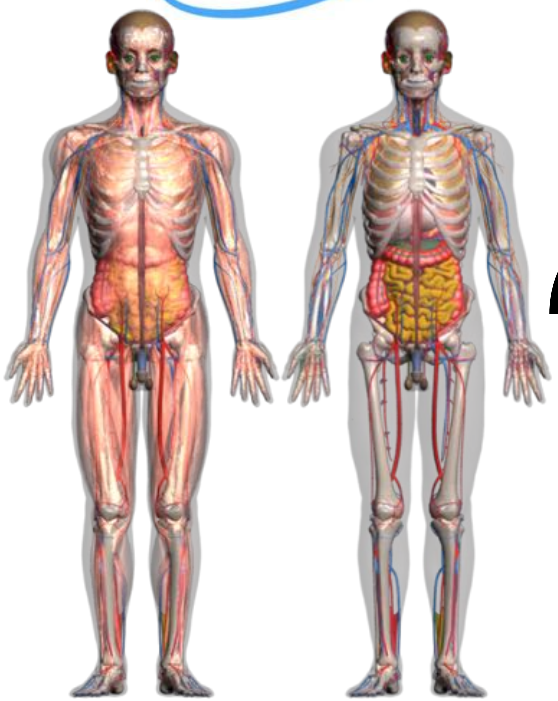
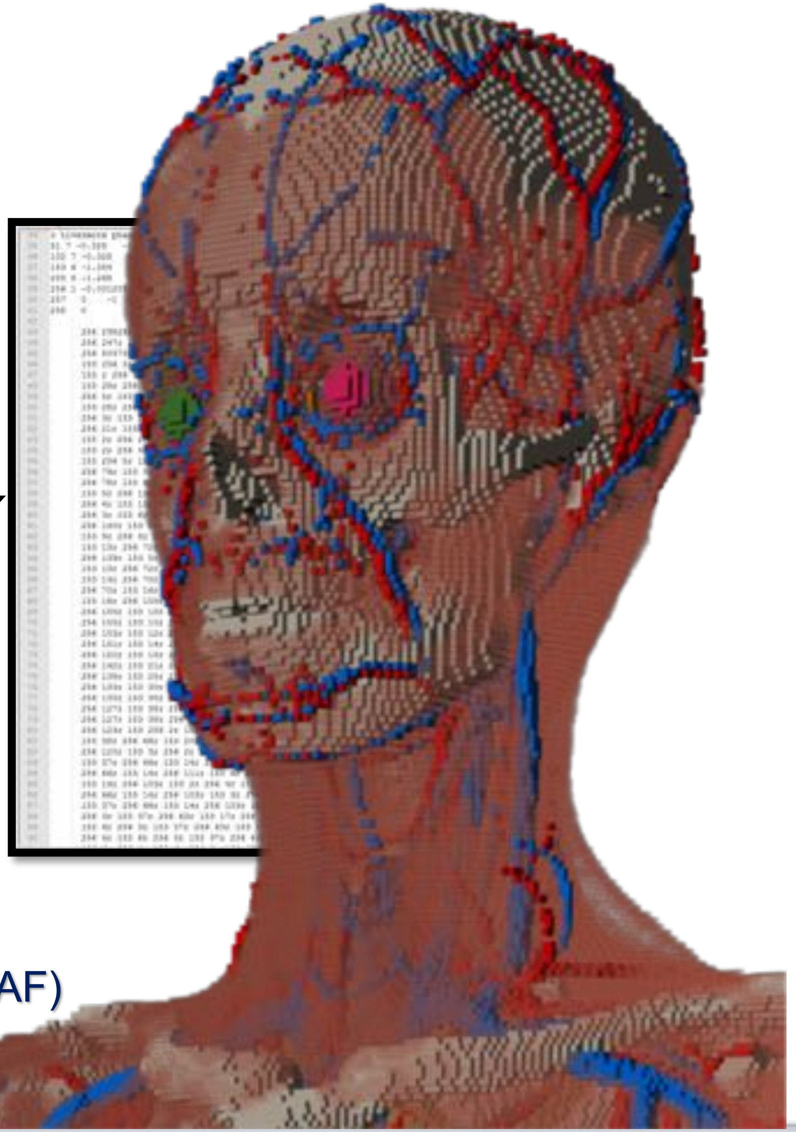
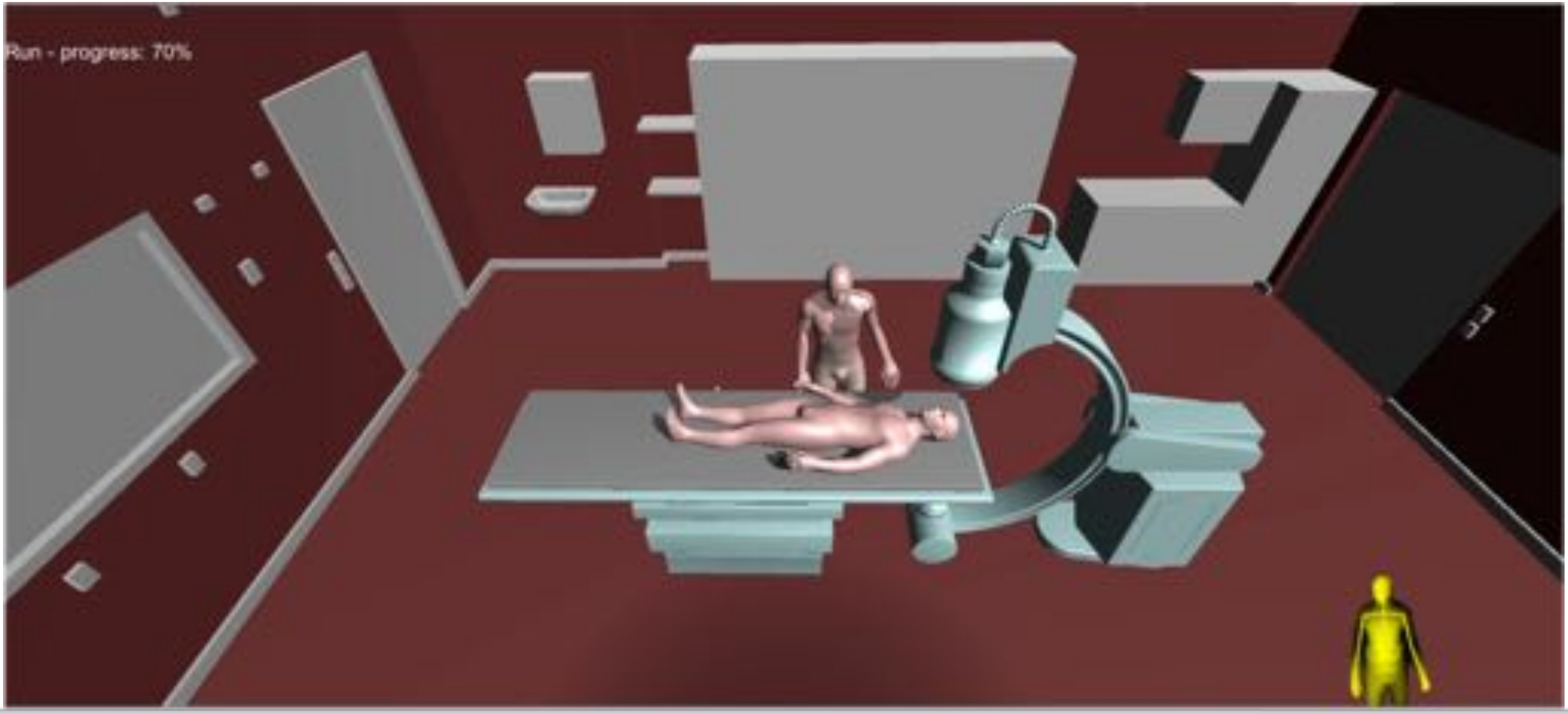




Realistic Anthropomorphic Flexible Phantom (RAF)

Animation of RAF phantom

Motion capture data applied to a **personalized skin** mesh



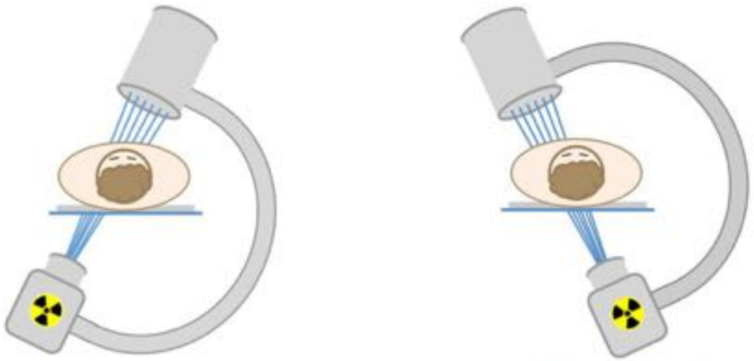
Radiological Input: Radiology Case

X-Ray spectrum

- Tube potential (kVp value)
- Dose at the reference point or DAP
- Added filtration
- Field size: collimated area (cm^2)
- Source-detector distance (cm)
- Patient's table position (x,y,z)
- Position of the source (x,y,z)

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

Patient's data:

- Gender
- Height, weight
- Anatomical region examined

Field Characterization: Neutron Workplaces

1. Use MC to calculate:
   - Fluence in cone angles of 45°, for each 45° horizontal plane
   - Fluence components in vertical cones

2. Convolve with tally multipliers within MCNP to give various angular components of effective dose

3. Normalize result in each cone to account for full 4π fluence-field

Scale results by source activity, and sum to give E rates…

If characterizing fluence-energy, can also calculate $H^*(10)$ map:

- Useful as a check
- Useful for confirmatory measurements with survey instruments
- Useful to provide scaling factor
- Useful as an alarm in time-dependent fields (e.g. with installed monitor)

Neutron Workplaces: Dose Mapping

- Avoid phantom problems by determining effective dose rate field map of modelled geometry in advance…

- Build map by characterizing fluence-energy-angle distribution of neutron and photon field as function of position ⇒


