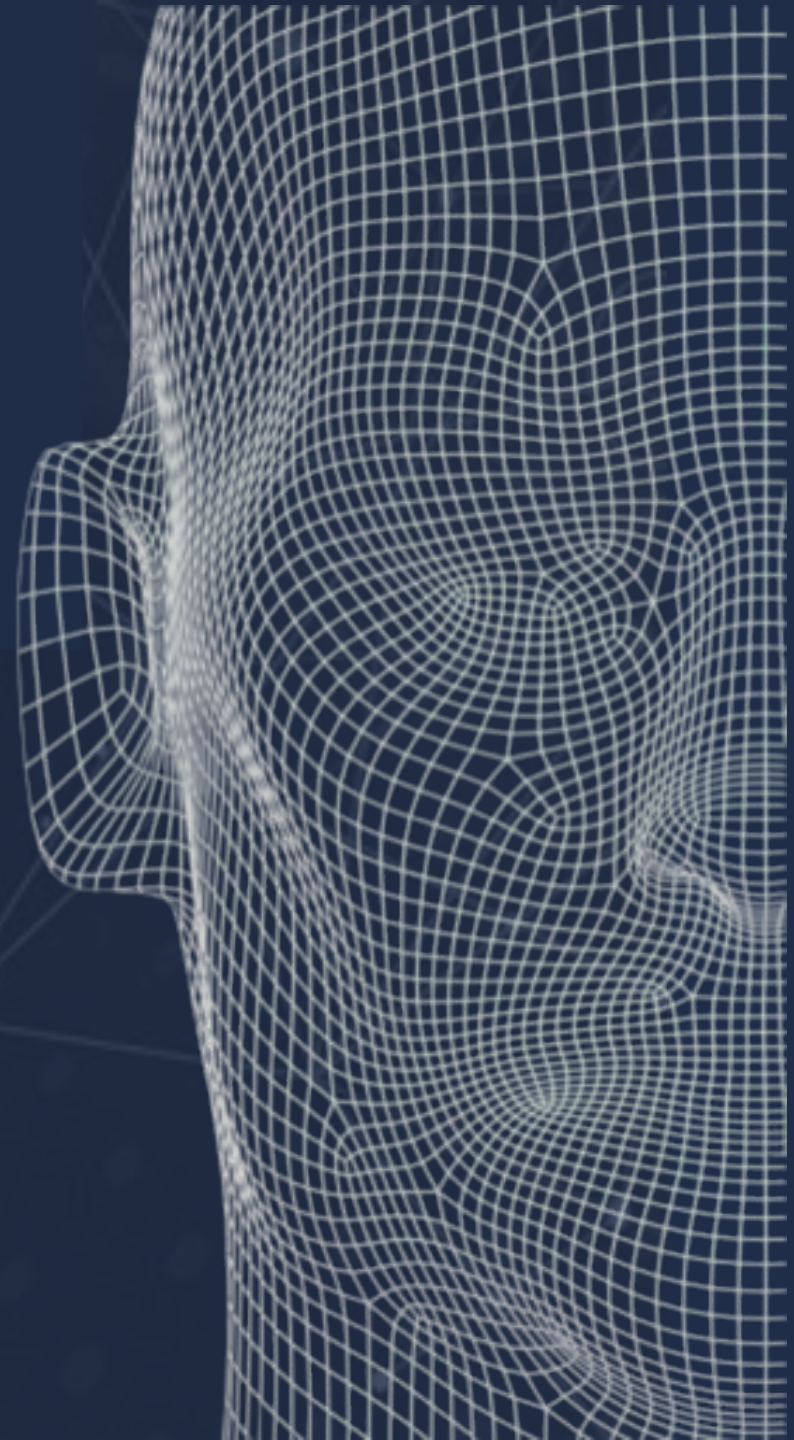




110011100011001001110111010100  
001101011101110110010000001110  
00001101101001011001111011000  
11100100011111010001001111001  
101000101011100101001001101000  
110001011110110101011010000010  
010111011100001011110010011110  
110001110011101111011010100010  
100001001101101001111100001011  
000010110001010100101001011001  
000010011101101100001111101000



# Personal Dose Computation Using Monitoring Systems and 3D Cameras

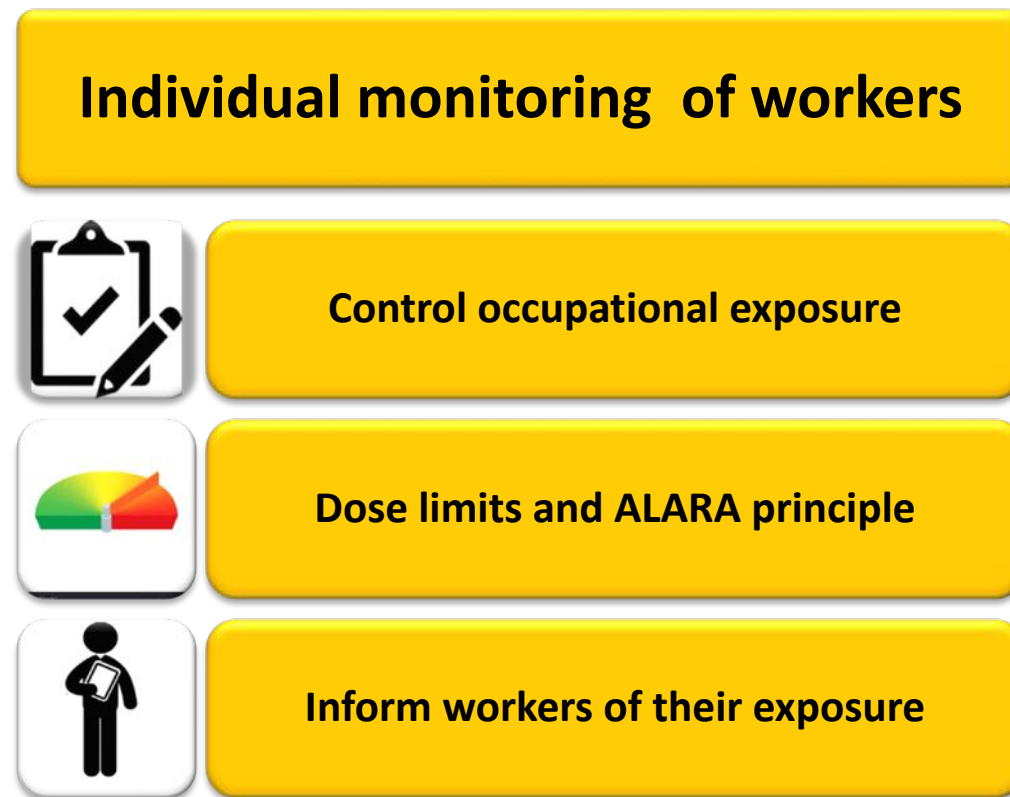
19<sup>th</sup> EAN Workshop: "Innovative ALARA Tools"

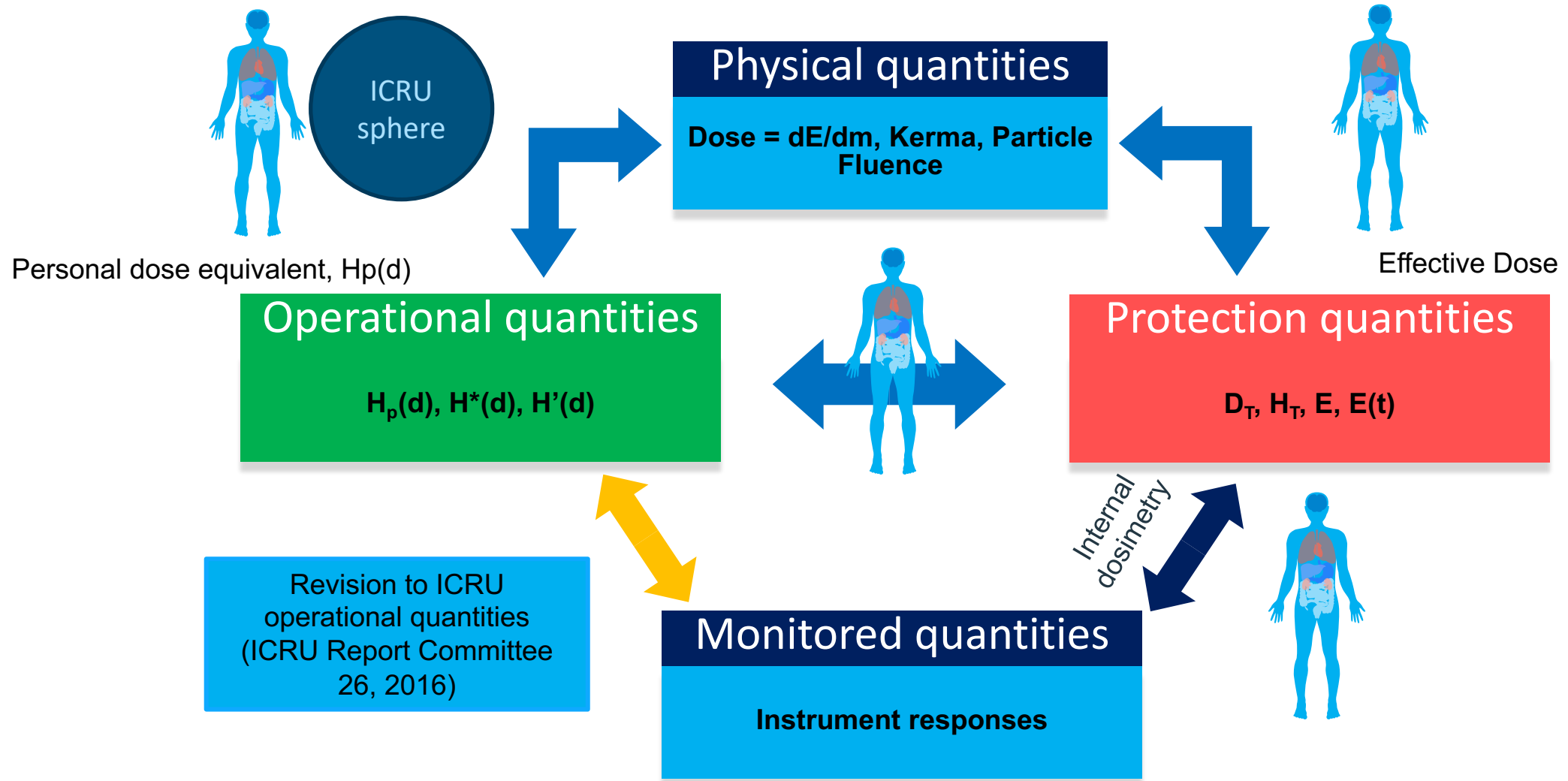
Athens, 2019

Mahmoud Abdelrahman, Pasquale Lombardo, Filip Vanhavere, and PODIUM team

# Framework for individual monitoring: why is dosimetry needed

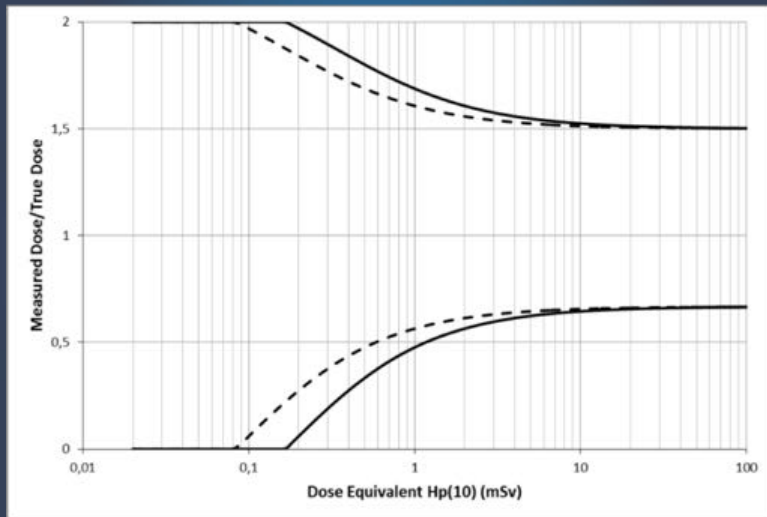
- Routine monitoring of the individual exposure of workers is an integral part of any radiation protection program





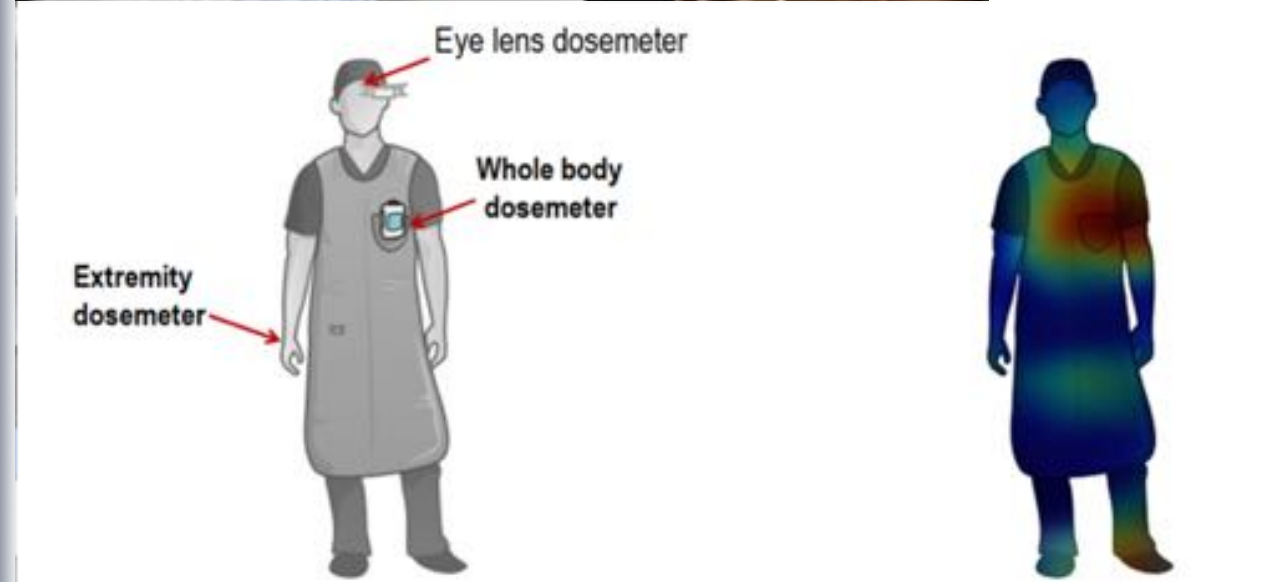
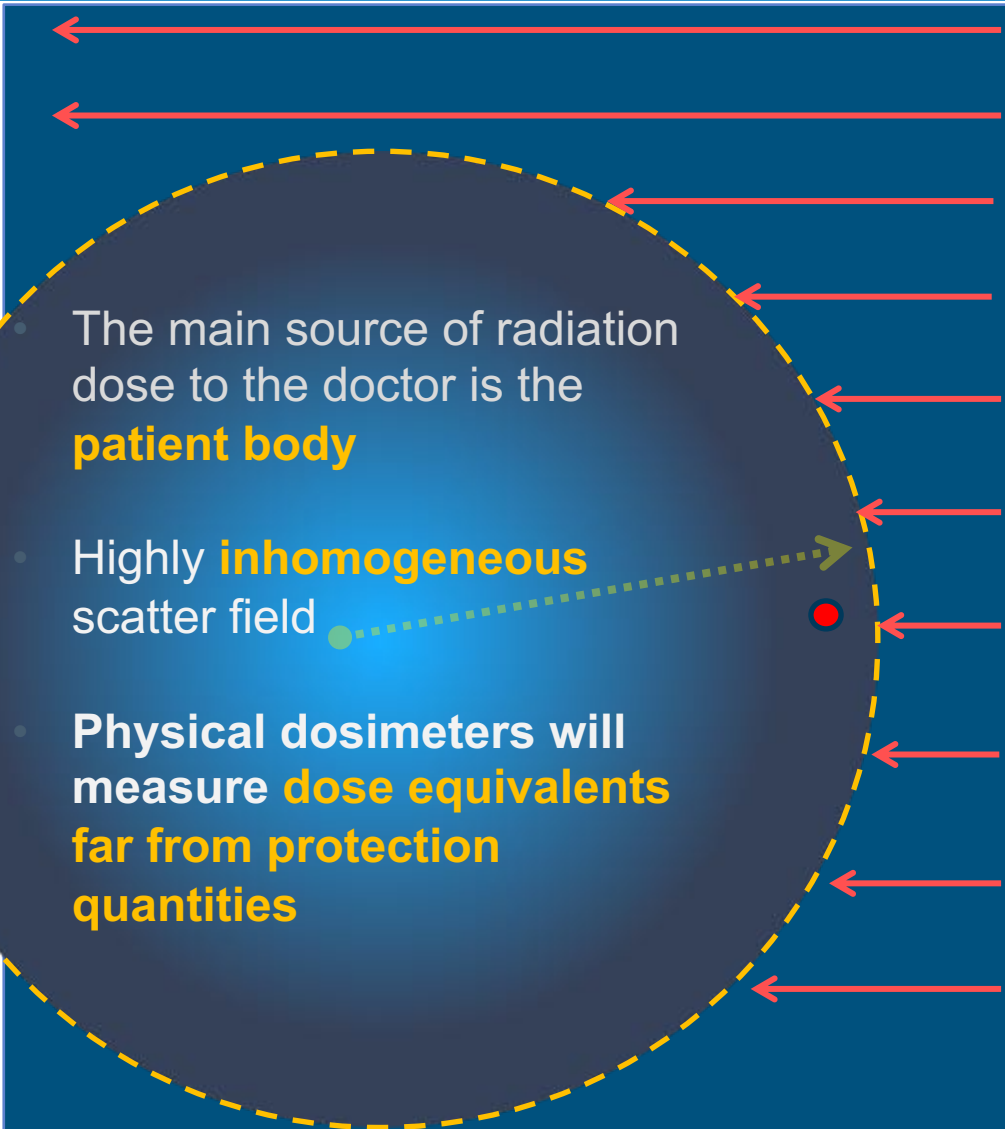
# Limitations of Personal Dosimetry: Safety Aspects