+

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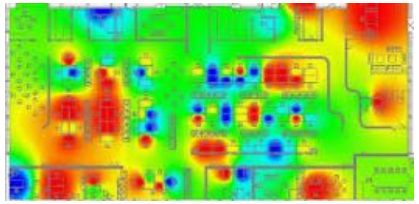

+ → $\int \dot{E}\, dt$


+

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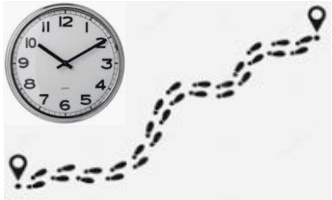


Simulations in IR

PENELOPE/PenEasyIR MCNPX	MC-GPU IR

MAKING SIMULATIONS FASTER

Use of different techniques to speed-up the simulation:

- *Geometries consisting of quadrics*
- *Use of a computer cluster (>40 CPU cores)*
- *Detection Forcing (variance reduction) technique:*
  - *Photon Fluence Point tally*

Photon Fluence Point tally:

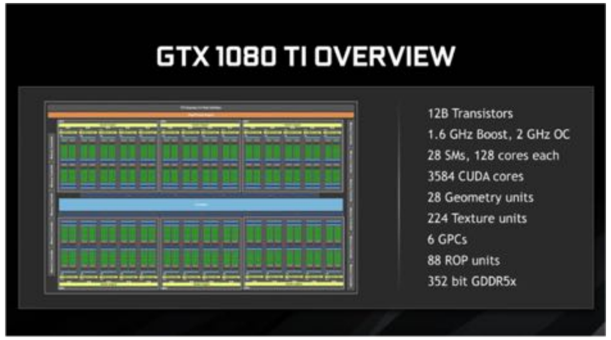
- *This tally estimates the energy photon fluence spectrum at a detection point D*
- *Radiological protection quantities can be calculated by using the corresponding conversion coefficients*

Parallelization among several GPU cards:

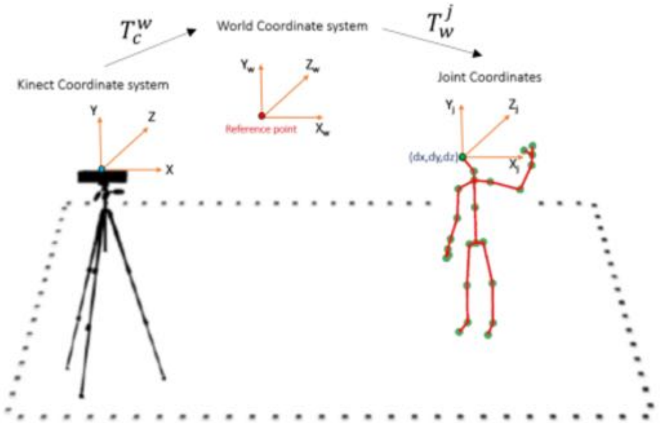
- *MPI implementation*

Computational time performance:

- *A set of functions have been developed to automatically set the optimal values for:*
  - *Number of blocks per kernel*
  - *Number of threads per block*
  - *Number of histories per thread to be simulated in the GPU*



FAST MONTE CARLO METHODS FOR INTERVENTIONAL RADIOLOGY:
ONLINE DOSIMETRY TOOLS



COMMON CHARACTERISTICS

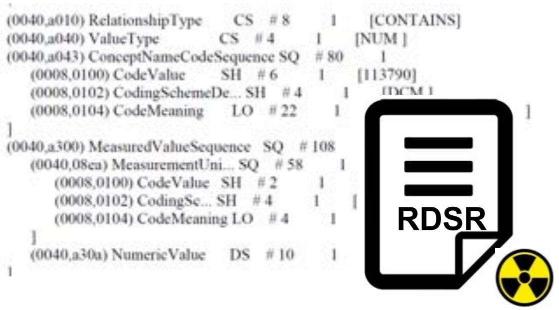
Tracking of the location and posture of medical staff

Information about the procedure

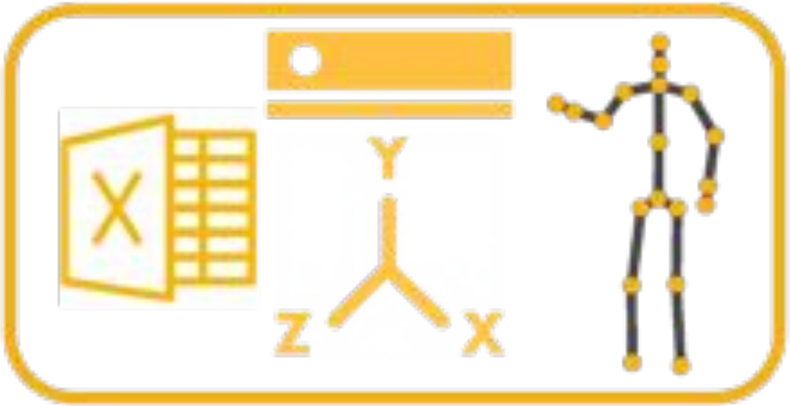
Input files

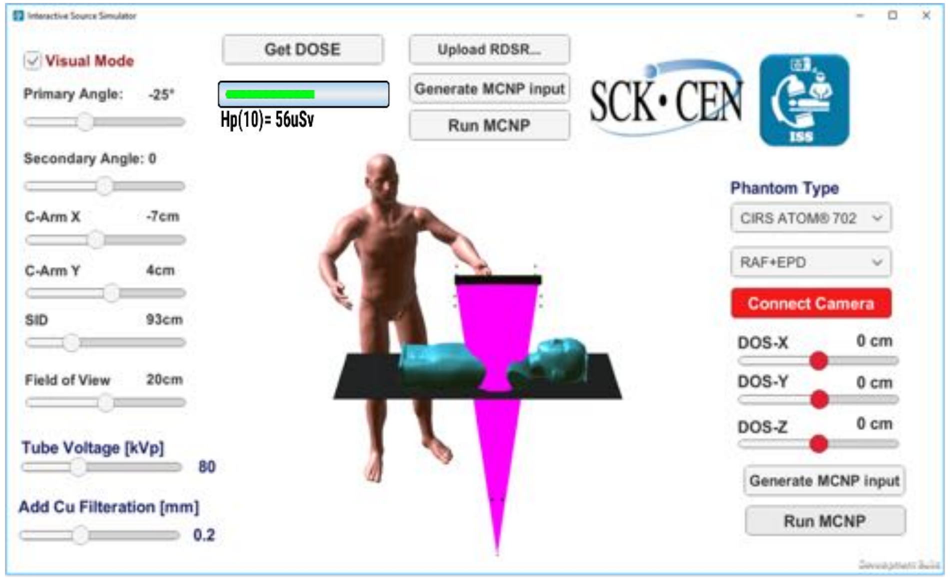
Cluster (CPU+GPU)

Results



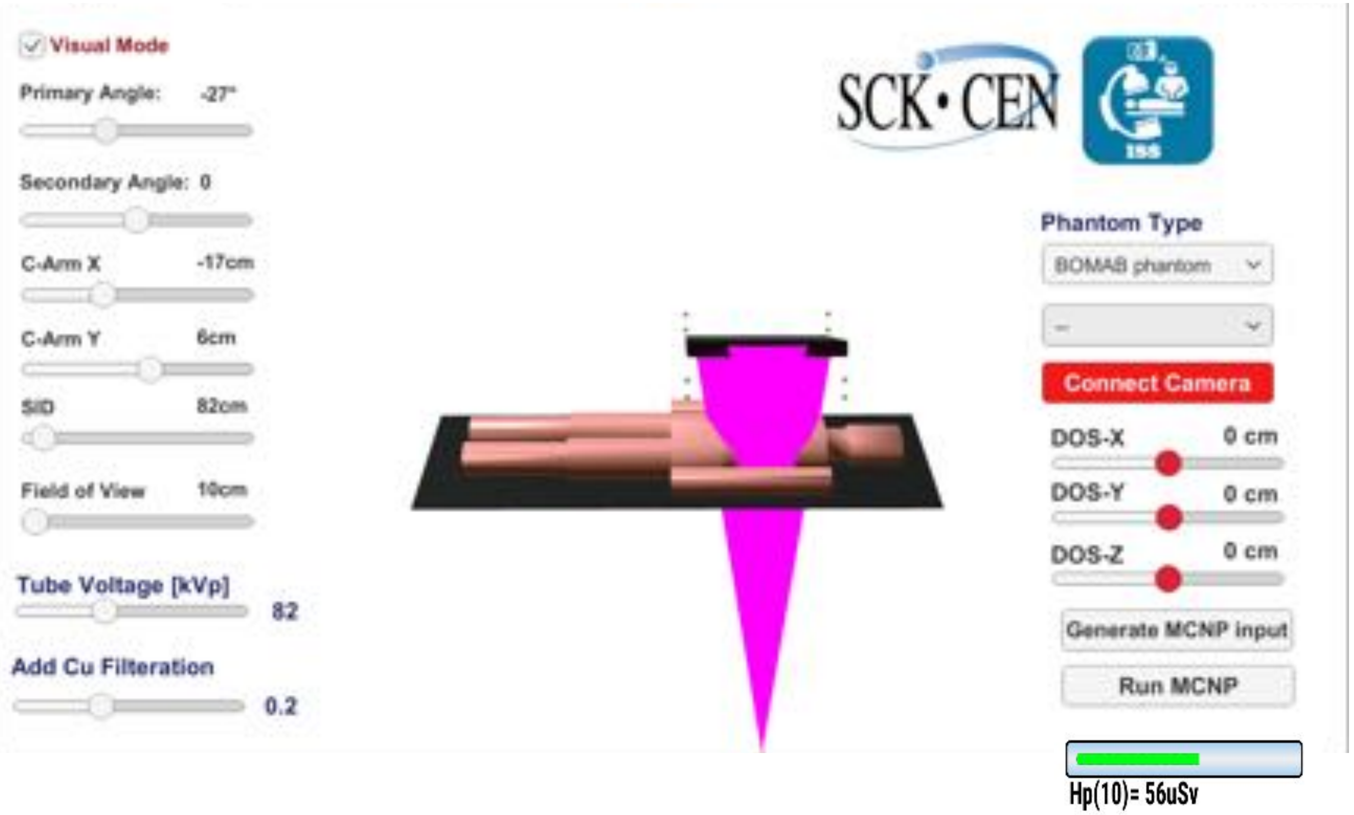
Example: MCNP Framework

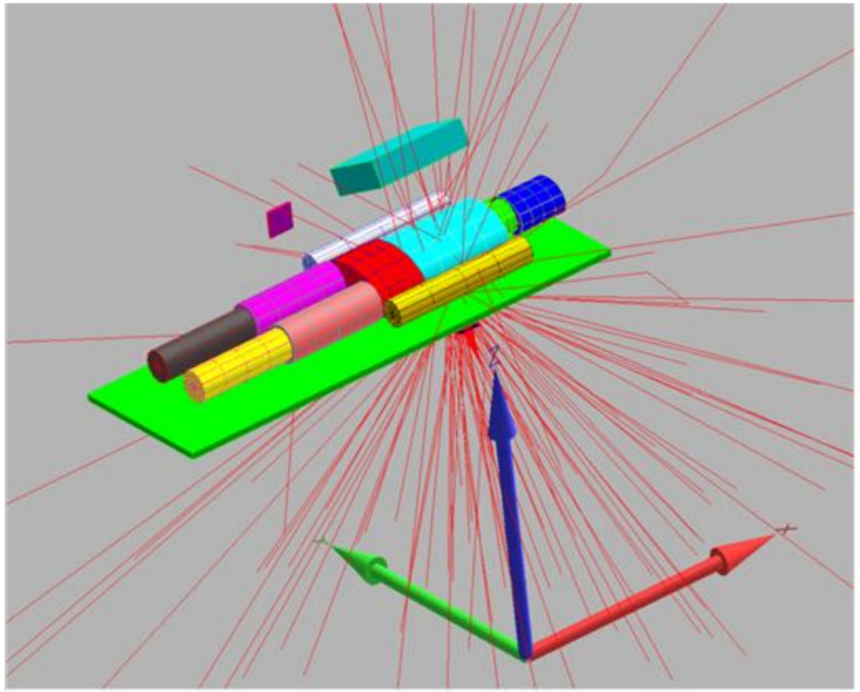




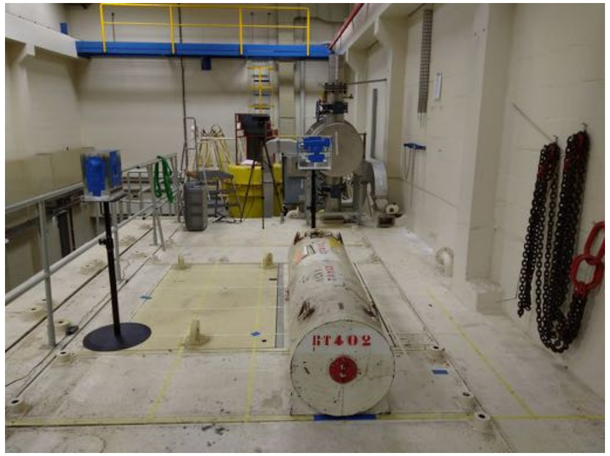
Interactive Source Simulator in IR

python NumPy SciPy pandas matplotlib unity Visual Studio

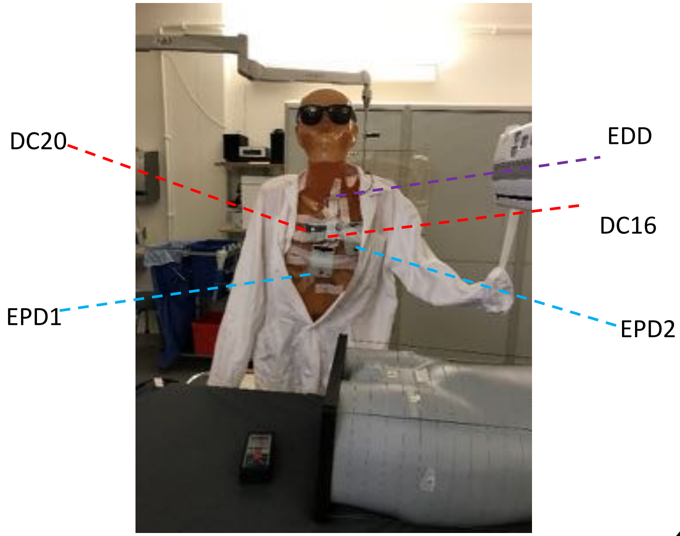

Visual Mode
Primary Angle: -27°
Secondary Angle: 0
C-Arm X -17cm
C-Arm Y 6cm
SID 82cm
Field of View 10cm
Tube Voltage [kVp] 82
Add Cu Filteration 0.2
SCK•CEN
Phantom Type
BOMAB phantom
Connect Camera
DOS-X 0 cm
DOS-Y 0 cm
DOS-Z 0 cm
Generate MCNP input
Run MCNP
Hp(10)= 56uSv