- 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

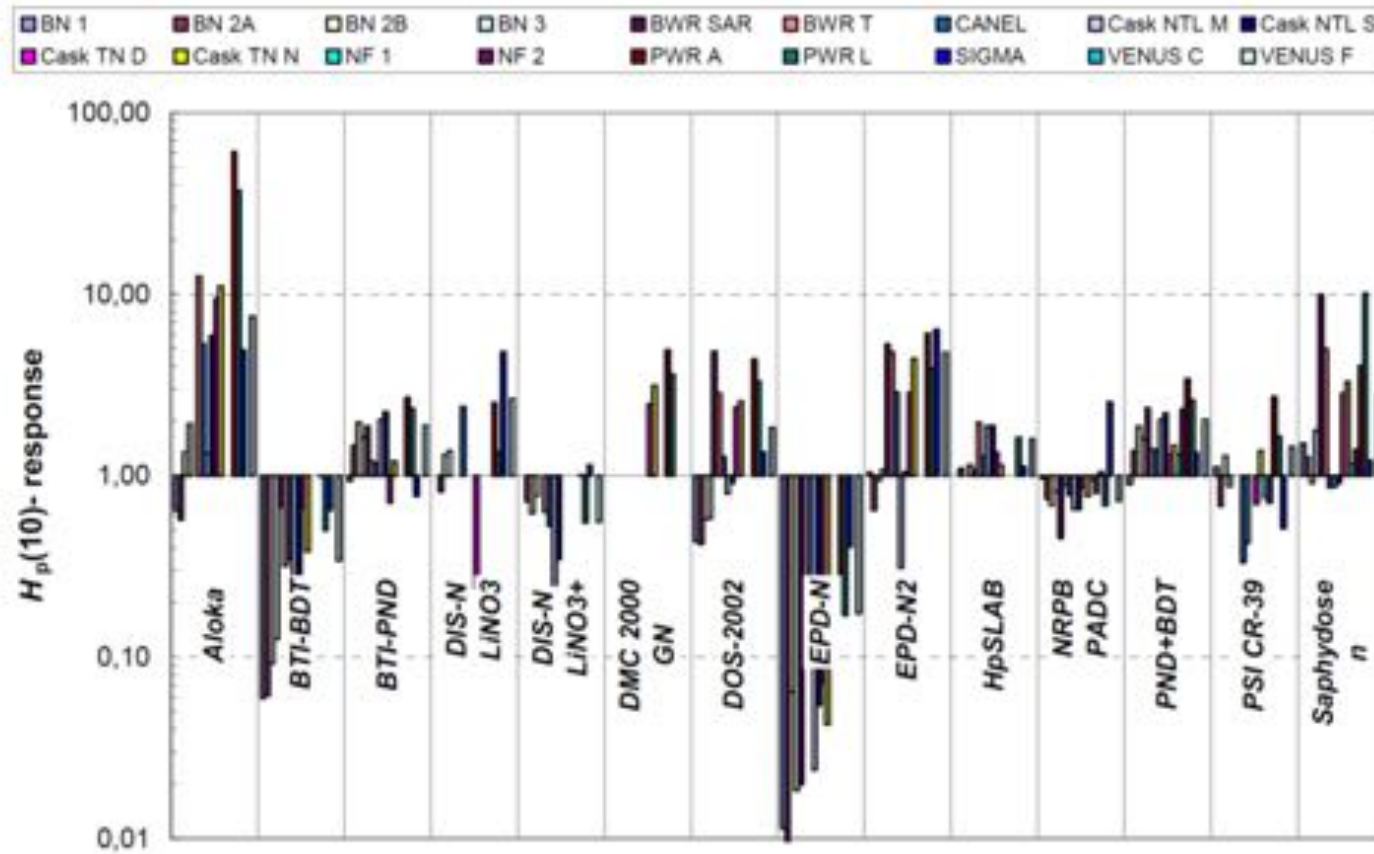


Dosimeters can be placed at several single points but dose distribution is highly inhomogeneous



# Limitations of Personal Dosimetry: Safety Aspects

Neutrons personal dosemeters have highly energy-dependent responses:

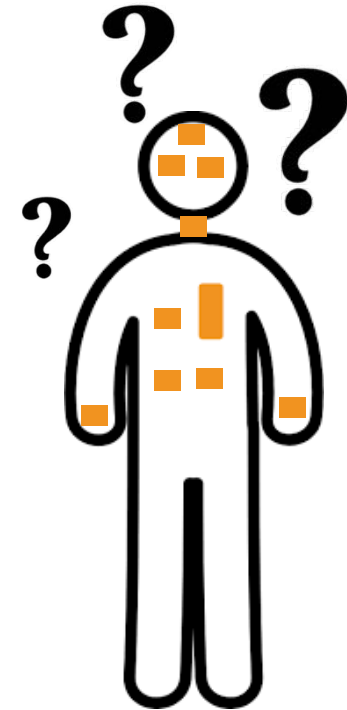


**±2 orders of magnitude variation in workplace fields!**

# Limitations of Personal Dosimetry: Practical Aspects

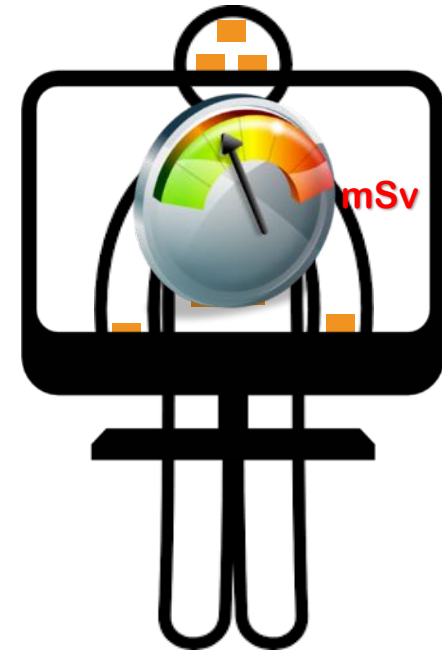


- Workers **do not like** wearing their dosimeter
  - Sometimes they **forget to wear** it...
  - Sometimes they **forget to change** it, or they **lose** it...
  - Sometimes they **place** it in the **wrong** position...
- Workers **really do not enjoy** wearing **more than one** dosimeter
  - Still, **not all body** is covered by doseimeters
  - Depending on the application, the use of doseimeters can **hinder work**
  - Added complexity in handling and **extra workload** for read-out



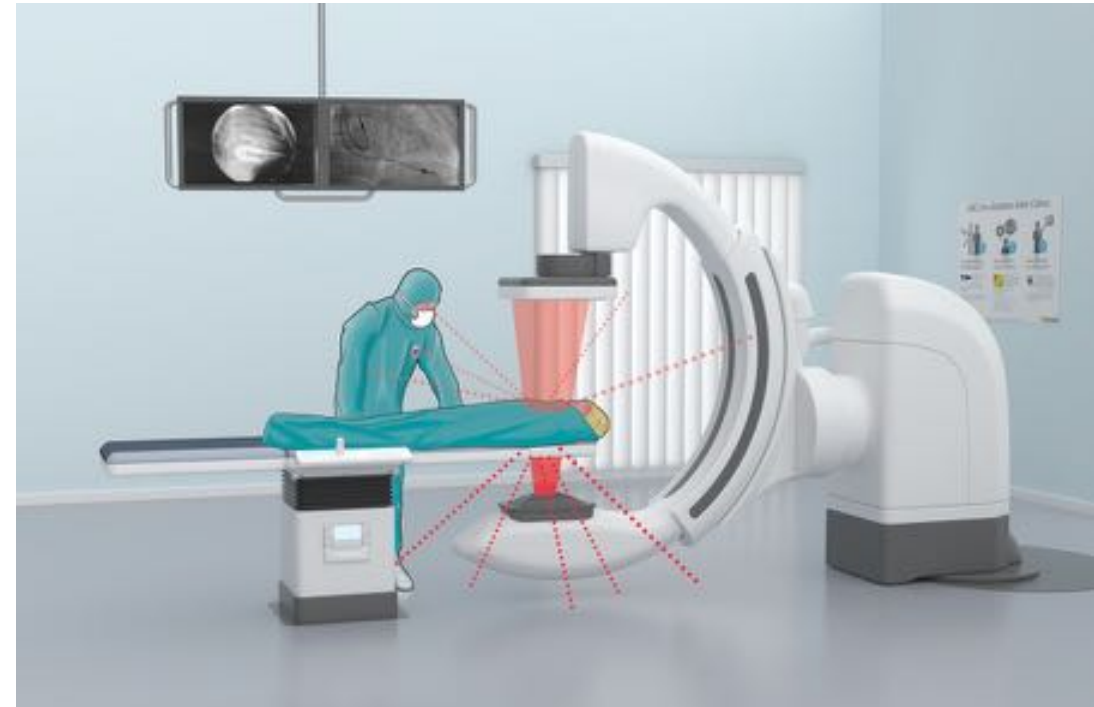
## Personal Dosimetry: what brings the future?

- 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 losing 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



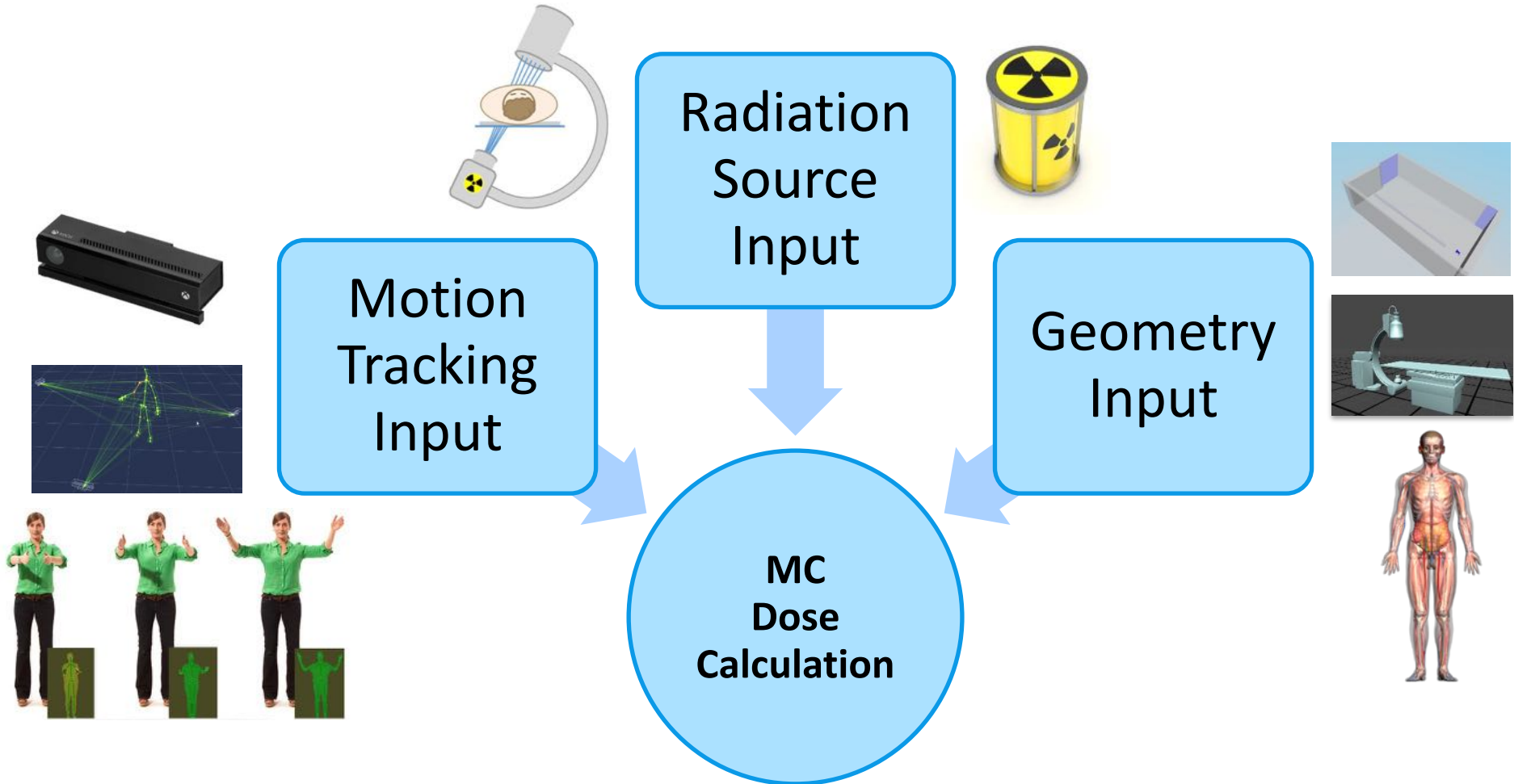
- **Improve occupational dosimetry** via an online dosimetry application using computer simulations: without the use of physical dosimeters
- **Develop an online application** in which we will calculate individual occupational doses
- In a limited time frame, simultaneously use an intermediate approach 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

# How is our virtual dosimetry system working?

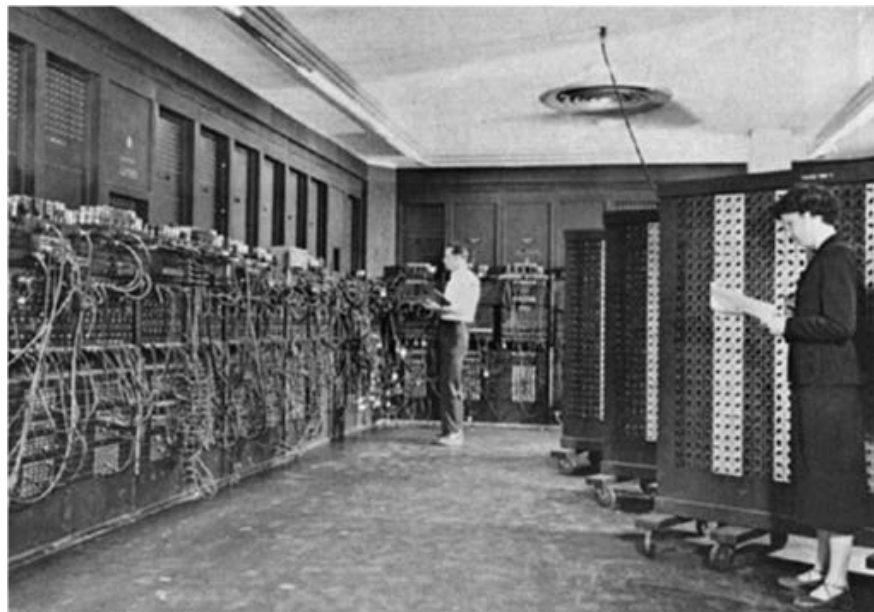
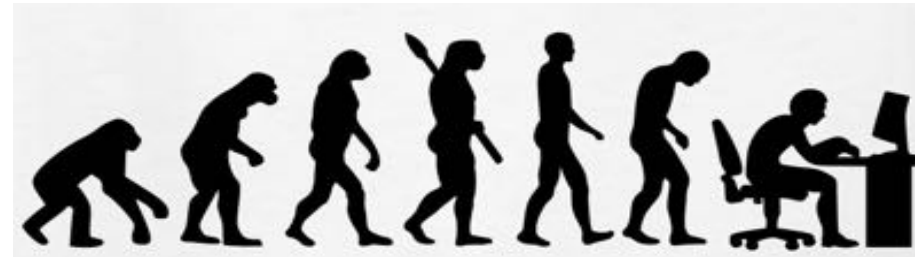
## Staff movement monitoring and Radiation field mapping



Motion Tracking



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



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



vs.