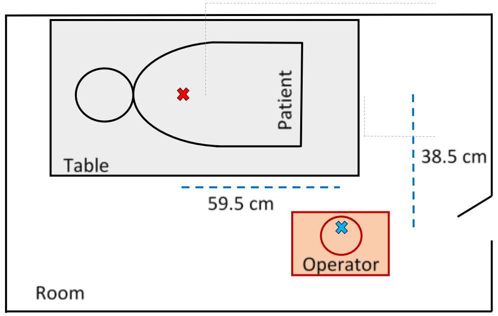
Validation



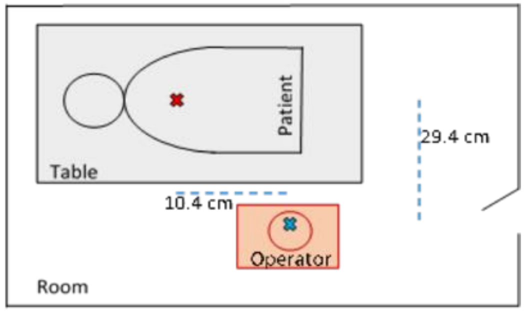
Controlled Experiment – SUS Malmö



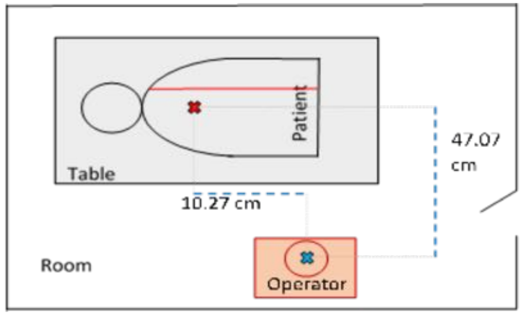
Experiment 1

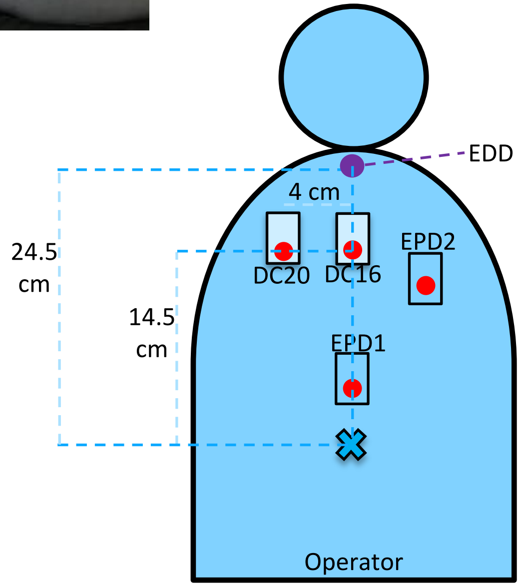


Experiment 2



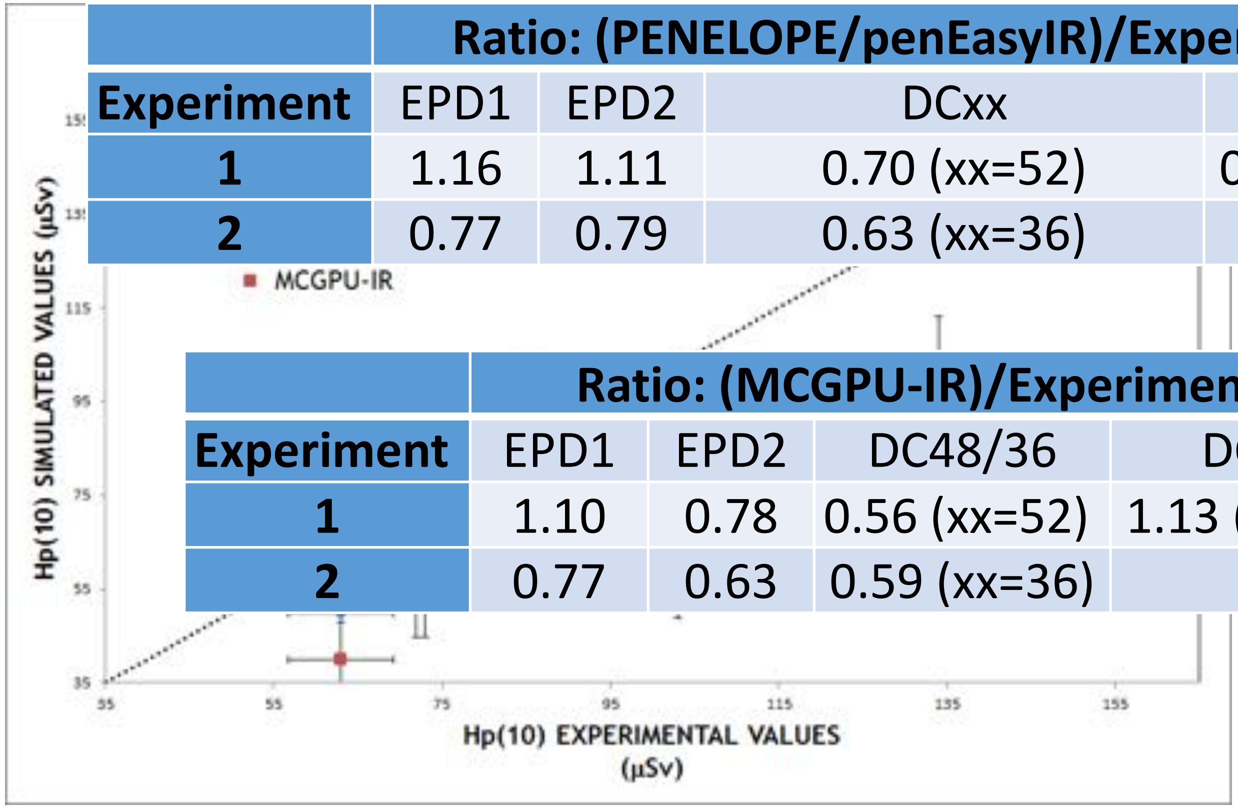
Experiment 3





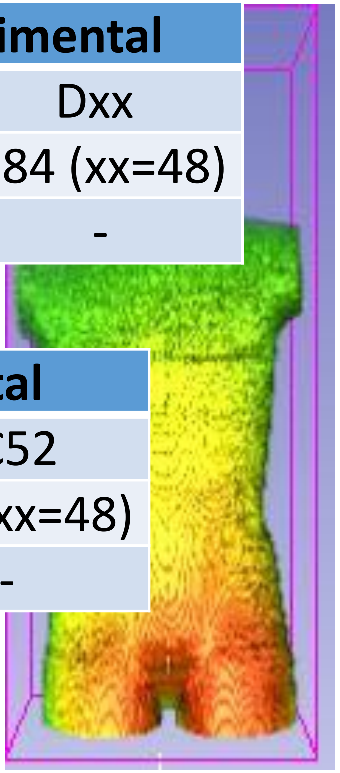
Controlled Experiment – SUS Malmö: results

RESULTS:OPERATOR DOSES



	Ratio: (PENELOPE/penEasyIR)/Experimental			
Experiment	EPD1	EPD2	DCxx	Dxx
1	1.16	1.11	0.70 (xx=52)	0.84 (xx=48)
2	0.77	0.79	0.63 (xx=36)	-

	Ratio: (MCGPU-IR)/Experimental			
Experiment	EPD1	EPD2	DC48/36	DC52
1	1.10	0.78	0.56 (xx=52)	1.13 (xx=48)
2	0.77	0.63	0.59 (xx=36)	-



Experimental measurements include the associated uncertainty (k=2)
Monte Carlo data includes both statistical uncertainty and the uncertainty related to normalization (k=2)

VUB UZ Universitair Ziekenhuis Brussel

Test at UZ-VUB - Brussels

Kinect 2

View from Kinect 1

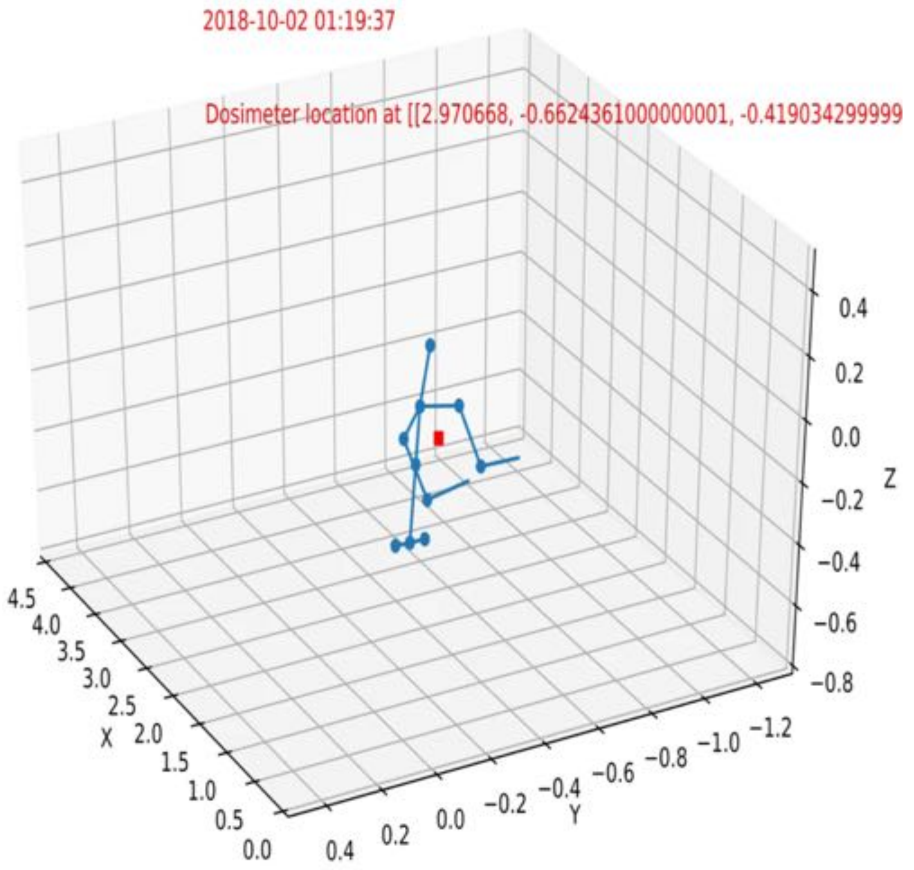
Test at UZ-VUB - Brussels

Test at UZ-VUB - Brussels

Test at CHU-Liège

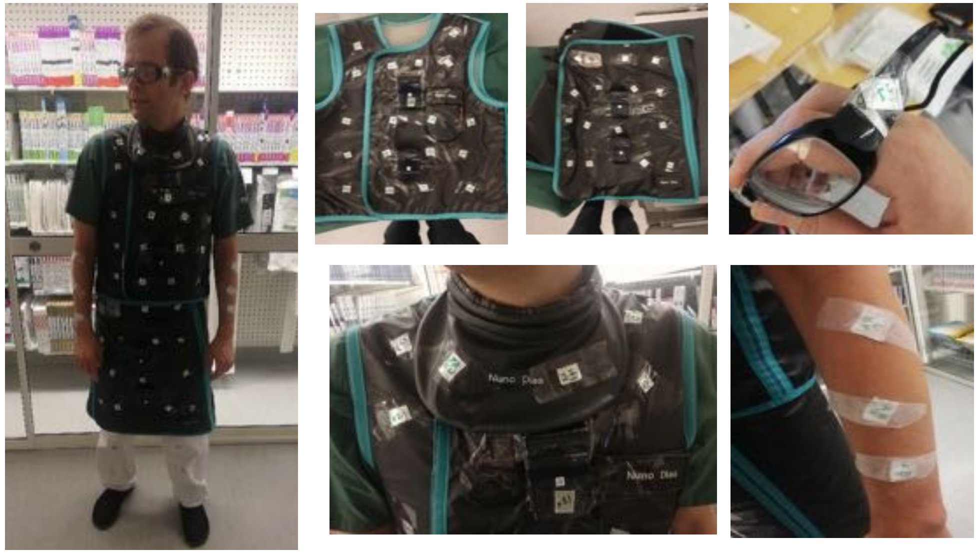
Test at CHU-Liège

Skeleton tracking of the first operator

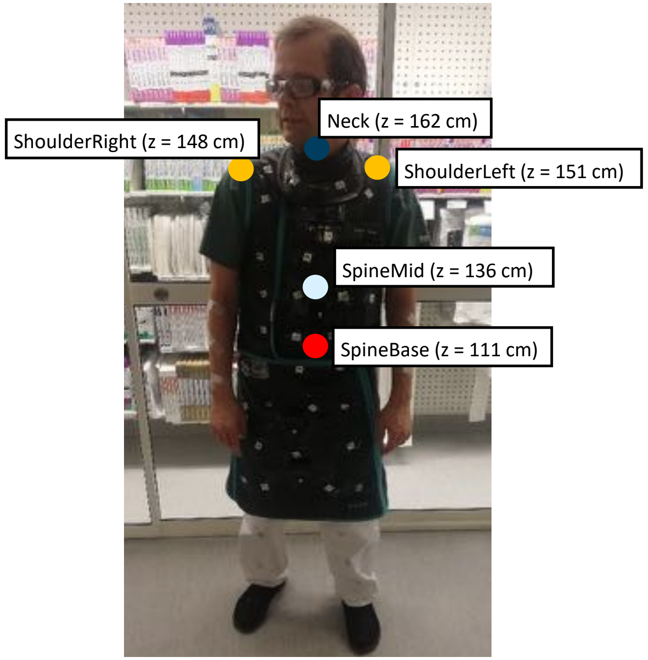


Clinical Test– SUS Malmö: results

Measurement points



Simulation points



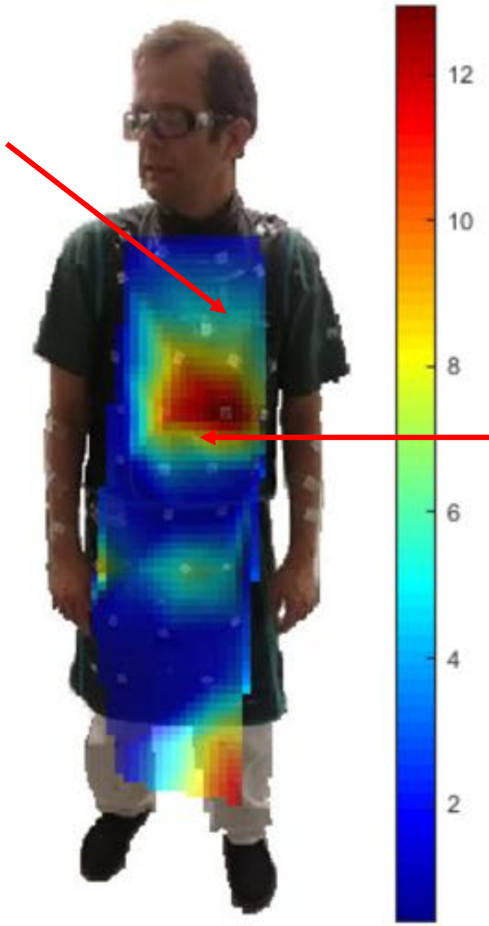
MCGPU-IR

- Four Mirion DMC 3000 and 35 NaCl pellets
- Renal artery angiography

Clinical Test– SUS Malmö: results

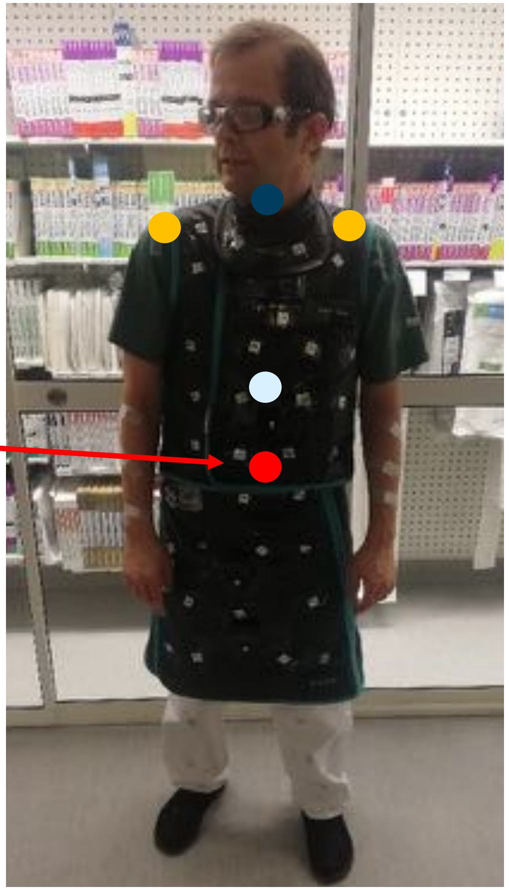
Heat map: NaCl pellets

Mirion DMC 3000
Hp(10) = 7 μSv



Mirion DMC 3000
Hp(10) = 30 μSv

Simulated
36.59 μSv

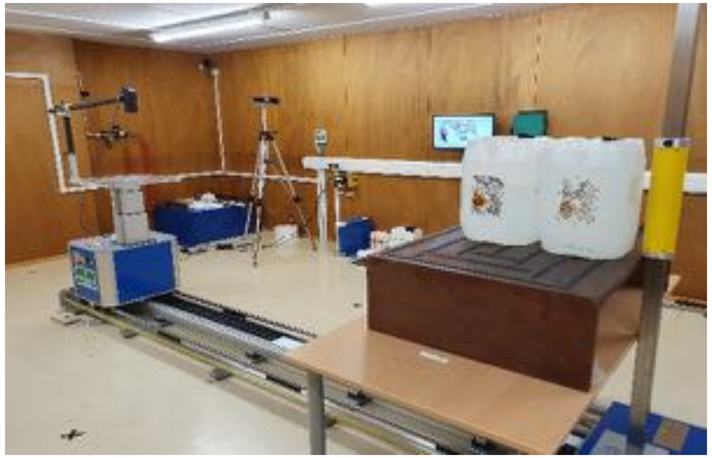


Clinical Validation: Results

Validation Case	Simulations Accumulated $H_p(10)$	Measured EPD Accumulated $H_p(10)$
Clinical Experiments		
EndoVasc CHU-Liège Case 4 (PCI)	38 µSv	23 µSv
EndoVasc SJH Case B	7.7 µSv	5 µSv
EndoVasc SJH Case C	68.3 µSv	55 µSv
EndoVasc SJH Case D (EVAR)	In progress	63 µSv
Cardiac SJH Case 1	388 µSv (without shielding)	31 µSv (with Shielding)