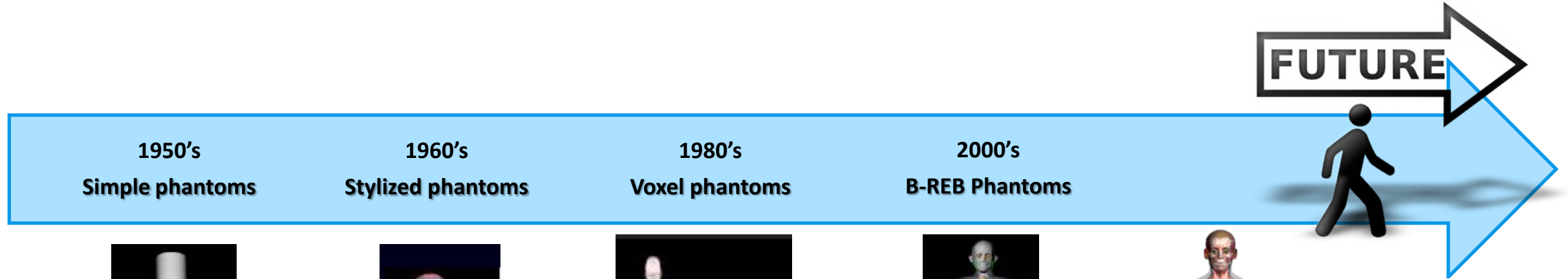
1990



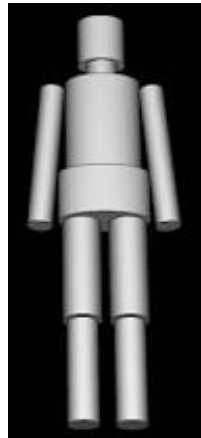
2019



# Geometry Input: Human Phantoms



**1950's**  
Simple phantoms



**BOMAB  
Phantom**

**1960's**  
Stylized phantoms



**ORNL  
Phantom**

**1980's**  
Voxel phantoms



**Irene, Baby  
& Child  
Voxel Phantoms**

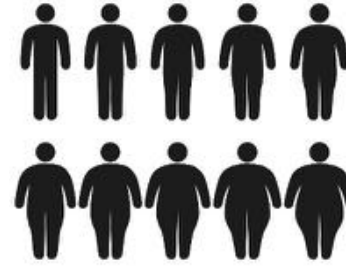
**2000's**  
B-REB Phantoms



**UF Adult male  
Phantom**



**Realistic  
Anthropomorphic  
Flexible Phantom\***



**Personalized  
Phantoms**

\*PhD: P. Lombardo





## RAF phantom (2018)



- **Polygonal Mesh B-Rep** phantom designed with 3Ds Max
- **Tissue masses** (without blood) were **fit to ICRP 89**, with differences within  $\pm 10\%$ .
- The phantom has about **2900 segmented tissues** forming 78 (+ 1) organs, grouped in  $\approx$  **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  $\pm 30\%$** .

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

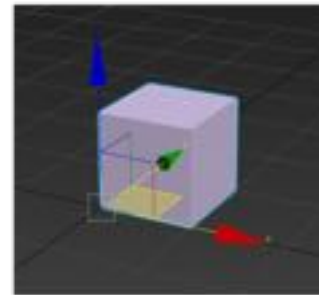
# Animating Computational Phantoms

Two approaches are used for posing:

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

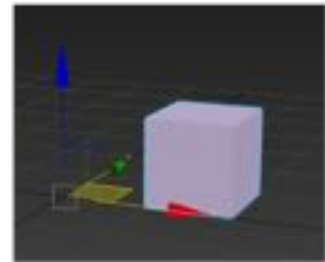
(2) a physical-simulation-based approach that allows the user to first prescribe the position of bones, then performs a tissue mechanics simulation of the passive deformation of the soft tissues, resulting in more-realistic joint-region geometries

Principles of computer animations

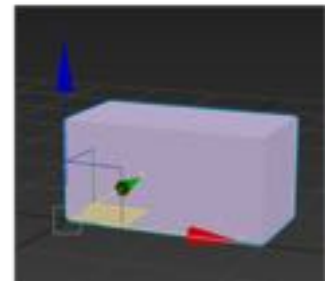


```
v 0.000000 1.000000 1.000000
v 0.000000 0.000000 1.000000
v 1.000000 0.000000 1.000000
v 1.000000 1.000000 1.000000
v 0.000000 1.000000 0.000000
v 0.000000 0.000000 0.000000
v 1.000000 0.000000 0.000000
v 1.000000 1.000000 0.000000
f 1 2 3 4
f 8 7 6 5
f 4 3 7 8
f 5 1 4 8
f 5 6 2 1
f 2 6 7 3
```

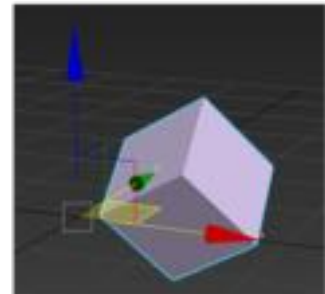
$$[0,1] * \begin{bmatrix} 1 & 0 & 0 & x \\ 0 & 1 & 0 & y \\ 0 & 0 & 1 & z \\ 0 & 0 & 0 & 0 \end{bmatrix}$$



$$[0,1] * \begin{bmatrix} x & 0 & 0 \\ 0 & y & 0 \\ 0 & 0 & z \end{bmatrix}$$

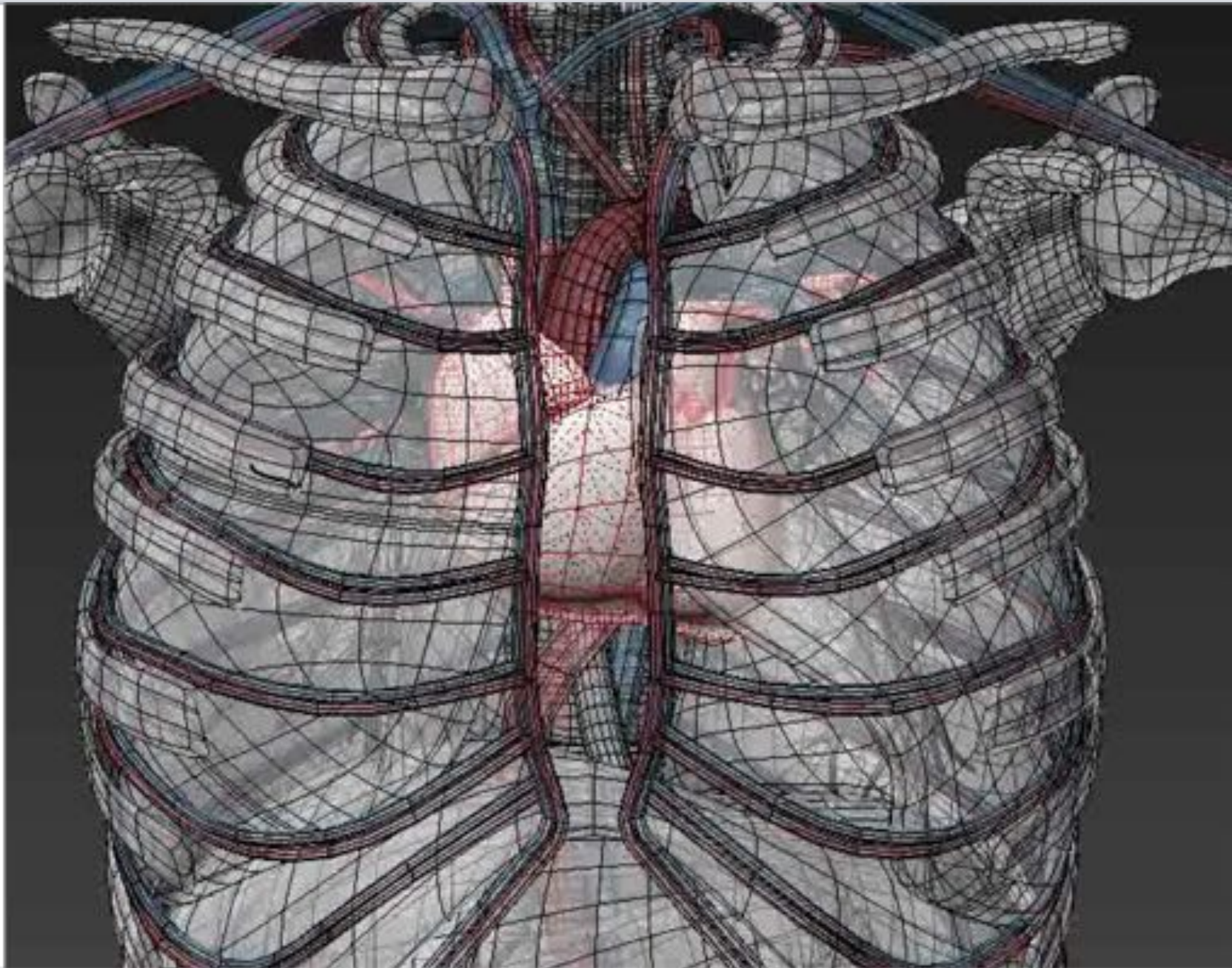


$$[0,1] * \begin{bmatrix} xx & xy & xz \\ yx & yy & yz \\ zx & zy & zz \end{bmatrix}$$





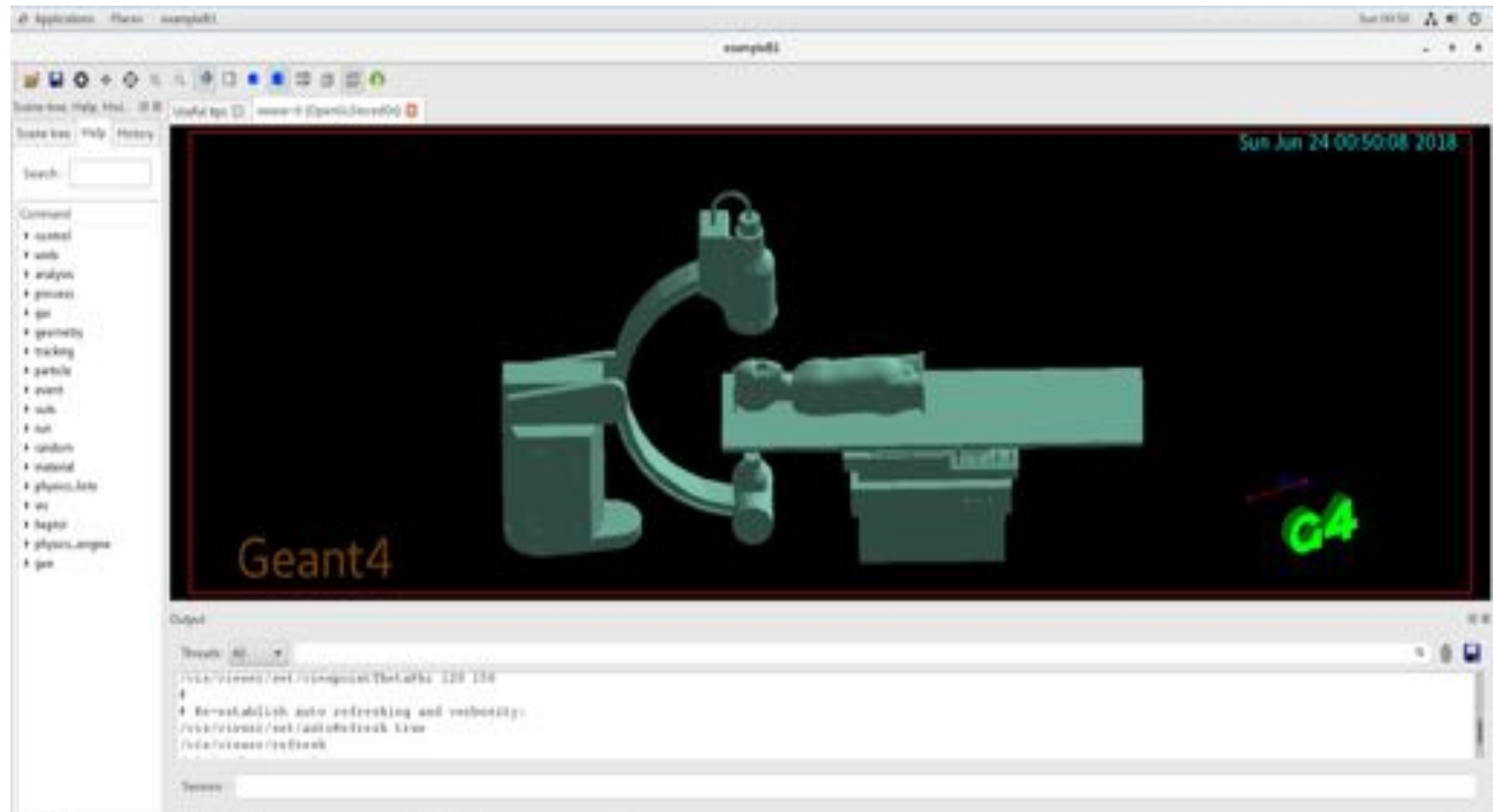






- Few MC codes like Geant-4 adapts Polygonal Meshes as input geometry

Polygonal  
mesh  
geometry in  
Geant-4





IPP

Function 1: change posture



Selected Equipment:  
Right Hand

Inverse Kinematics

INJECT



IK Marker Definition  
 IK root  Rotate C-Arm  Move feet

Bounding Box Dimensions  
Press buttons to calculate  
Calculate Bounding Box

Box x Box y Box z  
120 120 120

Load MOCAP PTHAC

Start camera 10 seconds 00

PROJECT single (legs) 140

PMS check for Xsens/Vu

Save MOCAP data Save MOCAP output

Visualize skin regions  
 High Res 7 min legs  PP graphics

OBU  ASCII STL  BINARY STL

Export results to gdrive

Visualize to MOCAP

- Load Pose  Import Data
- Load IKM  AOM detector
- Move IKM  Scatter Spheres
- Hip/TKI accelerometer  Zero G
- IMU sensors  1.27 frames
- Load Apron  Collar  Cap
- \_\_\_\_\_
- \_\_\_\_\_
- \_\_\_\_\_
- \_\_\_\_\_
- \_\_\_\_\_
- Filter Camera  VP Camera



**Selected Equipment:**  
Right Hand

Inverse Kinematics

INJECT



- Head Pose
- Spine Curve
- Inverse IK
- AOM detector
- Inverse IK
- Scatter Sphere
- Hip/Thigh detector
- Zero G
- 2D detector
- 122 frames
- Level Agent
- Collar
- Cap
- Filter Camera
- UP Camera

**IK Marker Definition:**  
 All roots  Rotate C-Arm  Move feet

**Bounding Box Dimensions:**  
 Press button to calculate  
**Calculate Bounding Box**

Box x	Box y	Box z
128	128	128

**Load MCHP PTIAC**

Select camera (1400x1000)

PUNCT angle (deg)

PMS check for MCHP

**Save MCHP file** **Save MCHP image**

- Visualize skin regions
- High Res 7 mil legs  PP graphics
- OBJ  ASCII STL  BINARY STL

**Export results to gdrive**

**Visualize to MCHP**



IP:

Port:

Selected EndEffector:

Left Hand

Inverse Kinematics

INJECT



All Axes activation  
 Wrist  Rotate C-Arm  Move feet

Bounding Box Dimensions

Press button to calculate

Calculate Bounding Box

Box x	Box y	Box z
120	120	120

Load MCRP PTHAC

Block motion (degrees)

KINECT angle (deg)

PHG check for Visibility  Visible

- Inner Face  Inner Shell
- Internal Body  AGM detector
- Inner RBF  Scatter Sphere
- Hg(Tl) diameter  Zero G
- 2D Vectors  12D Vectors
- Lead Apron  Collar  Cap
- [Download model](#)
- 
- 
- 
- Frontal Camera  IP Camera

Search MCRP job  Load MCRP output

Visualize skin regions

High Res? cut legs  PP graphics

OBJ  ASCII STL  BINARY STL

Export mesh to job

Visualize to MCRP





Sex:

Height:

Selected EndEffector  
Left Foot

Inverse Kinematic

CONNECT



3D Mouse definition  
 W zoom  Rotate  Arm  Move pan

Resizing Box Dimensions

Press button to calculate

Calculate Resizing Box

Res x	Res y	Res z
128	128	128

Load MCMF PTHAC

Send image coordinates

KINECT angle (deg)

PHO stick for Mouse/Win  Show/Hide

- Mouse Filter
- Mouse Speed
- Mouse SRT
- Mouse RMP
- Pgc(10) diameter
- 20 frames
- Lead Apron
- 
- 
- 
- Facial Camera
- IP Camera
- AGM detector
- scatter Sphere
- Calc G
- 100 frames
- Collar
- Cap

Search MCMF var  Read MCMF output

- Visualize skin regions
- High Res 7 feet legs
- PP graphics
- OBJ
- ASCII STL
- BINARY STL

Export mesh to gltf

001

Connect to MCMF



Sex:

Person:

Select Extremities:

Inverse Kinematics

KINECT

- Joint Flex
- Joint Dext
- Joint SRT
- AGM detector
- Joint RMP
- Inertial Sensors
- Hip(I2) diameter
- Calc G
- 20 frames
- 100 frames
- Lead Apron
- Collar
- Cap
- ...
- ...
- ...
- Follower Camera
- LP Camera



3D Pose rotation:  
 W. Axis  Rotate C-Axis  Move feet

Bounding Box Dimensions:

Press button to calculate

Calculate Bounding Box

Box x	Box y	Box z
120	120	120

Load MCMF/PTAC

Search MCMF commands:

KINECT angle (Right):

HDI stack for Visualize:

Search MCMF url:  Press MCMF output

Visualize stick regions

High Res if not open  PP graphics

OBJ  ASCII STL  BINARY STL

Export mesh to gltf





Selected Equipment

None

Inverse Kinematics

KINECT

- Kinect V1
- Kinect V2
- Kinect V3
- Kinect V4
- Kinect V5
- Kinect V6
- Kinect V7
- Kinect V8
- Kinect V9
- Kinect V10
- Kinect V11
- Kinect V12
- Kinect V13
- Kinect V14
- Kinect V15
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- Kinect V92
- Kinect V93
- Kinect V94
- Kinect V95
- Kinect V96
- Kinect V97
- Kinect V98
- Kinect V99
- Kinect V100