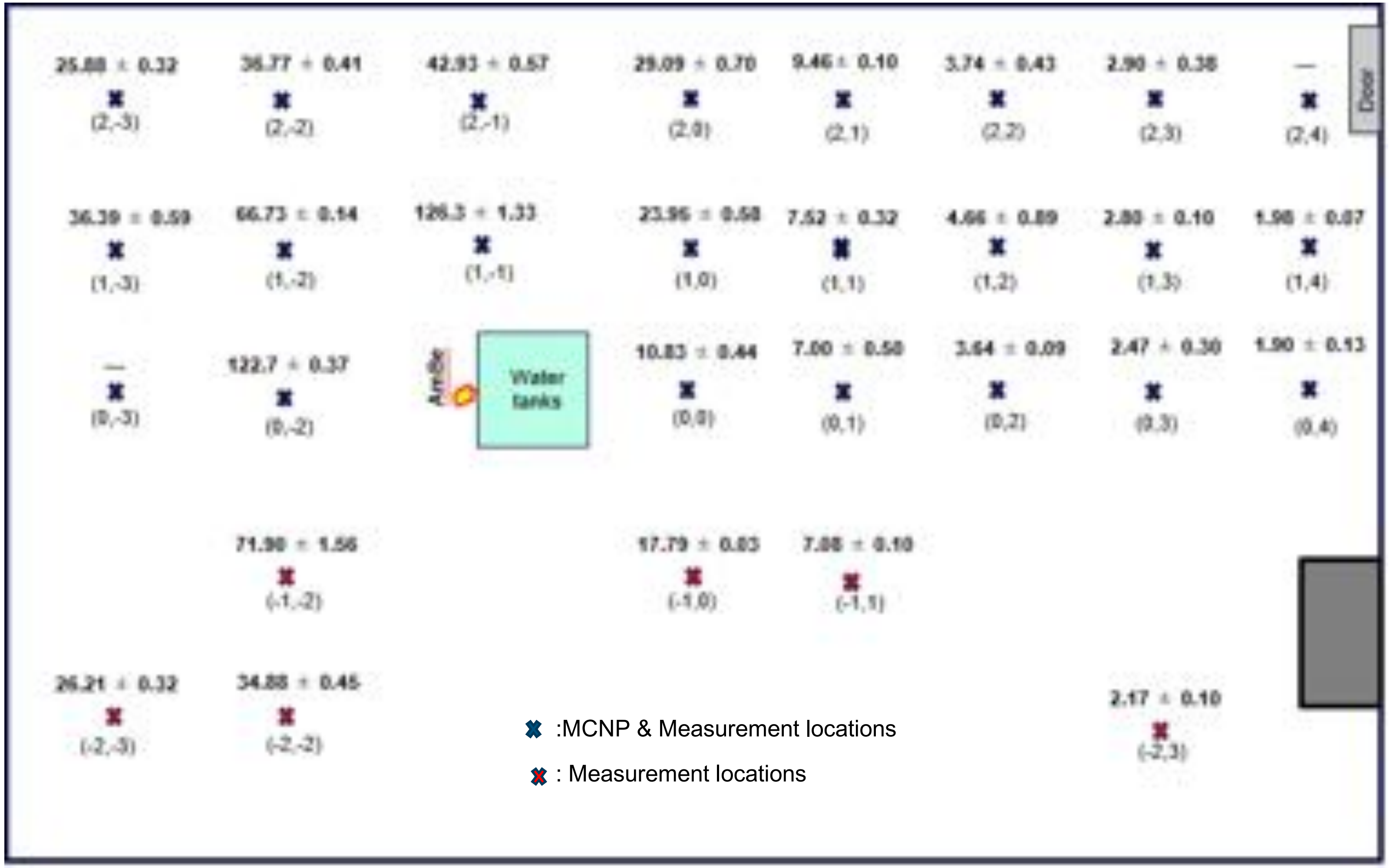
Neutron Case 1: Simulates Field PHE

- Kinect set-up in laboratory to track people in real-time…

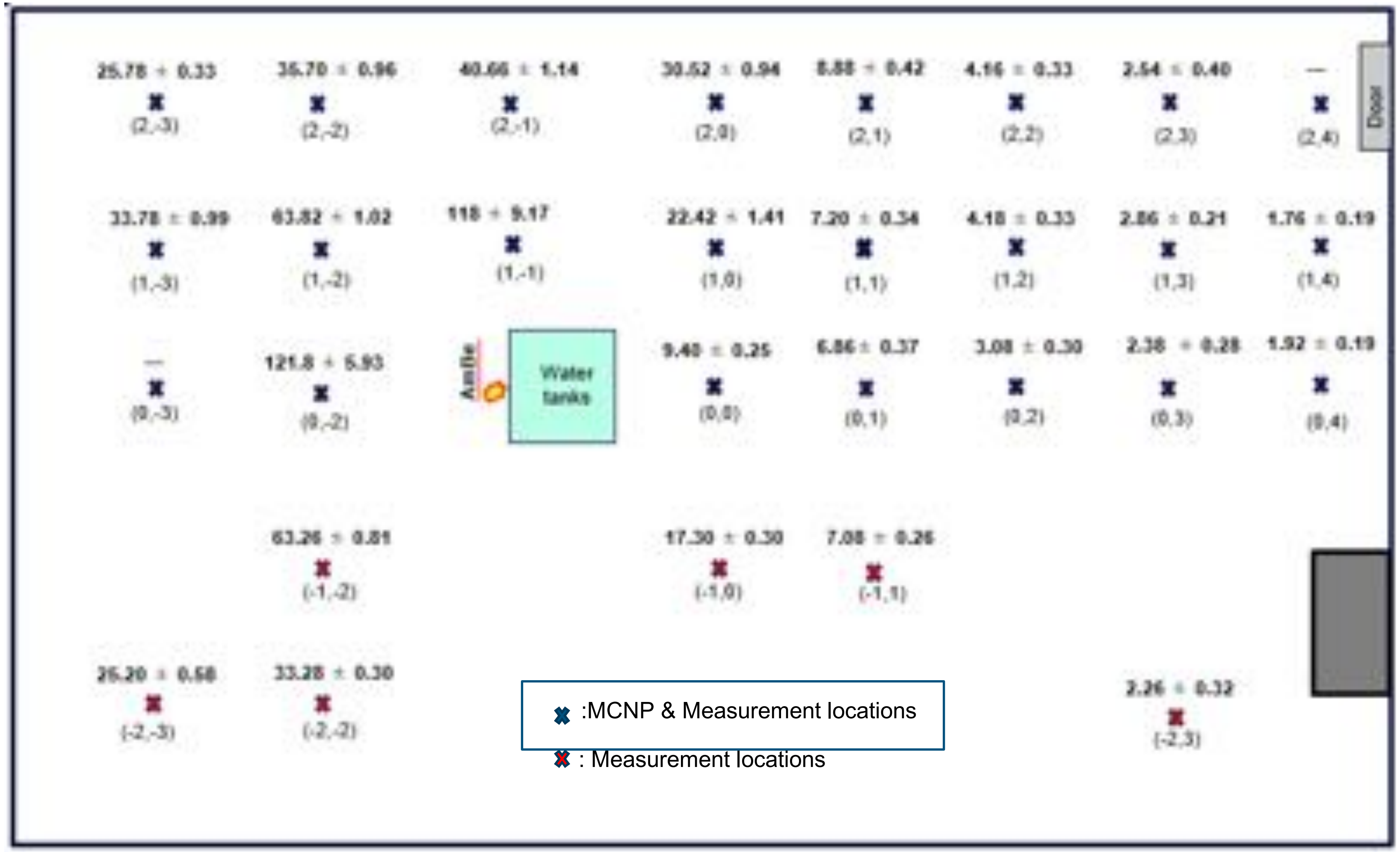


Images courtesy of PHE

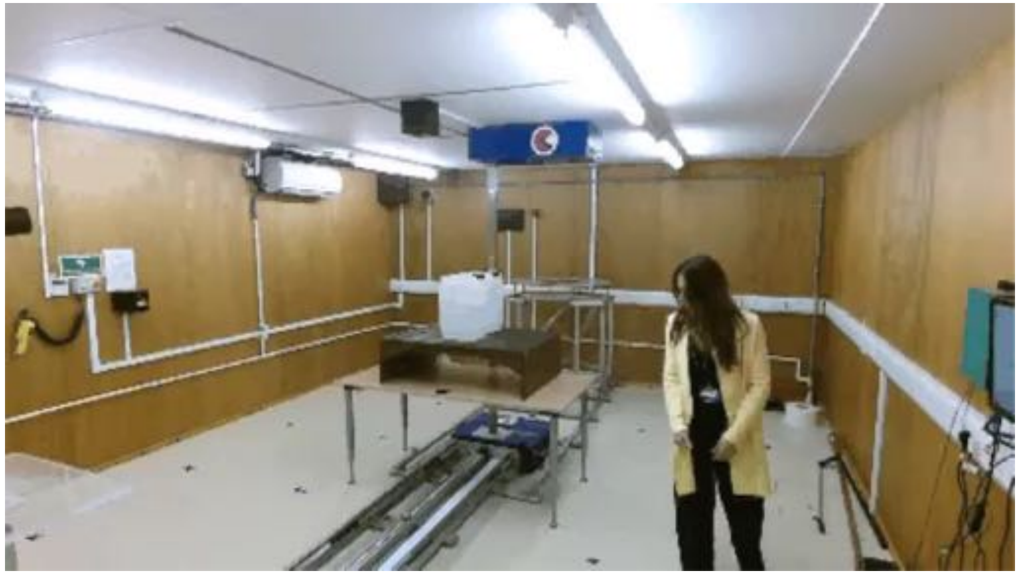
Neutron Dose Rate - GNU: µSv/h

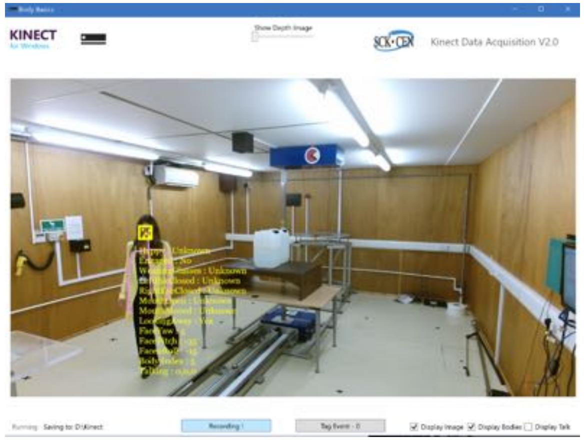


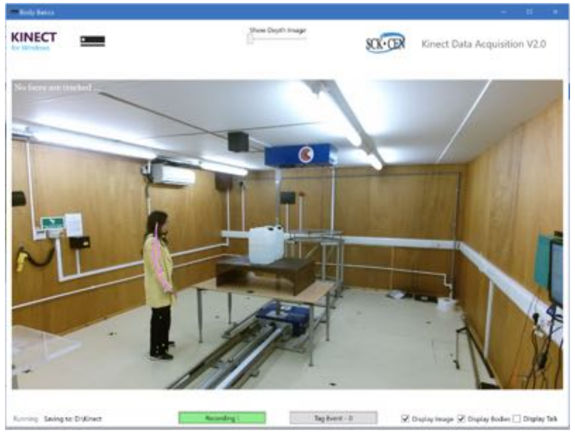
Neutron Dose Rate – T405: µSv/h



- Kinect set-up in laboratory to track people in real-time…







Tracking Output File

+ Dose Rate Map

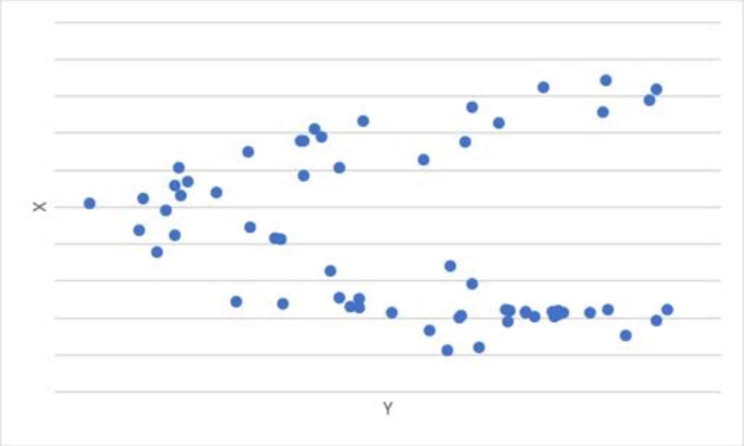
+ Dose Conversion Algorithm

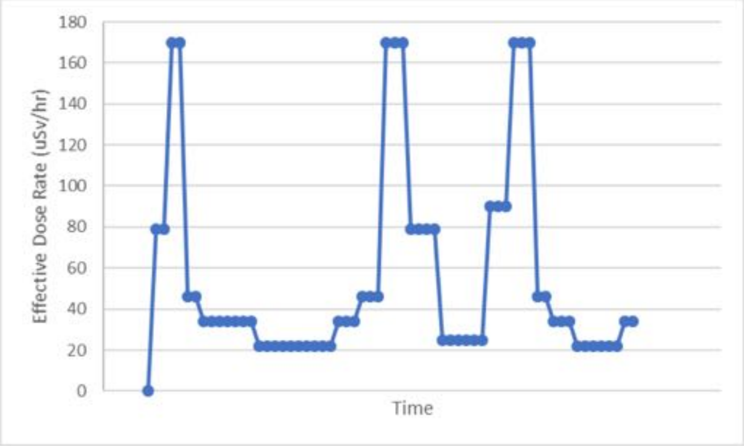
→ **Dose Data !**

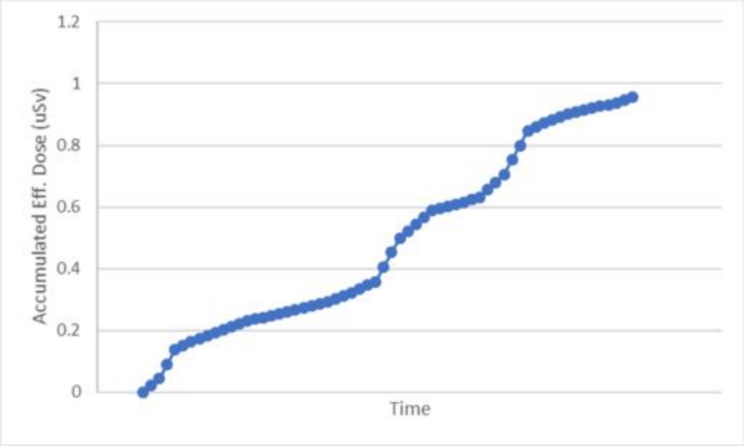
PODIUM Personal Online Dosimetry Using computational Methods

CONCERT European Joint Programme for the Integration of Radiation Protection Research