Show skeleton  
 Rotate C-Axis  
 Show feet  
 Bounding Box Dimensions  
 Press button to calculate  
 Calculate Bounding Box  
 Box x: 128    Box y: 128    Box z: 128

Get MOP/PTRAC  
 Get MOP/PTRAC: 30  
 KINECT angle (deg): 100  
 FWD stick for Visualize: Visualize

Search MOP/PTRAC    Read MOP/PTRAC  
 Visualize with regions  
 High Res T and legs    PP graphics  
 DRU     ASIS STL     SMAR STL  
 Export model to gltf  
 ZEP    Visualize to MOP



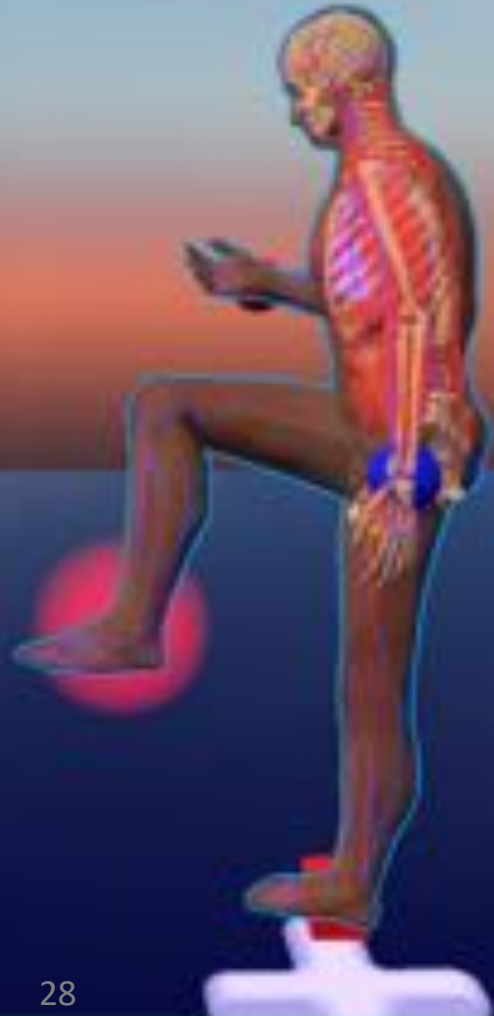
**Selected EndEffector**

**LAB Foot**

**Inverse Kinematics**

**KINECT**

- Leaded Glass
- Leaded Brick
- Leaded Wall
- Hp(10) dosimeter
- T1 tissue
- Lead Apron
- Collar
- Cap
- Leaded Clothing**
- Leaded Suit**
- ACME detector**
- Acrylic Sphere**
- Zero G**
- 122 sources**
- 120 sources**
- Further Camera**
- LIP Camera**



**IK Knees definition**

No motion  Rotate C-Arm  Move feet

**Bounding Box Dimensions**

Press buttons to translate

**Calculate Bounding Box**

Box x	Box y	Box z
<input type="text" value="120"/>	<input type="text" value="120"/>	<input type="text" value="120"/>

**Use MONP-PTIAC**

**Shift angle (degrees)**

**KINECT angle (deg)**

**PHI mask for VisorVis** **VisorVis**

**Search MONP sim** **Read MONP output**

**Visualize skin region**

**High ResCT cut legs**  **PP graphics**

**OBJ**  **ASCII STL**  **BINARY STL**

**Export mesh to gltf**

**287** **Visualize to MONP**



IC:

No. room:

Inverse Kinematics

**KINECT**

- Move Face
- Move Head
- Move Neck
- Move R&L
- Hip(12) detector
- 3D detector
- Lead Apron
- Collar
- Cap
- Finger Camera
- IP Camera



Move room  Rotate C-Axis  Move bed

Branding Box Dimensions

Press button to calculate

Calculate Branding Box

Box x	Box y	Box z
128	128	128

Load MONP PTHAC

Select source geometry: 20

KINECT angle (deg): 120

PNG stack for VisualViz: VisualViz

Search MONP art    Read MONP output

Visualize skin regions

High Res F and legs     PF graphics

OBJ     ASCII STL     BINARY STL

Export mesh to plot

207



IN

No item

Selected Exoskeleton

Right Hand

Inverse Kinematics

KINECT

- Kinect v1
- Kinect v2
- Kinect ASX
- AGM detector
- Kinect RAP
- Kinect Sphere
- Hq(TS) accelerometer
- Cam G
- PS features
- 122 features
- Lead Apion
- Collar
- Cap
- Feather Camera
- UP Camera



All Power activation  
 All items  Rotate 2-Axis  Move head

Bounding Box Dimensions  
Press button to calculate  
Calculate Bounding Box

Box x	Box y	Box z
128	128	128

Get MCMF/PTIAC

Get 4 body components

KINECT angle (legs)

PEG stick for Voxelite

Search MCMF xml

Voxelite skin regions  
 Right Hand 2nd leg  PF graphics  
 CPU  KINCT STL  BNAKT STL

Export model to joint



IPP

## Function 2: voxelization



Selected EndEffector  
Left Foot

Inverse Kinematics

KINECT

- Home Field  Home Glass
- Home SRF  AGM detector
- Home RAR  Laser Sphere
- Hgt(H) dosimeter  Zero G
- 20 Visours  120 Visours
- Lead Apron  Collar  Cap
- Head-mounted display
- \_\_\_\_\_
- \_\_\_\_\_
- \_\_\_\_\_
- Facial Camera  off Camera



All Masses adjusted  
 All mass  Rotate C-Arm  Move bed

Bounding Box Dimensions

Press button to calculate

Calculate Bounding Box

Box x	Box y	Box z
120	120	120

Read MOCAP-PTIAC

Detect events (seconds)

KINECT angle (deg)

PFB stack for Visibility

Read MOCAP xml

Flexibles with regions

High Res 1 out step  PP graphics

OBJ  ASCII STL  BINARY STL

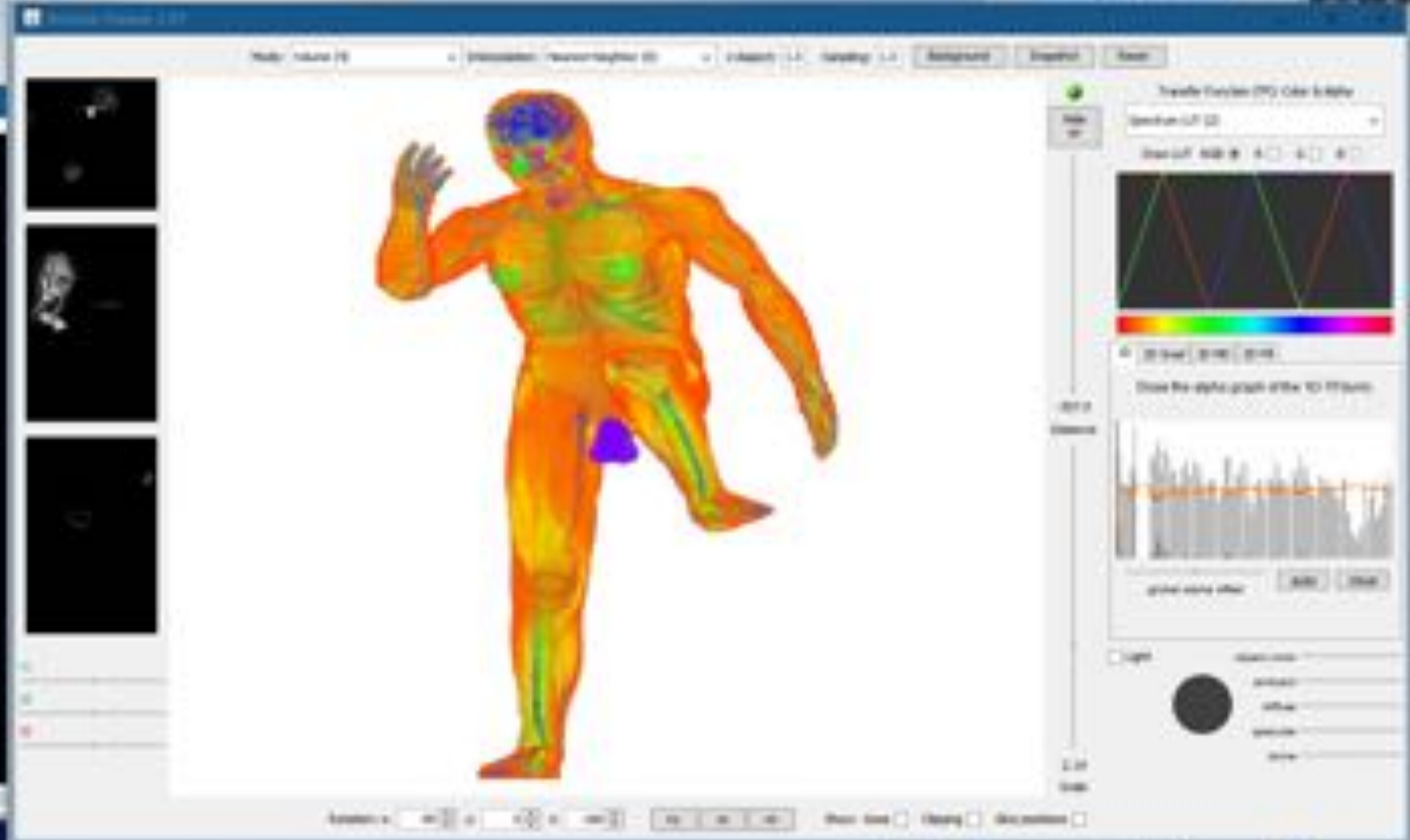
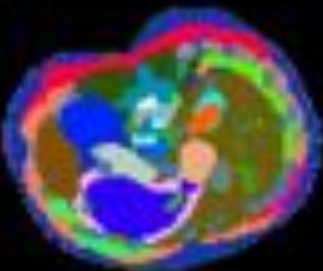
Export mesh to point

107

Visibility to MOCAP

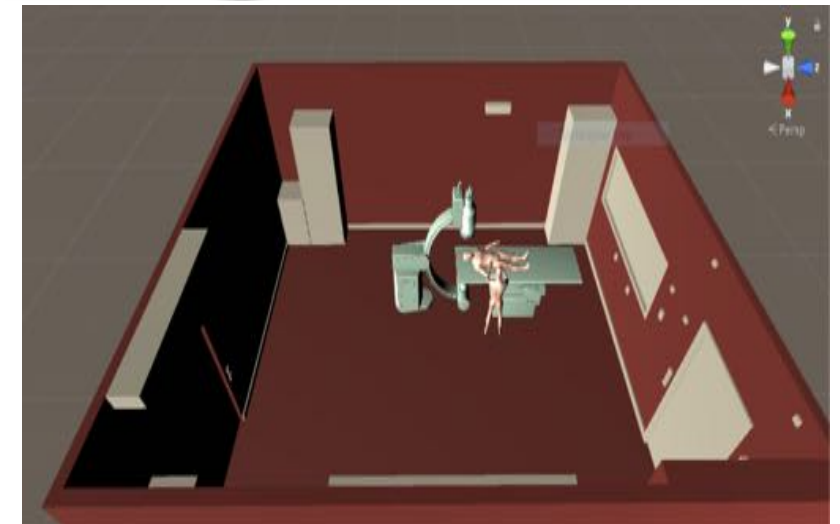
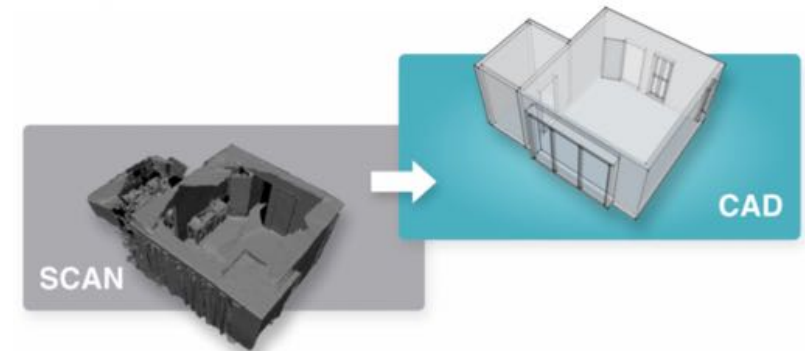
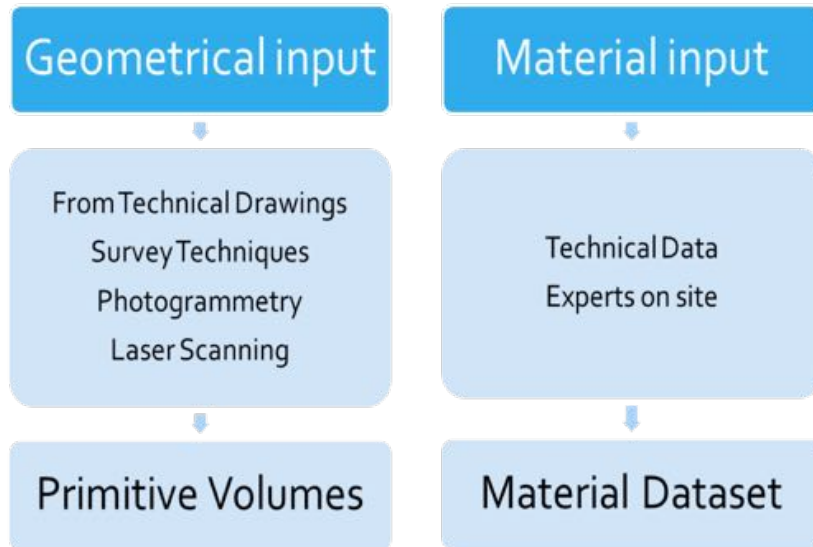


SCK • CEN



3D Camera Off Camera

- Define of the workplace geometry for the calculations



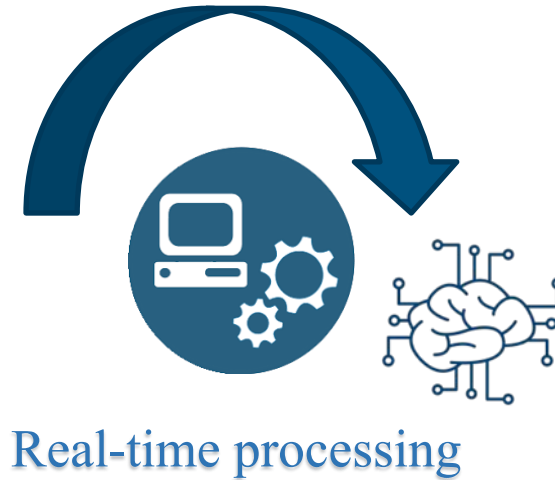
- Simple geometries can be easily modeled
- Complex geometries can be prepare by:
  - ❑ converting CAD files to different formats
  - ❑ by scanning of the workplace
- Modeling and tracking of important moving objects (shielding) is also needed

- **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**

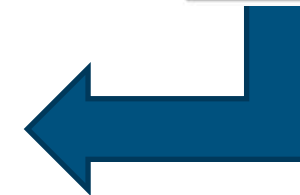
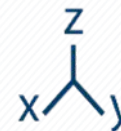
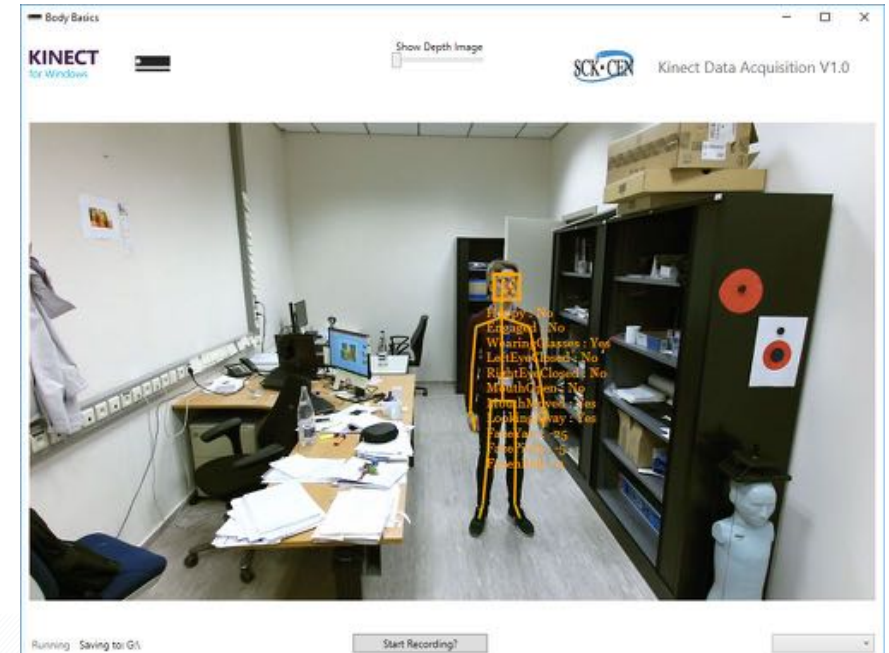


## Tracking system based on single depth camera

Depth Image



Skeleton Tracking

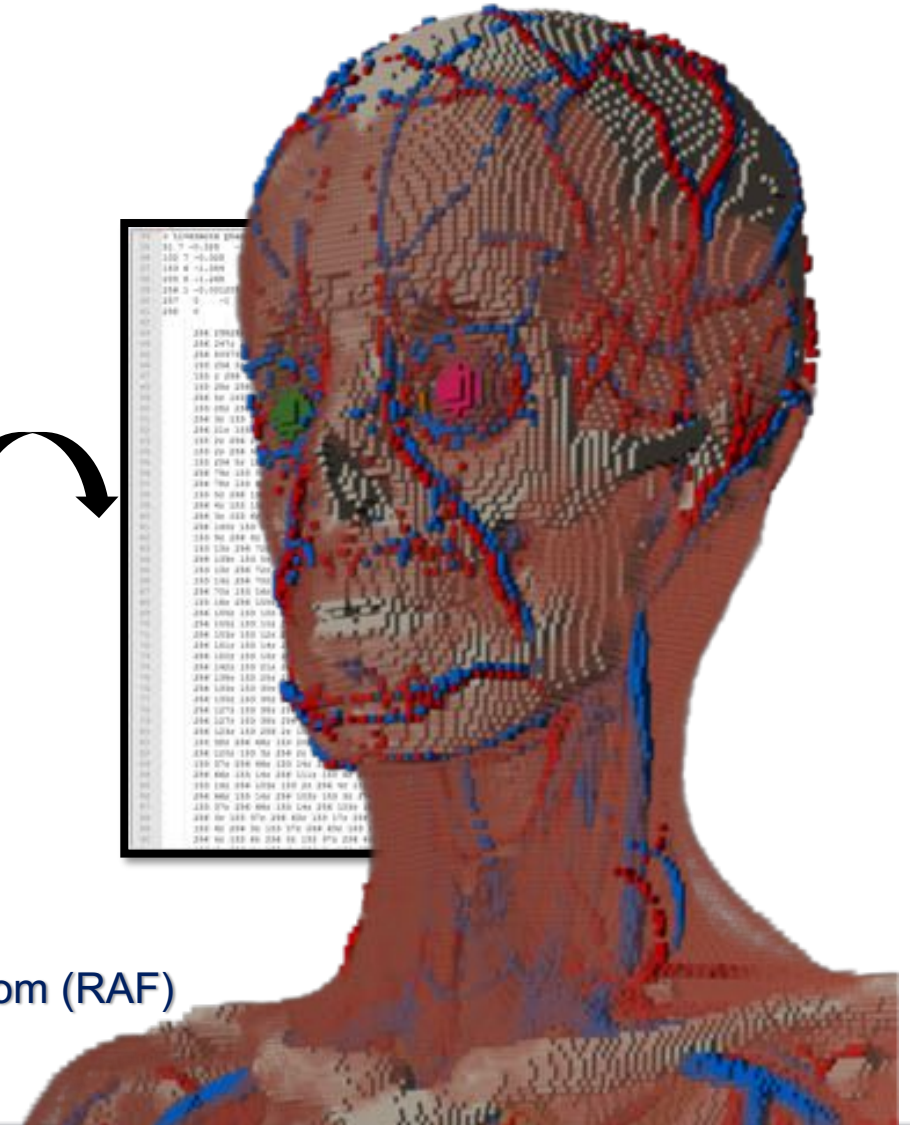
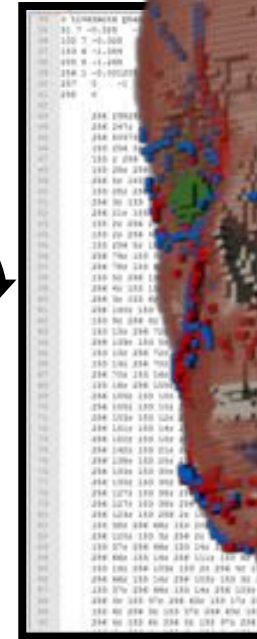
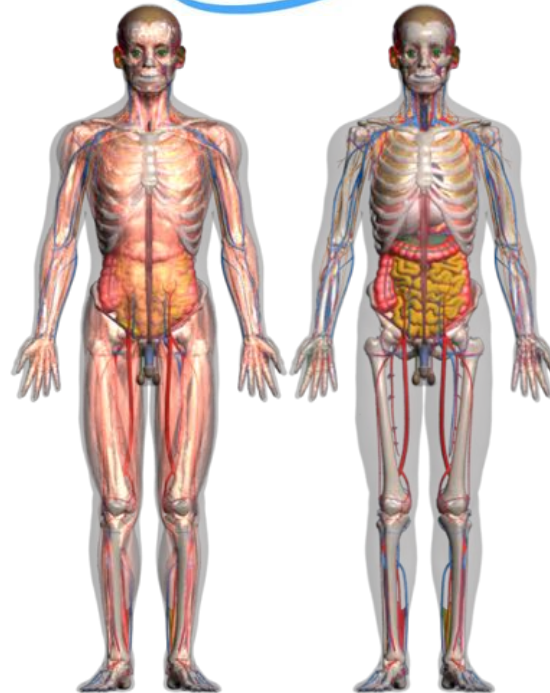


Storing XYZ coordinates or send to a cloud

# From Motion Tracking to Computational Phantom

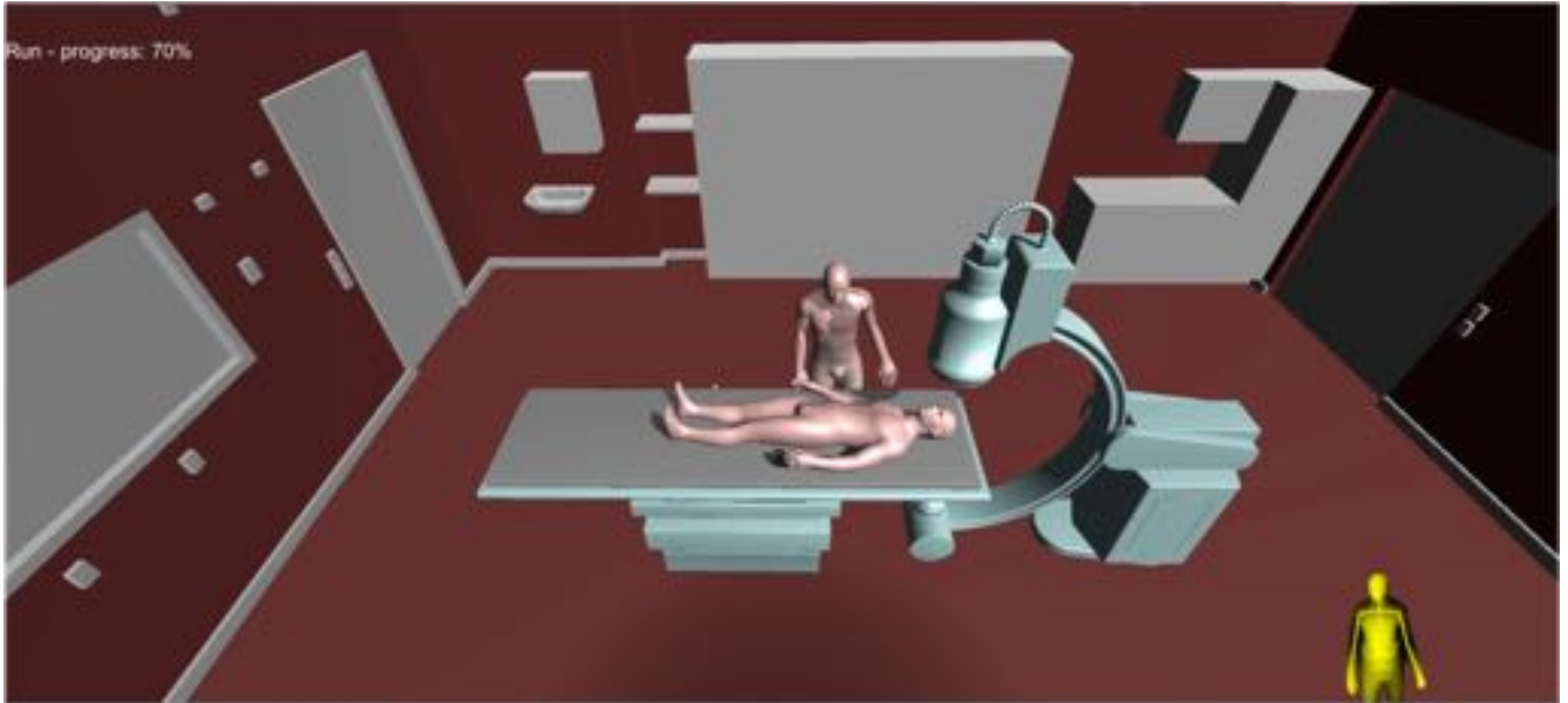


SCK•CEN



Realistic Anthropomorphic Flexible Phantom (RAF)

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

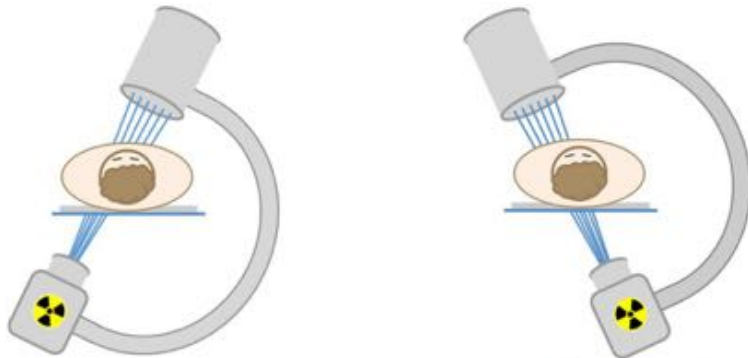


## X-Ray spectrum

- Tube potential (kVp value)
- Dose at the reference point or DAP
- Added filtration
- Field size: collimated area (cm<sup>2</sup>)
- 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 <sub>eq</sub>
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

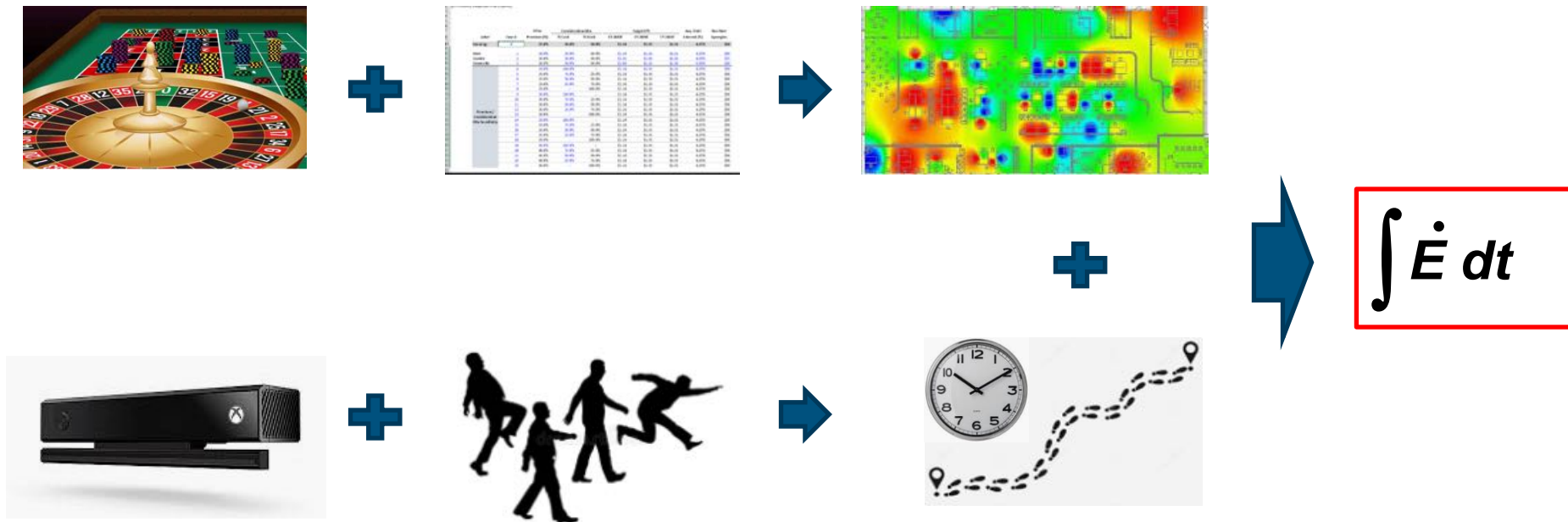
1. Use MC to calculate:
    - Fluence in cone angles of  $45^\circ$ , for each  $45^\circ$  horizontal plane
    - Fluence components in vertical cones
  2. Convolve with tally multipliers within MCNP to give various angular components of effective dose
  3. Normalize result in each cone to account for full  $4\pi$  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)



- 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  $\Rightarrow$



**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:*

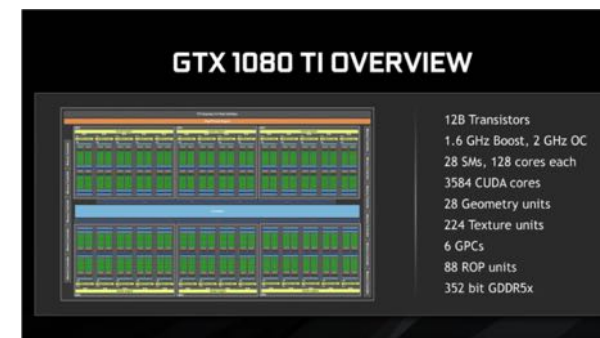
- This tally estimates the energy photon fluence spectrum at a detection point  $D$
- Radiological protection quantities can be calculated by using the corresponding conversion coefficients

*Parallelization among several GPU cards:*

- MPI implementation

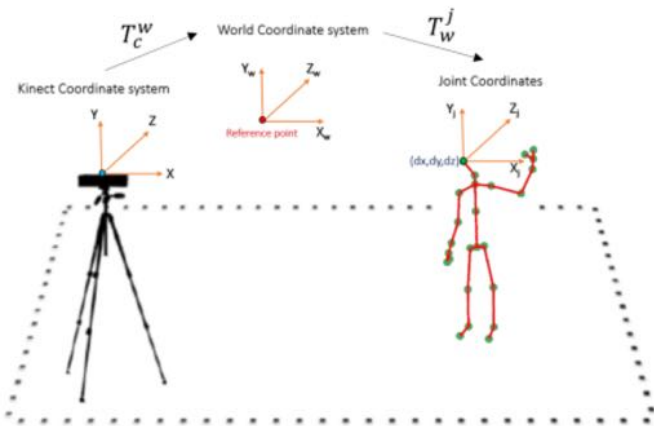
*Computational time performance:*

- 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

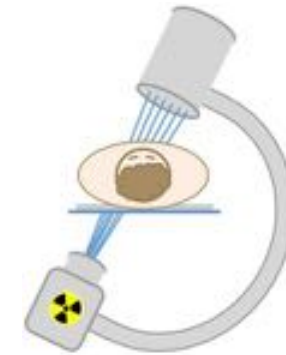
### COMMON CHARACTERISTICS



Tracking of the location and posture of medical staff



Information about the procedure



Input files

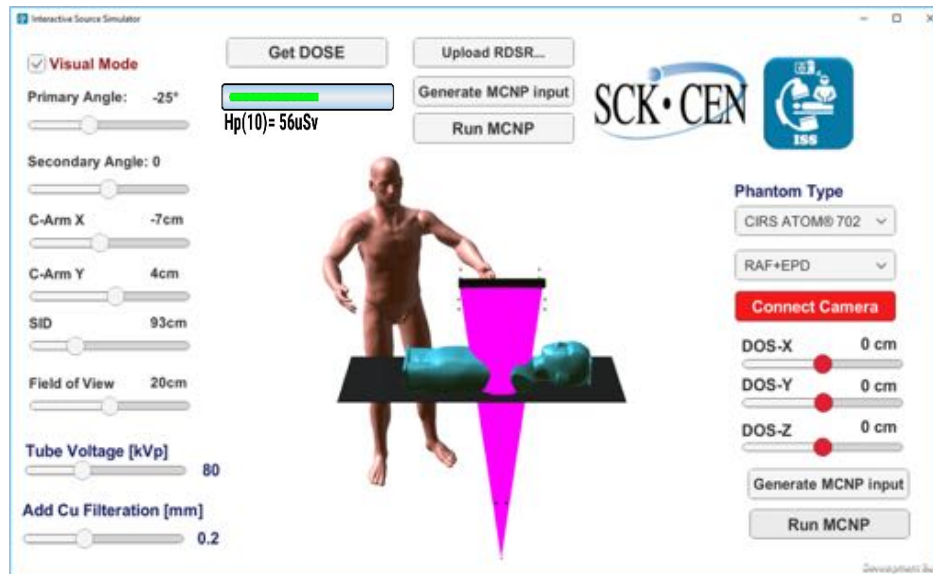
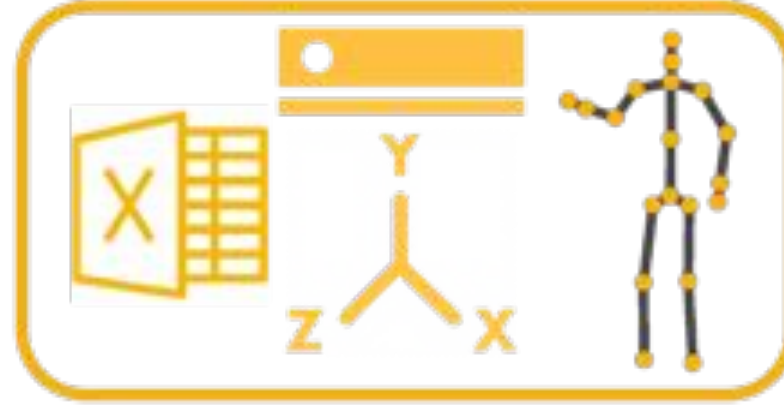
Cluster (CPU+GPU)