Simulated field: PHE



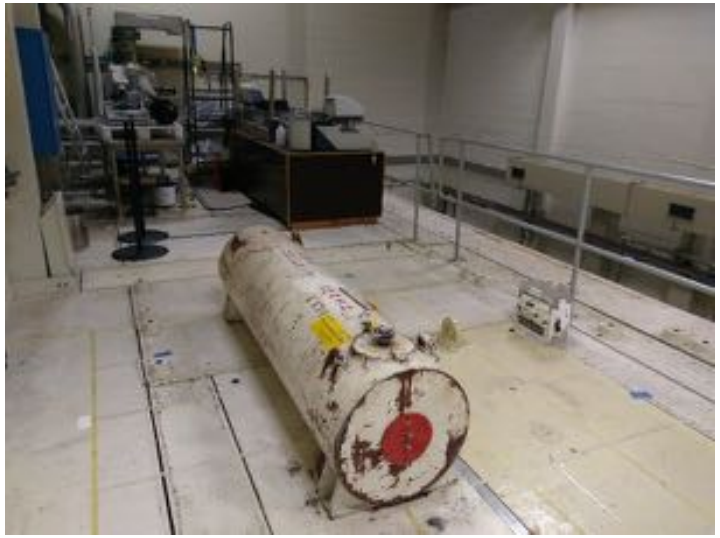


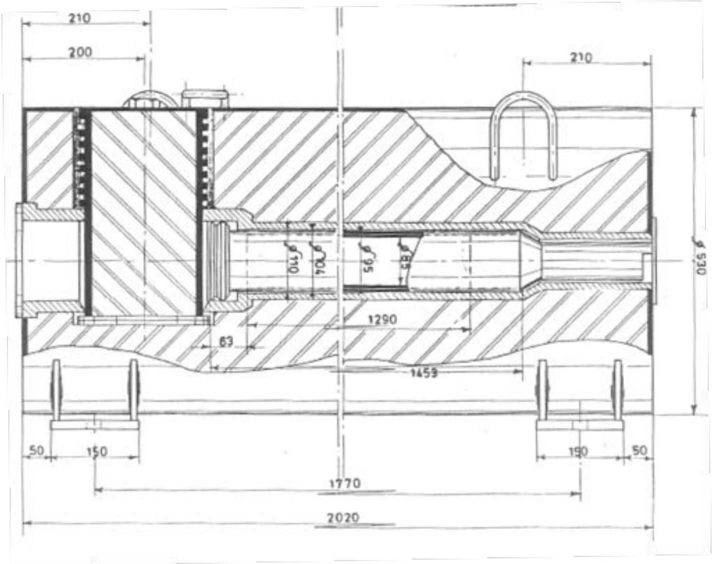


Dose Rate:	uSv/hr	1sd	uSv/hr	1sd	uSv/hr	1sd	
	(0,Y)		(100,Y)		(200,X)		
	0.56	0.01	0.61	0.01	1.59	0.03	(X,400)
	0.73	0.01	0.83	0.01	1.40	0.02	(X,300)
	1.13	0.02	1.44	0.02	2.91	0.03	(X,200)
	1.96	0.02	4.48	0.04	7.34	0.05	(X,100)
	4.32	0.03	25.86	0.09	30.20	0.10	(X,0)
	SOURCE		174.54	0.26	46.39	0.13	(X,-100)
	79.13	0.12	77.01	0.18	33.50	0.12	(X,-200)
	23.06	0.07	33.15	0.12	21.68	0.09	(X,-300)

Effective dose ~1μSv in ~1minute $\Rightarrow$ 60 μSv/hr average

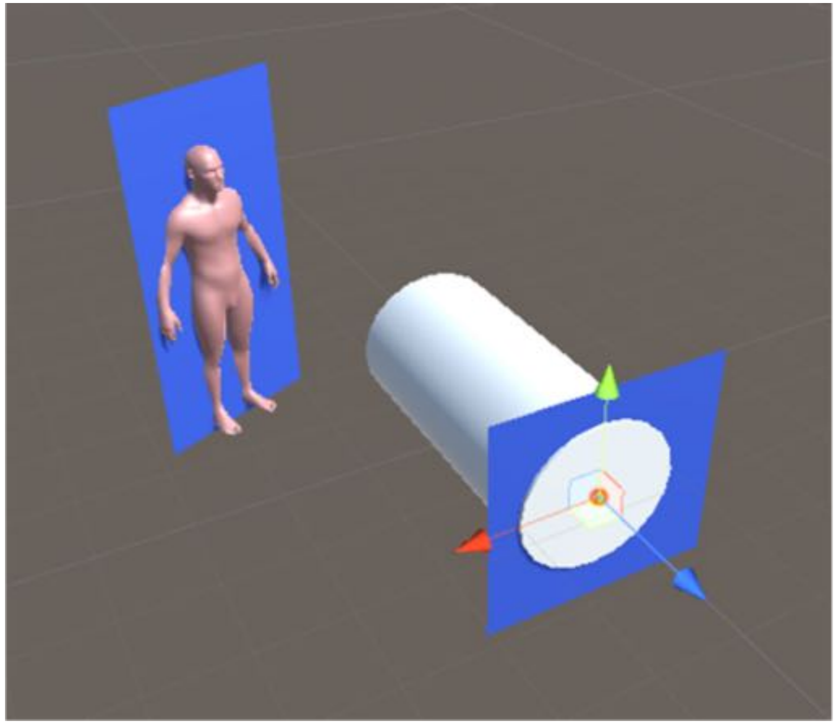
- Test in real workplace field (SCK-CEN) also performed (*full results available soon…*)





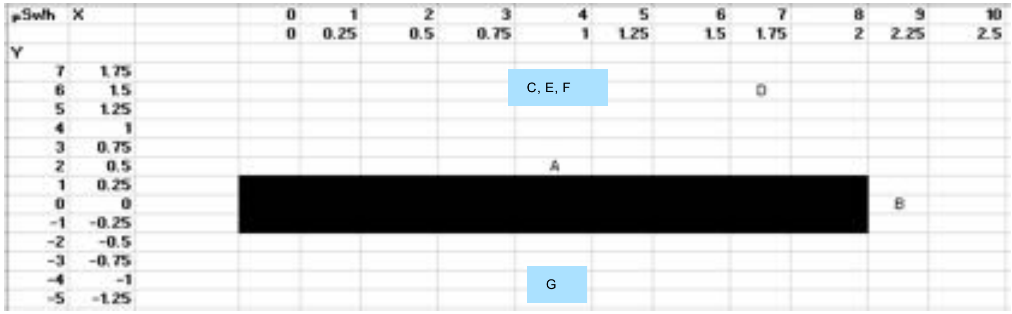
Particularly challenging: Precise source composition / geometry unknown!

Neutron fields: SCK-CEN



MCNP modelling again used to generate dose rate map

Use plausible guess spectra for source → *Iterative approach*



50×50cm² (*x*,*y*) grid, heights: 18, 55 and 125 cm

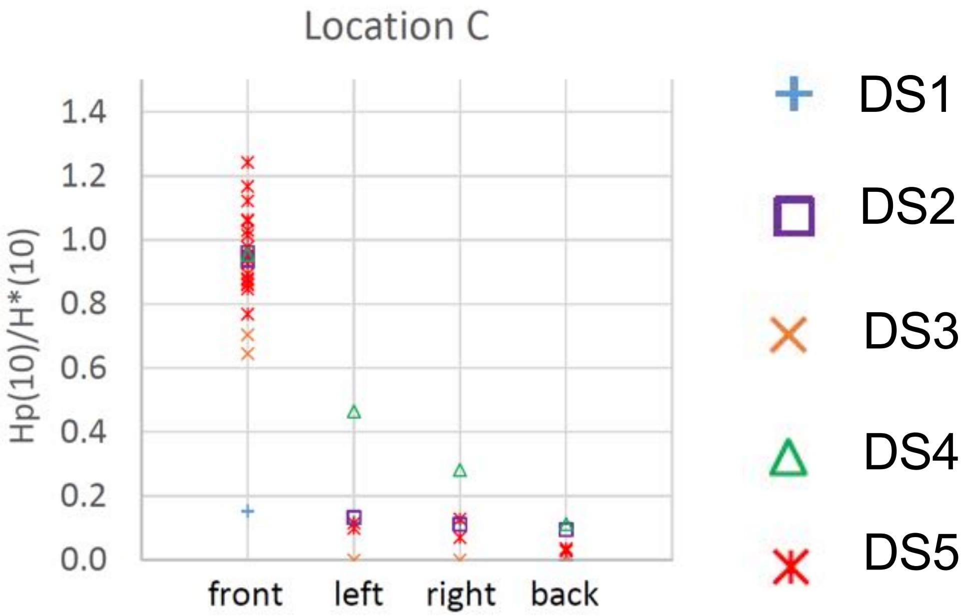
Neutron fields: SCK-CEN

Personal dosemeter response varies greatly with position…

Position C: Hp(10)/H*(10)