Results

```

(0040,a010) RelationshipType CS # 8 1 [CONTAINS]
(0040,a040) ValueType CS # 4 1 [NUM ]
(0040,a043) ConceptNameCodeSequence SQ # 80 1
(0008,0100) CodeValue SH # 6 1 [113790]
(0008,0102) CodingSchemeDe... SH # 4 1 [ICM1]
(0008,0104) CodeMeaning LO # 22 1
]
(0040,a300) MeasuredValueSequence SQ # 108
(0040,08ca) MeasurementUni... SQ # 58 1
(0008,0100) CodeValue SH # 2 1
(0008,0102) CodingSec... SH # 4 1
(0008,0104) CodeMeaning LO # 4 1
]
(0040,a30a) NumericValue DS # 10 1
    
```





Interactive Source Simulator in IR



**SCK•CEN**

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 Filtration: 0.2

Phantom Type: BOMAS phantom

Connect Camera

DOS-X: 0 cm

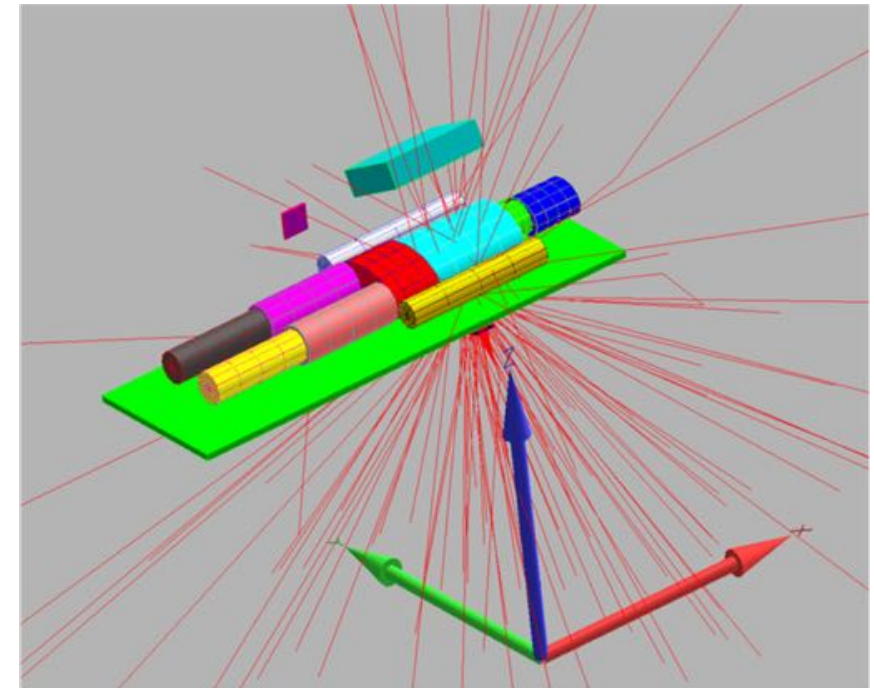
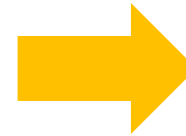
DOS-Y: 0 cm

DOS-Z: 0 cm

Generate MCNP input

Run MCNP

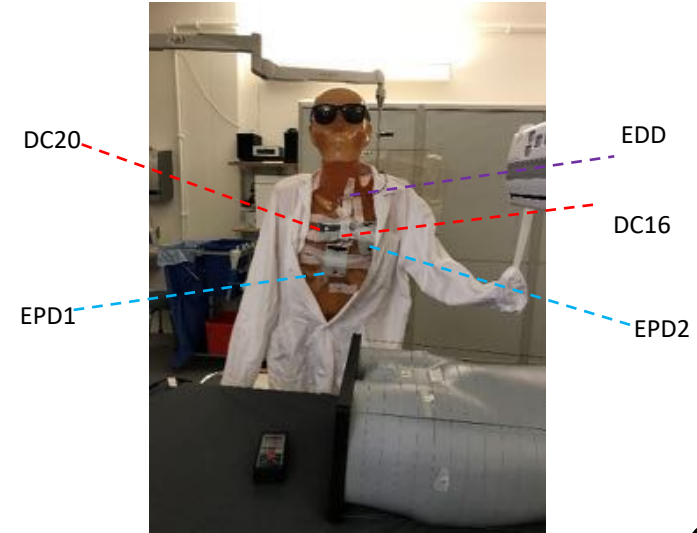
Hp(10) = 56uSv



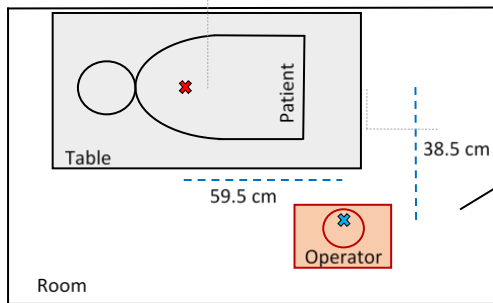




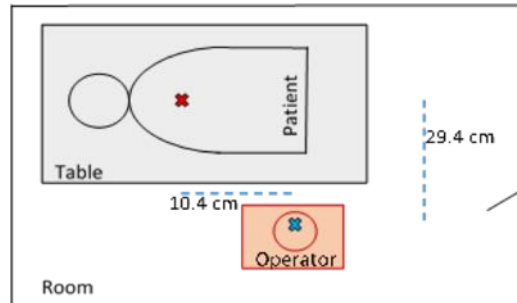
**LUND**  
UNIVERSITY



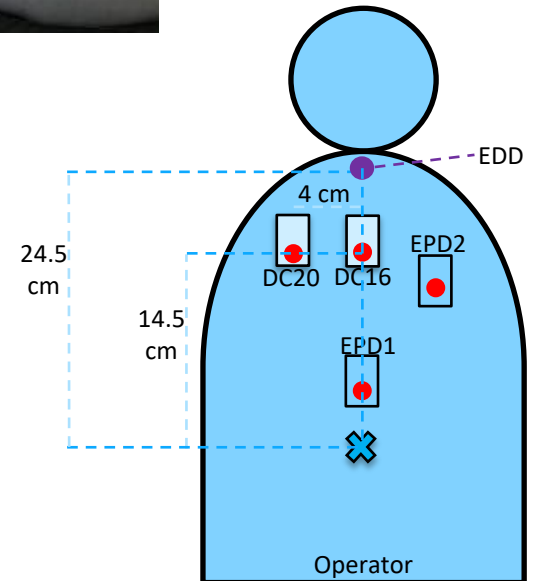
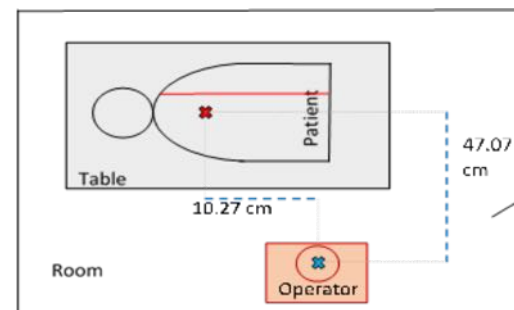
### Experiment 1



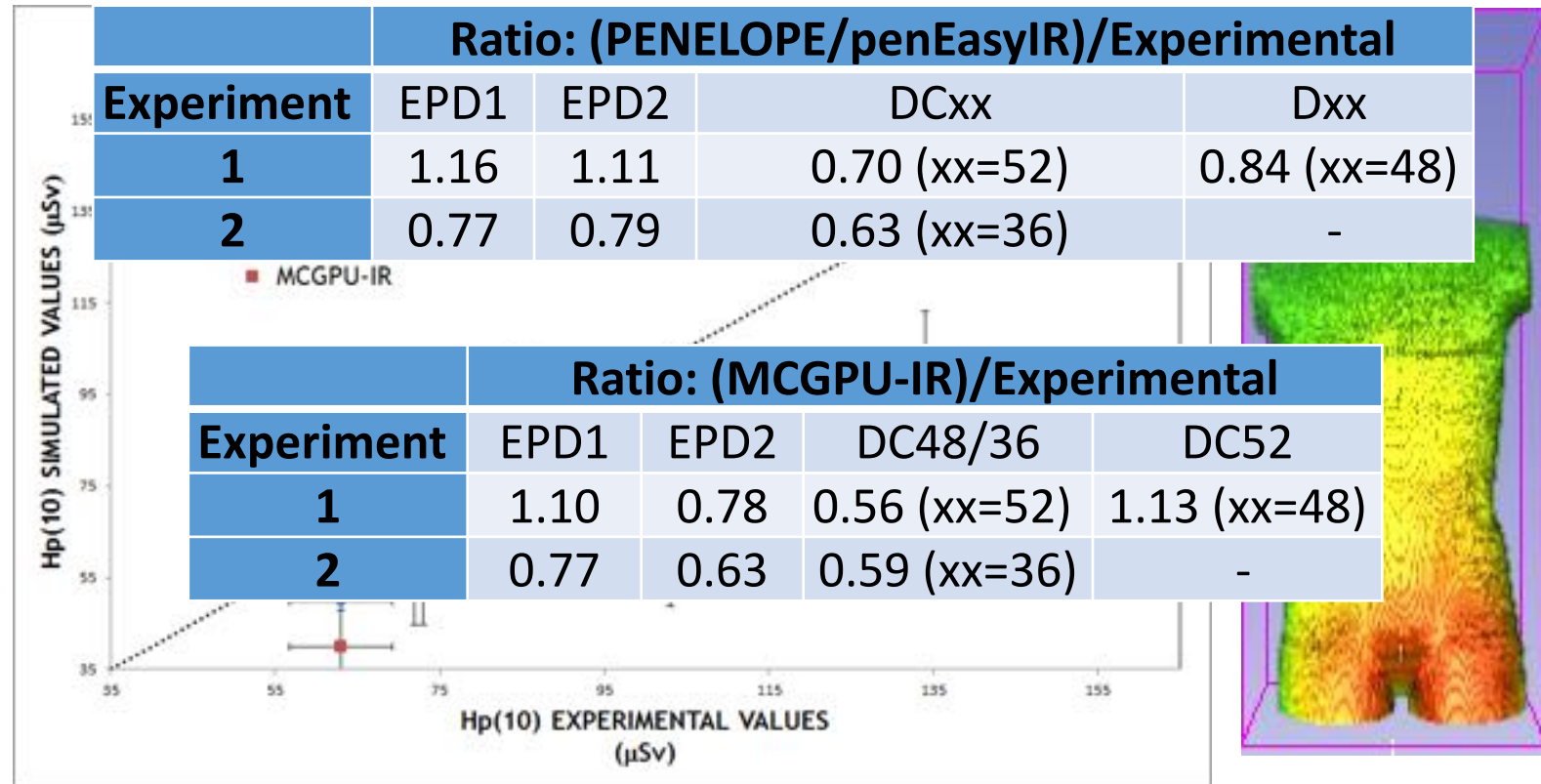
### Experiment 2



### Experiment 3



## RESULTS: OPERATOR DOSES



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



## Kinect 2



## View from Kinect 1

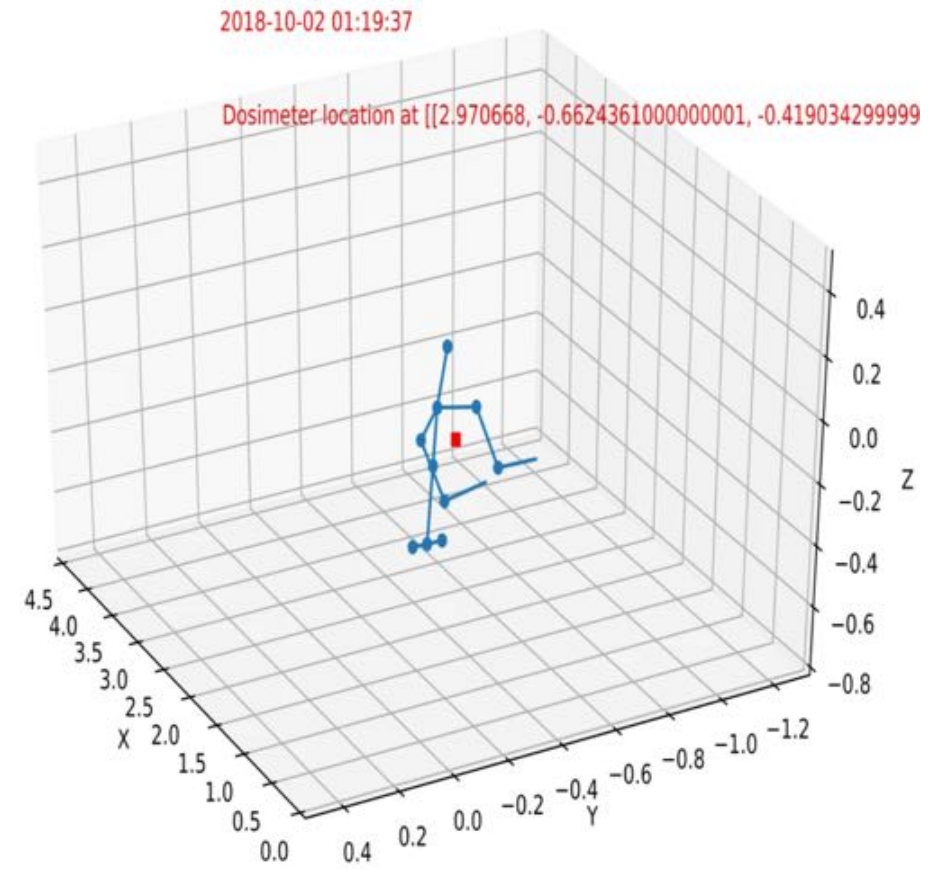




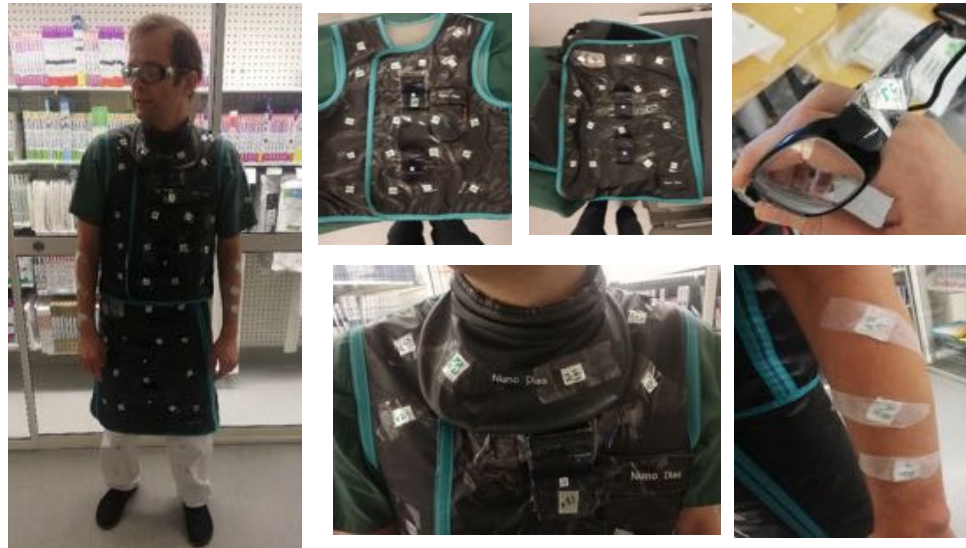




# Skeleton tracking of the first operator



## Measurement points



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

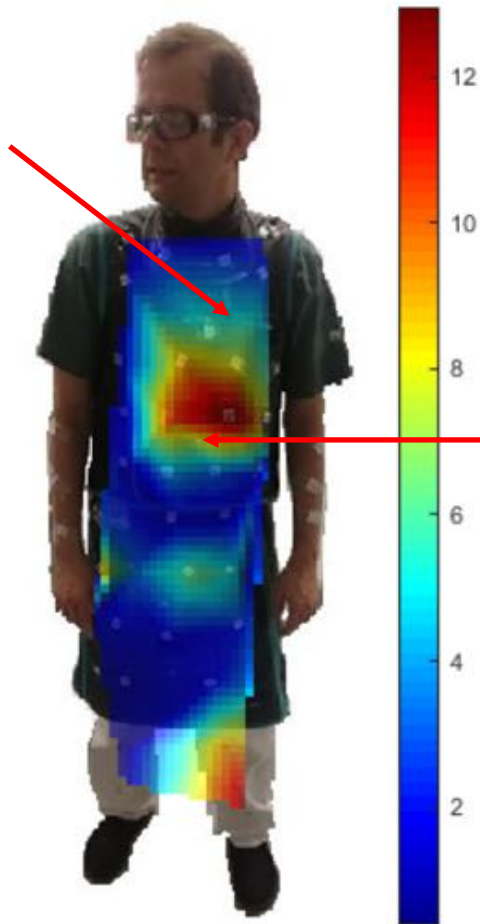
## Simulation points



**MCGPU-IR**

Heat map: NaCl pellets

Mirion DMC 3000  
Hp(10) = 7  $\mu$ Sv



Mirion DMC 3000  
Hp(10) = 30  $\mu$ Sv

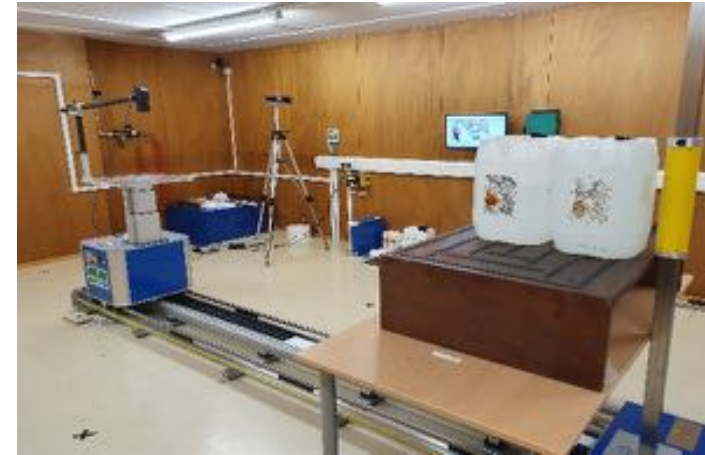
Simulated  
36.59  $\mu$ Sv





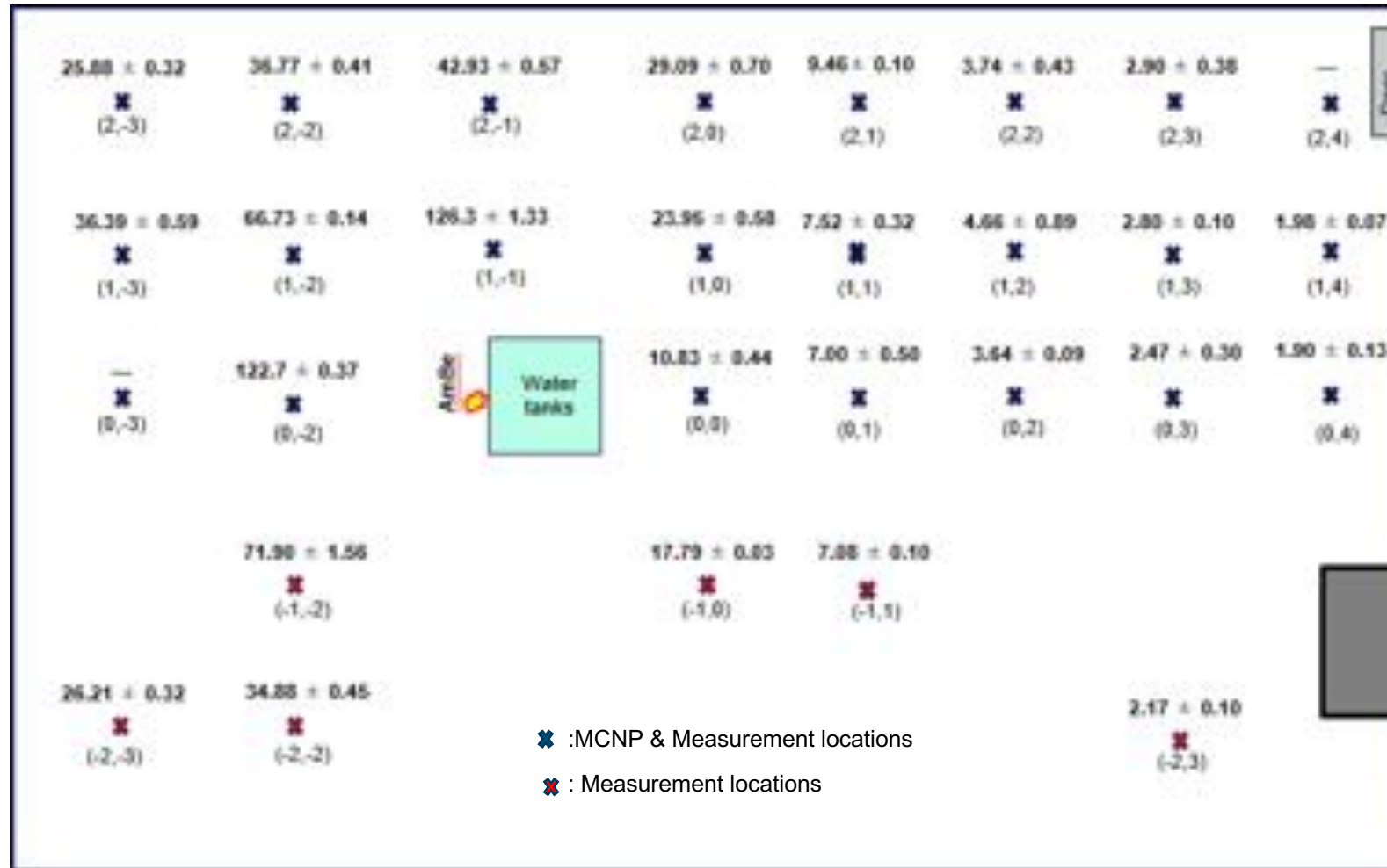
Validation Case	Simulations Accumulated $H_p(10)$	Measured EPD Accumulated $H_p(10)$
<b>Clinical Experiments</b>		
<b>EndoVasc CHU-Liège Case 4 (PCI)</b>	38 $\mu\text{Sv}$	23 $\mu\text{Sv}$
<b>EndoVasc SJH Case B</b>	7.7 $\mu\text{Sv}$	5 $\mu\text{Sv}$
<b>EndoVasc SJH Case C</b>	68.3 $\mu\text{Sv}$	55 $\mu\text{Sv}$
<b>EndoVasc SJH Case D (EVAR)</b>	In progress	63 $\mu\text{Sv}$
<b>Cardiac SJH Case 1</b>	388 $\mu\text{Sv}$ (without shielding)	31 $\mu\text{Sv}$ (with Shielding)

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

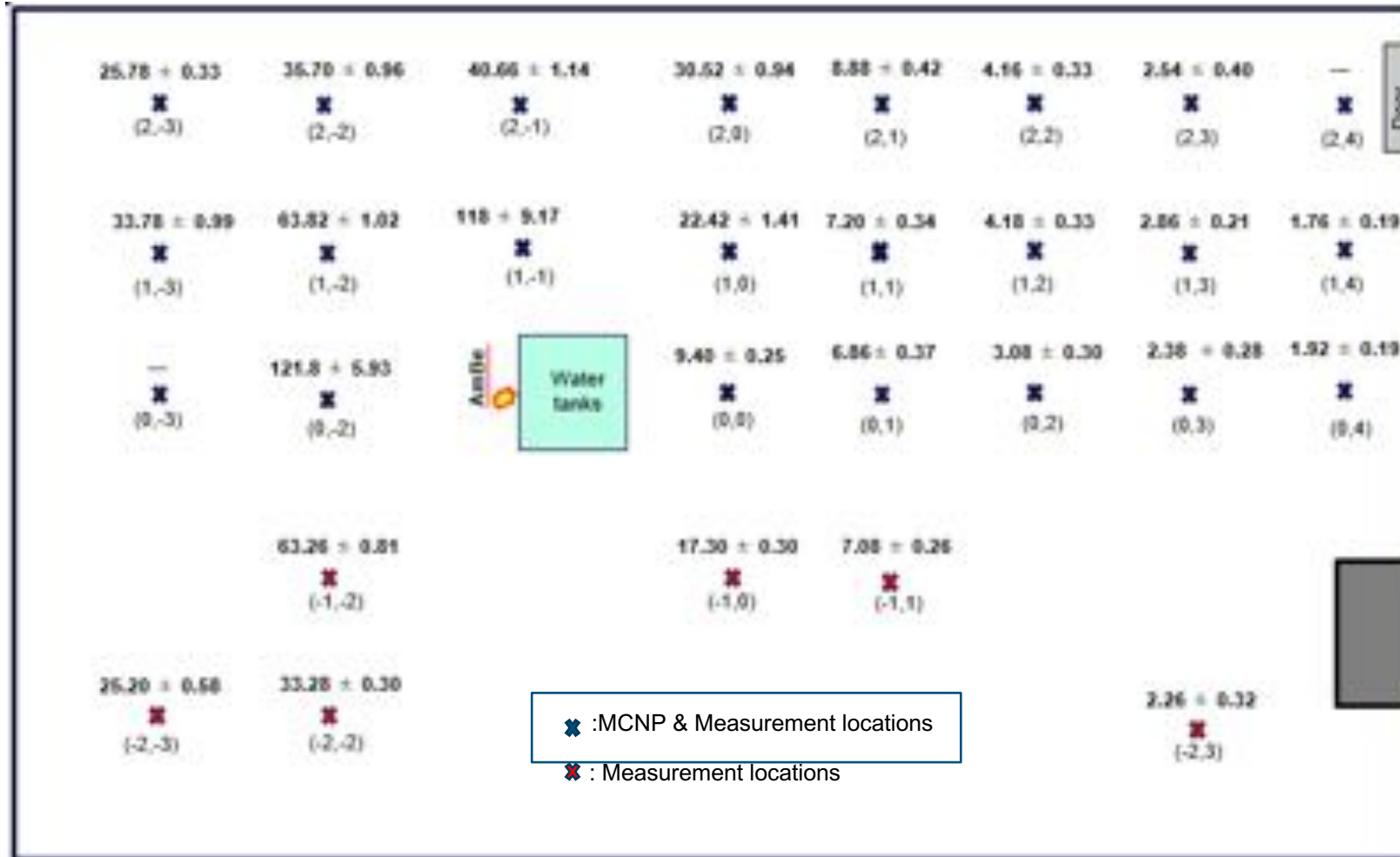


Images courtesy of PHE

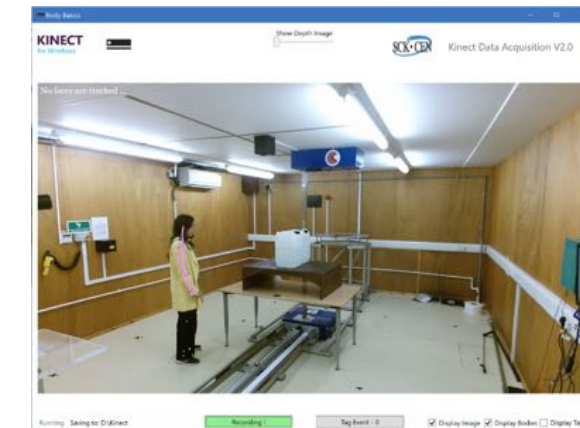
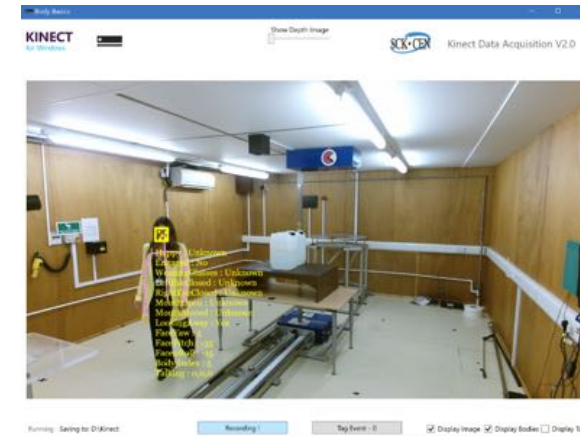
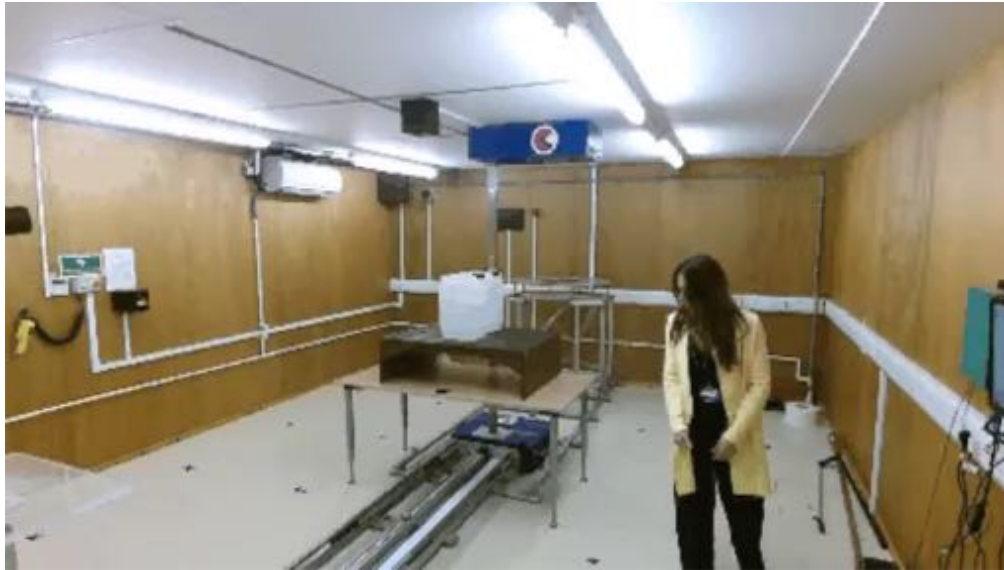
# Neutron Dose Rate - GNU: $\mu\text{Sv/h}$



# Neutron Dose Rate – T405: $\mu\text{Sv/h}$



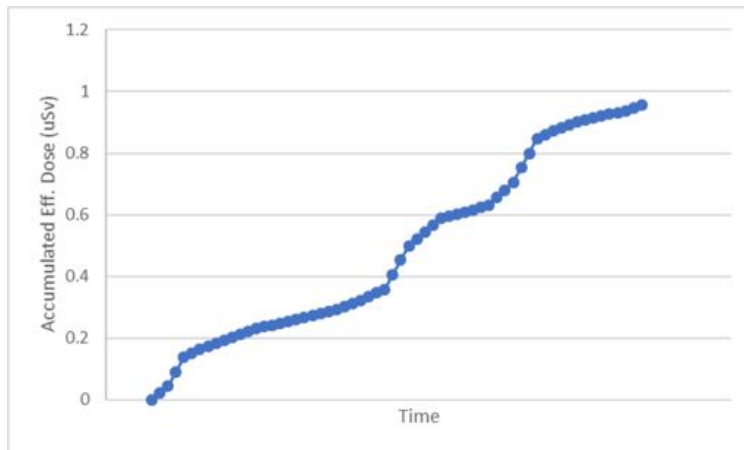
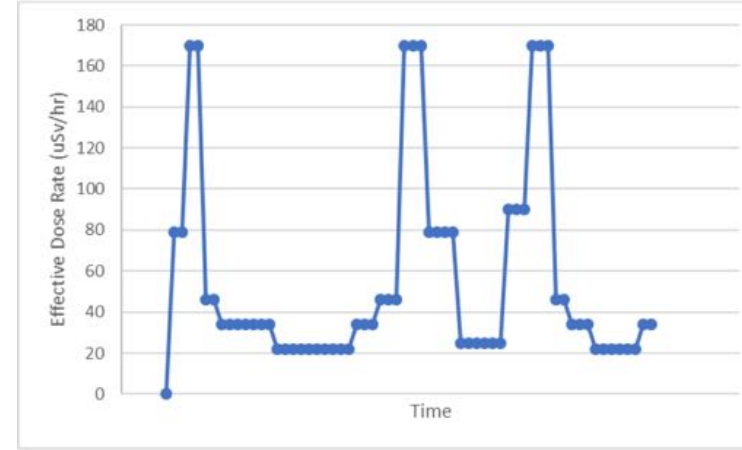
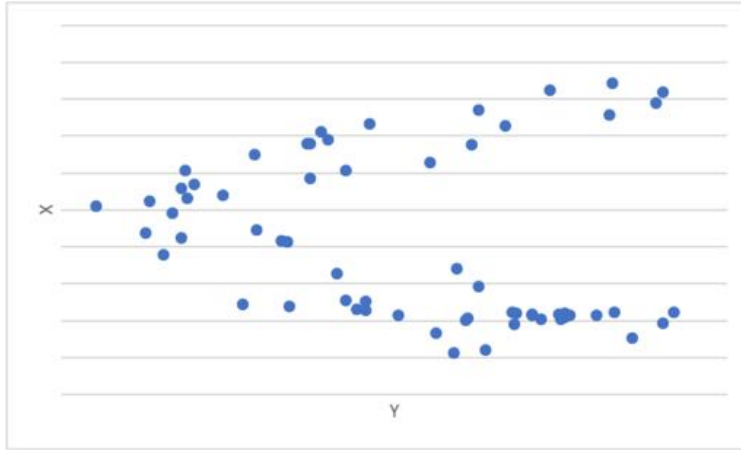
- Kinect set-up in laboratory to track people in real-time...