0.86	0.86	1.06	0.94
0.87	0.95	0.77	1.06
0.98	1.12	0.93	-
1.02	1.24	1.03	1.17

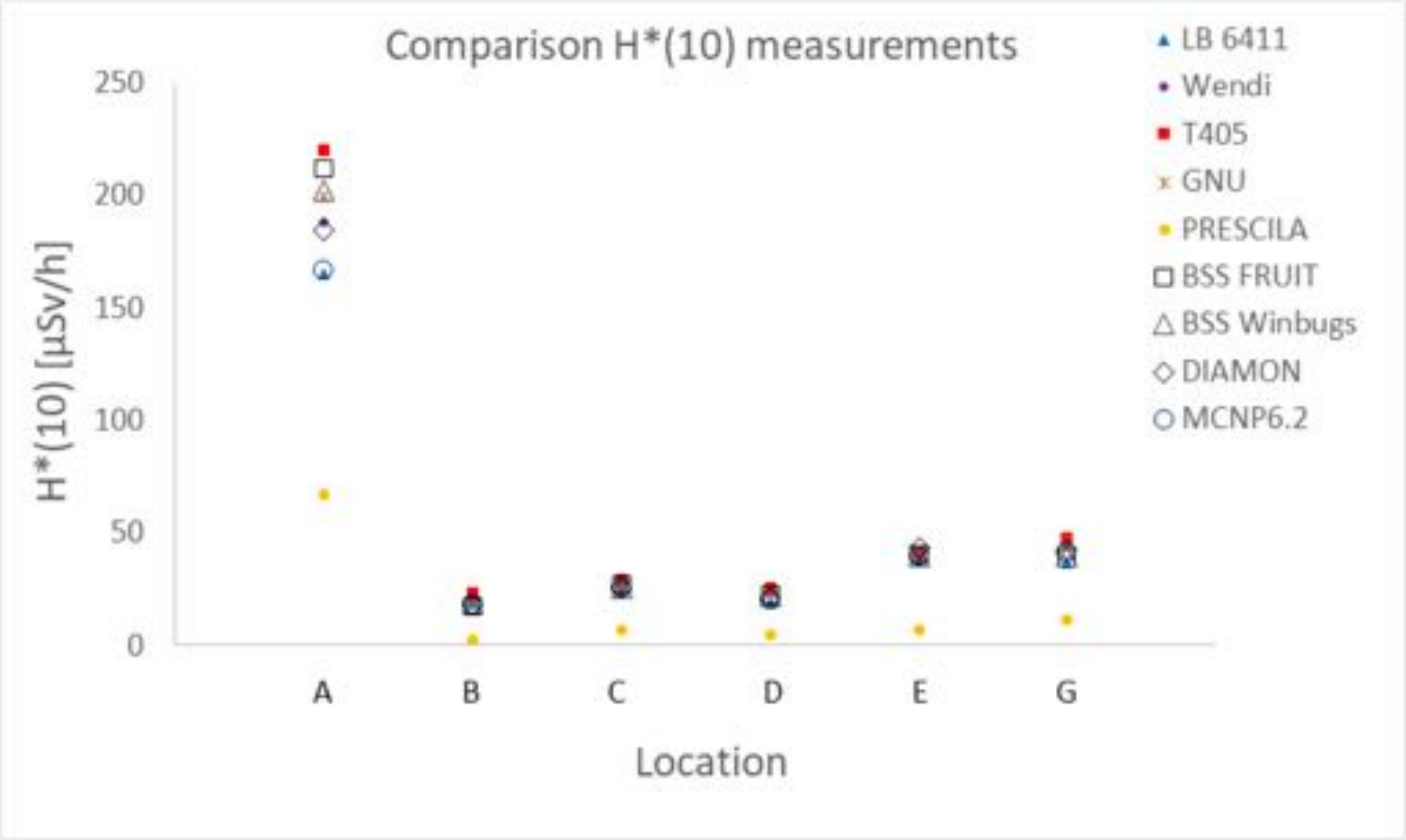
Average: 0.99
Stdev: 13%
Max/min: 1.4



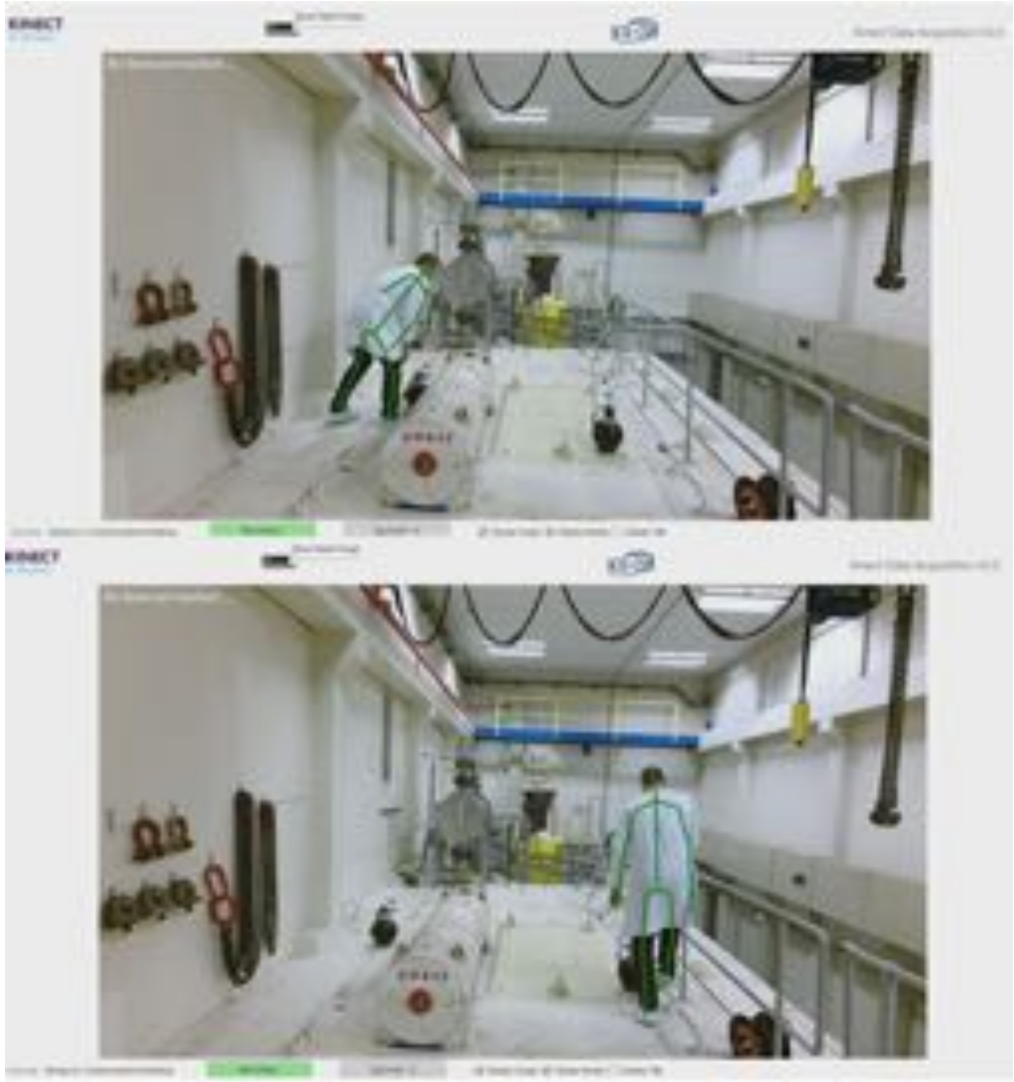
Neutron fields: SCK-CEN

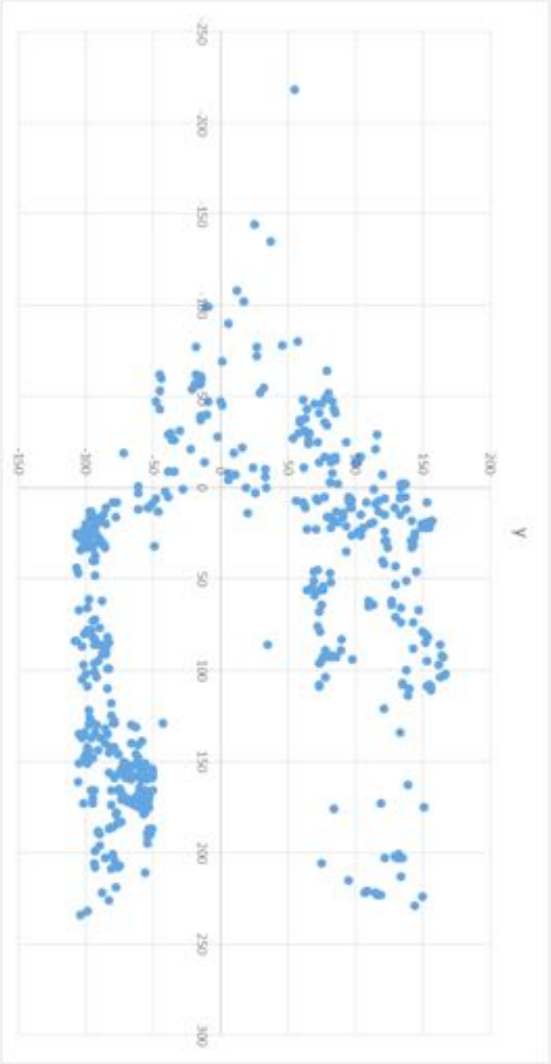
Early comparisons of Modelled vs. Measured data look promising…

- Guess spectrum approach for source successful!
- Iteration of source term likely to give even better agreement



Neutron fields: SCK-CEN



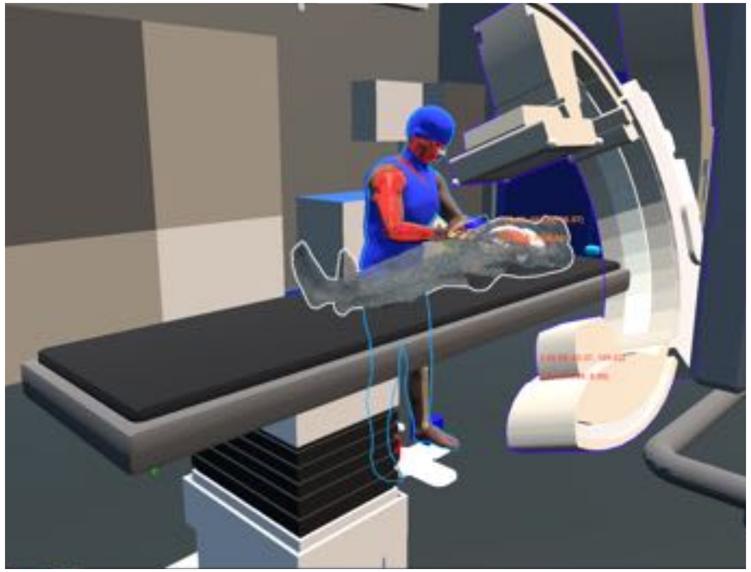


PODIUM Personal Online Dosimetry Using computational Methods

EUROPEAN JOINT PROGRAMME FOR THE INTEGRATION OF RADIATION PROTECTION RESEARCH CONCERT

Conclusion

- The feasibility study has been a success:
  - The technology is available for:
    - Tracking people to be monitored,
    - Calculating doses fast (by look-up table / dose mapping or Monte-Carlo)
    - having detailed and personalized phantoms.
- Within **PODIUM** project, a **computational dosimetry system** was developed to overcome limitations of physical dosimeters in certain workplaces
- Preliminary **validation** results show the validity of the method in **interventional radiology** and some **neutron workplaces**
- Challenges:
    - Privacy, ethics, data protection and IT security
    - Complete automatic set-up.
    - to gain real-time position and dose information from X-ray machines



www.podium-concerth2020.eu

SCAN ME

PODIUM Personal Online Dosimetry Using computational Methods

CONCERT European Joint Programme for the Integration of Radiation Protection Research

Thank you for your attention

The PODIUM team

SCAN ME

https://podium-concerth2020.eu/

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SCK•CEN
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Centre d'Etude de l'Energie Nucléaire
Belgian Nuclear Research Centre

Stichting van Openbaar Nut
Fondation d'Utilité Publique
Foundation of Public Utility

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CENTRE D'ETUDE DE L'ENERGIE NUCLEAIRE