Tracking Output File  
+ Dose Rate Map  
+ Dose Conversion Algorithm



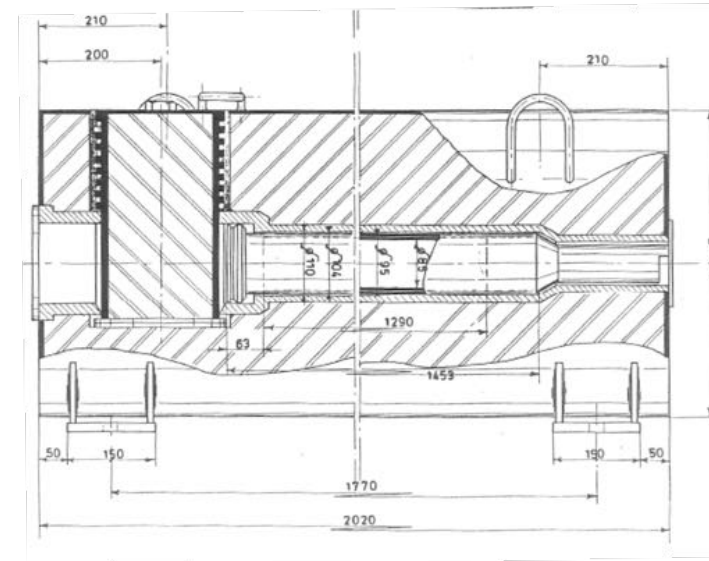
**Dose Data !**



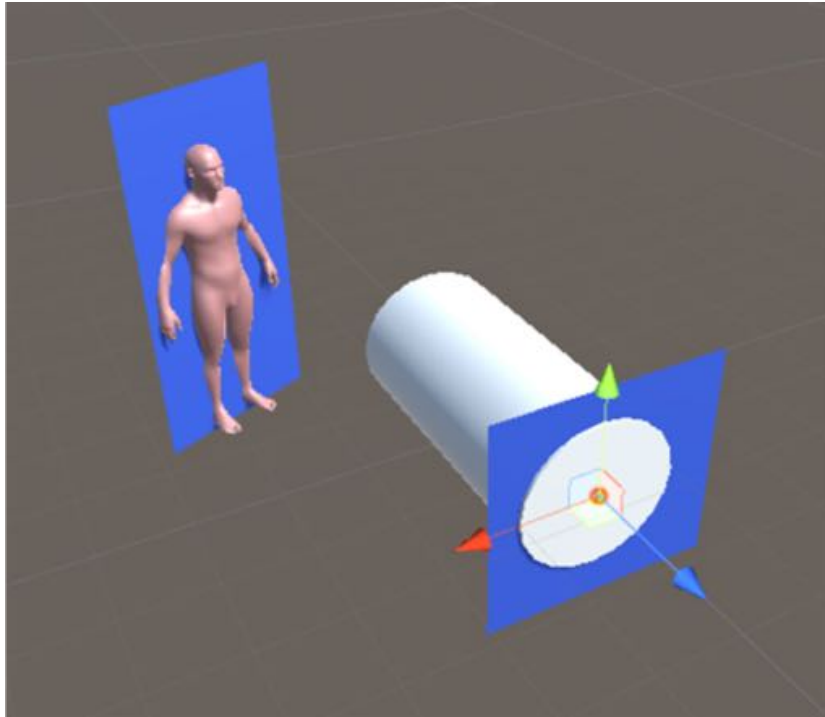
Dose Rate:	uSv/hr		1sd		uSv/hr		1sd		uSv/hr		1sd	
	(0,Y)	(100,Y)	(200,X)	(X,400)	(X,300)	(X,200)	(X,100)	(X,0)	(X,-100)	(X,-200)	(X,-300)	
	0.56	0.61	1.59	0.03	0.01	0.01	0.03	0.01	0.02	0.02	0.03	
	0.73	0.83	1.40	0.02	0.01	0.01	0.02	0.01	0.02	0.02	0.03	
	1.13	1.44	2.91	0.03	0.02	0.02	0.03	0.02	0.03	0.03	0.05	
	1.96	4.48	7.34	0.05	0.02	0.04	0.05	0.04	0.05	0.05	0.10	
	4.32	25.86	30.20	0.10	0.03	0.09	0.10	0.09	0.10	0.10	0.20	
	<b>SOURCE</b>	174.54	46.59	0.13	0.28	0.13	0.13	0.13	0.13	0.13	0.13	
	79.13	77.01	33.50	0.12	0.18	0.12	0.12	0.12	0.12	0.12	0.12	
	23.06	33.15	21.68	0.09	0.12	0.09	0.09	0.09	0.09	0.09	0.09	

Effective dose  $\sim 1\mu\text{Sv}$  in  $\sim 1\text{minute}$   $\Rightarrow$   $60\mu\text{Sv/hr}$  average

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



**Particularly challenging:** Precise source composition / geometry unknown!



MCNP modelling again used to generate dose rate map

Use plausible guess spectra for source → *Iterative approach*

μSw/h	X	0	1	2	3	4	5	6	7	8	9	10
		0	0.25	0.5	0.75	1	1.25	1.5	1.75	2	2.25	2.5
Y	7	1.75										
6	1.5					C, E, F			0			
5	1.25											
4	1											
3	0.75											
2	0.5					A						
1	0.25											
0	0											
-1	-0.25											
-2	-0.5											
-3	-0.75											
-4	-1											
-5	-1.25											

50×50cm<sup>2</sup> (x,y) grid, heights: 18, 55 and 125 cm





## Personal dosimeter response varies greatly with position...

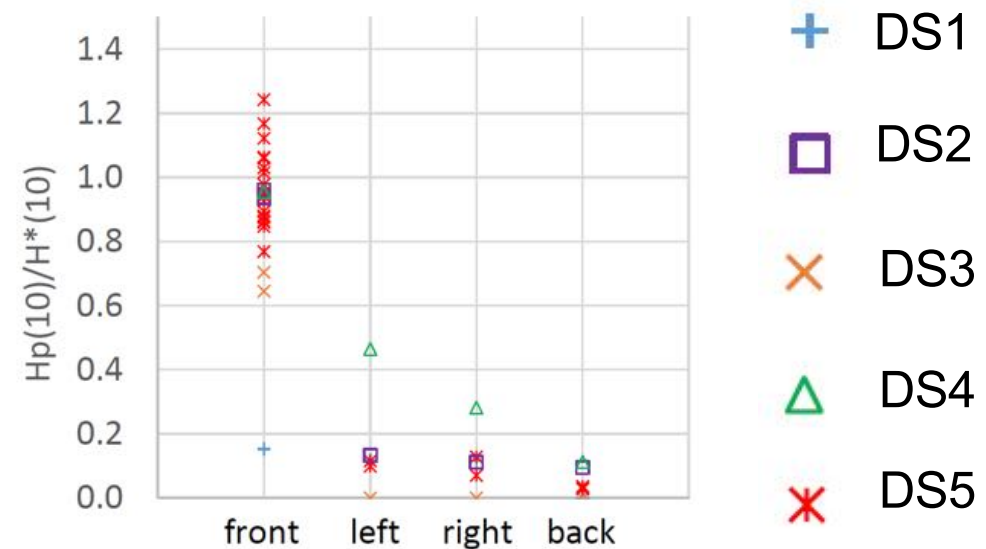


Position C:  $H_p(10)/H^*(10)$

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

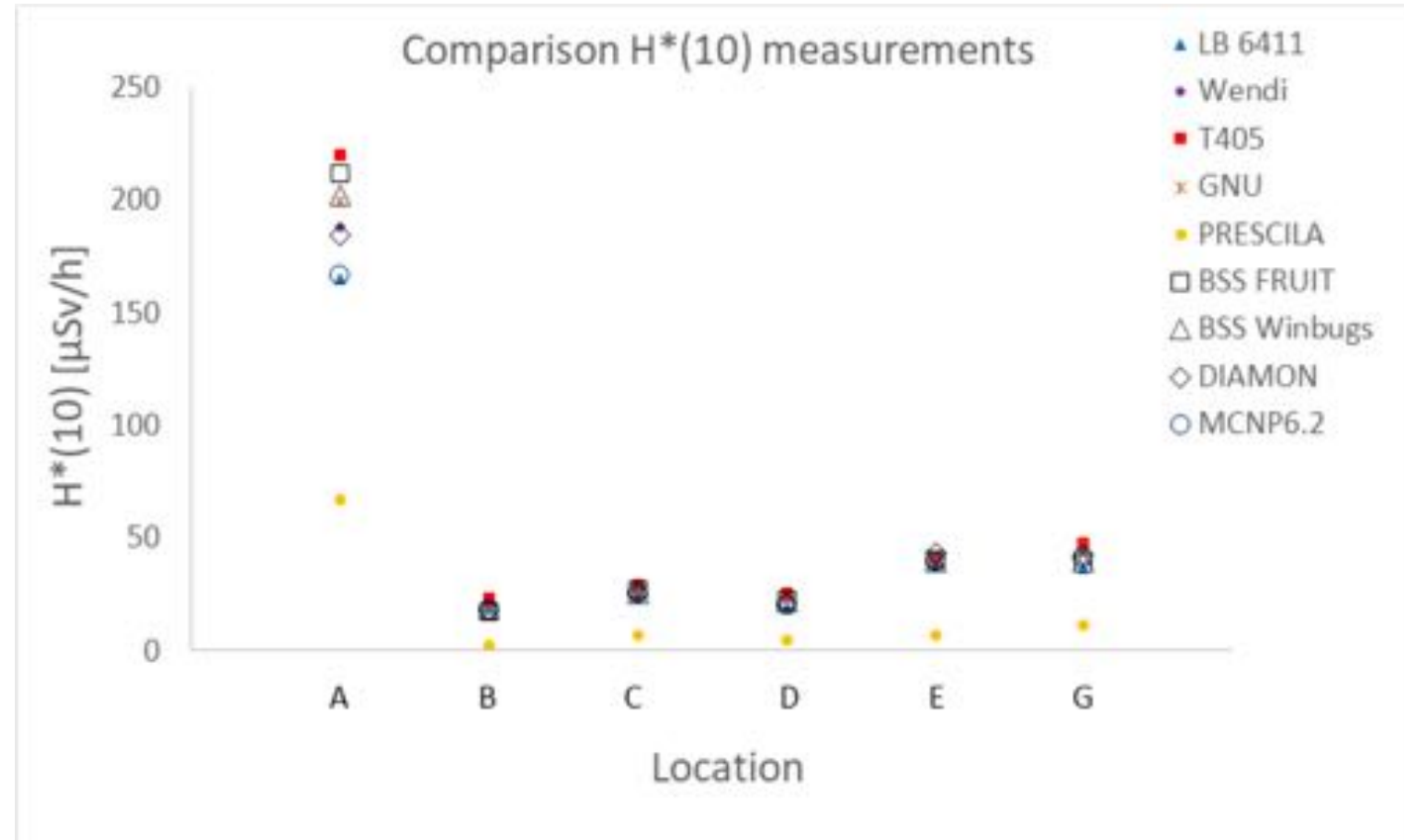
Average: 0.99  
Stdev: 13%  
Max/min: 1.4

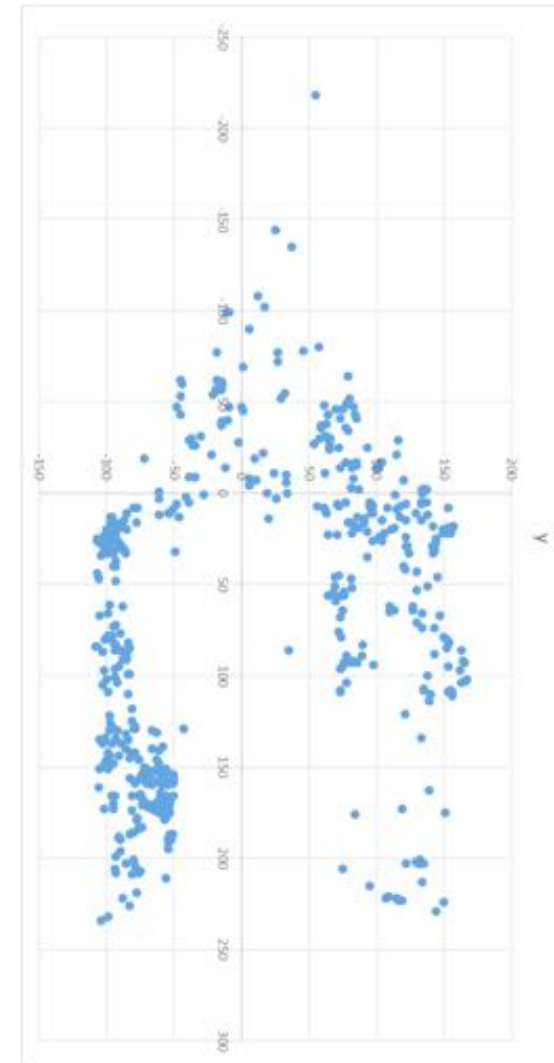
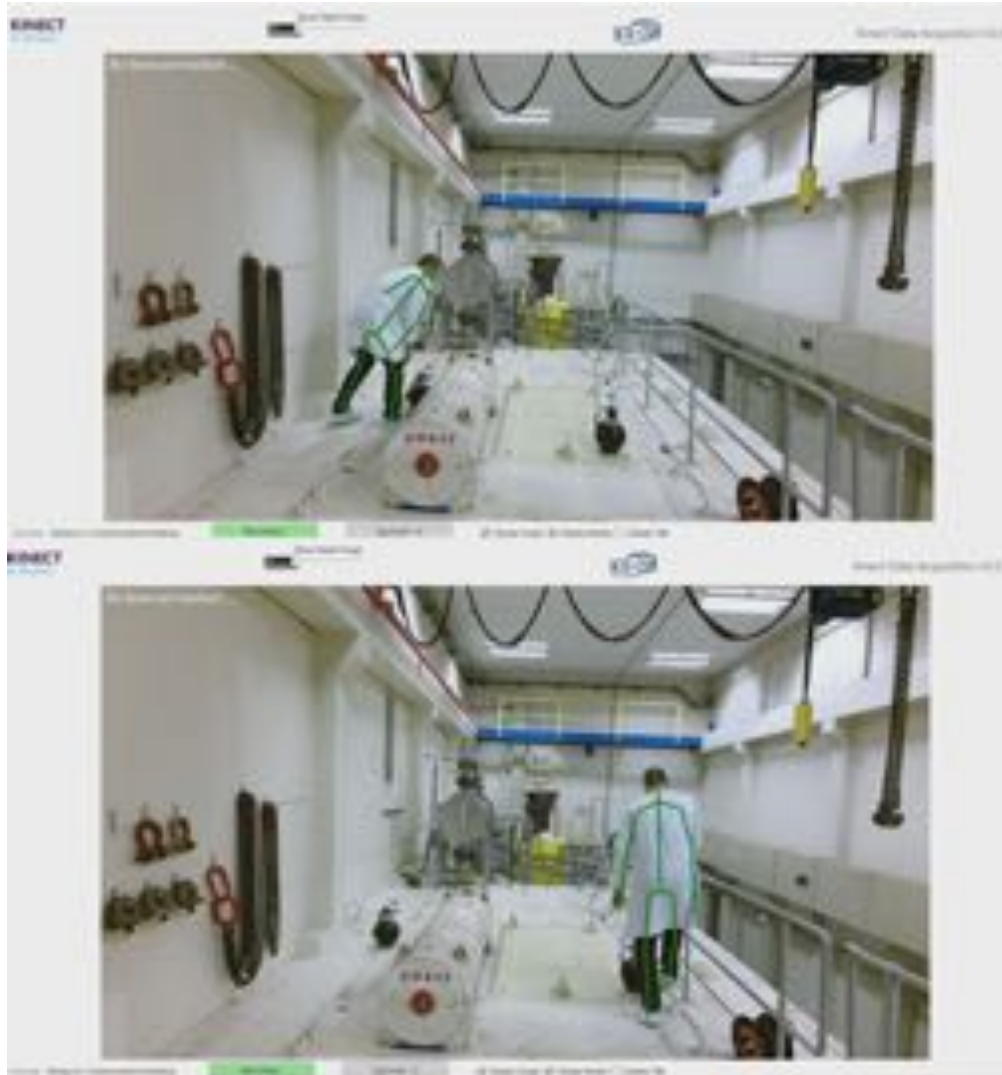
Location C



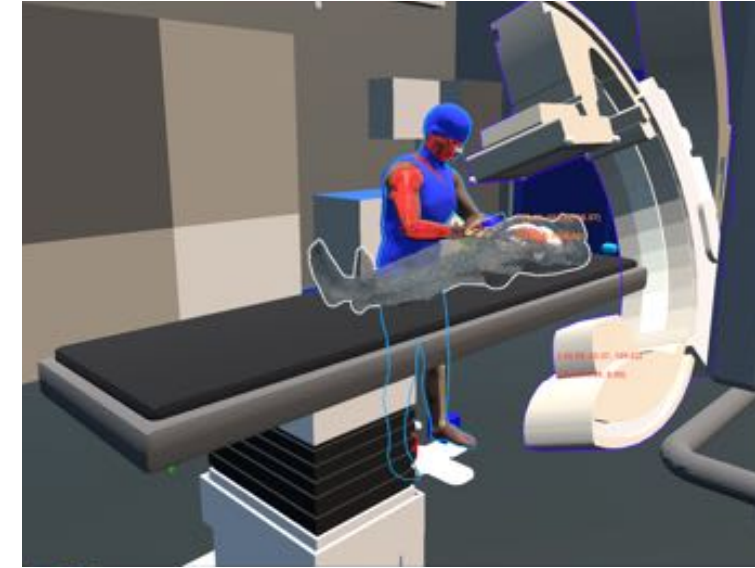
Early comparisons of Modelled vs. Measured data look promising...

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





- 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](http://www.podium-concerth2020.eu)





# Thank you for your attention



The PODIUM team



<https://podium-concerth2020.eu/>



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