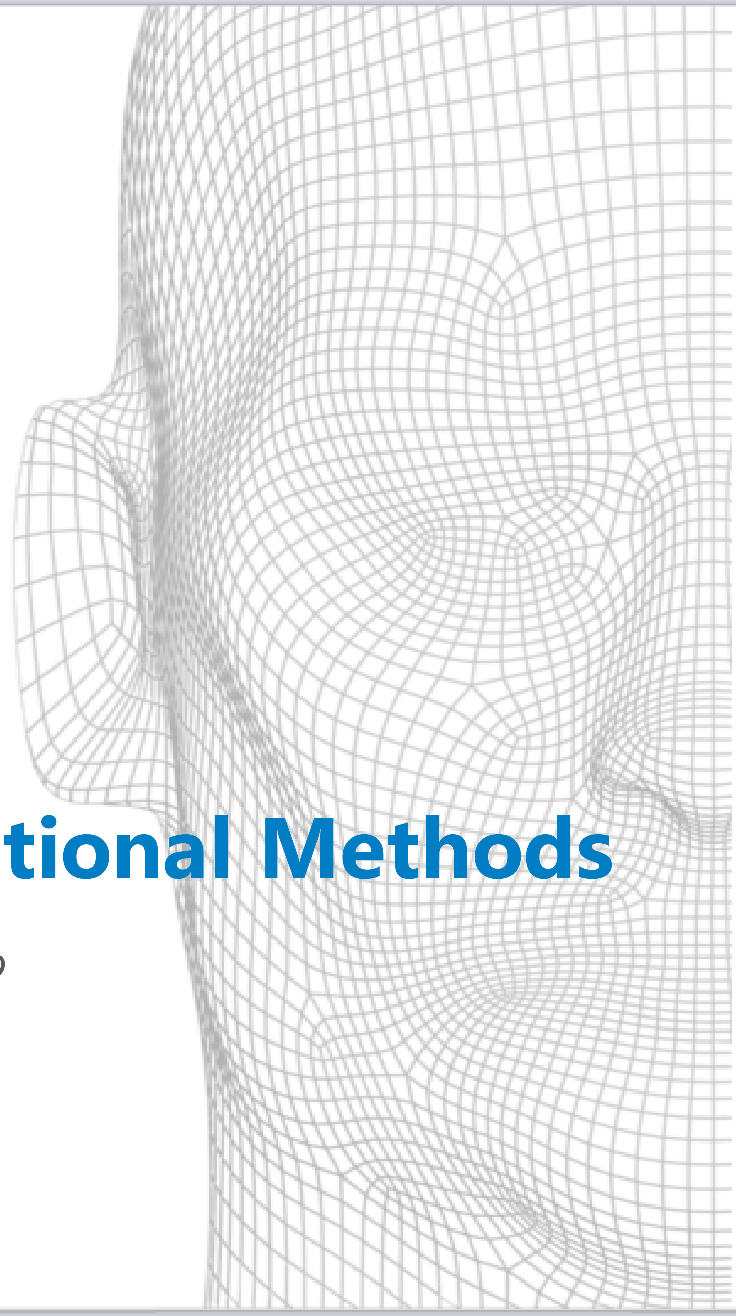
SCK•CEN

STUDIECENTRUM VOOR KERNENERGIE
CENTRE D'ETUDE DE L'ENERGIE NUCLEAIRE



Personal Online DosImetry Using CoMputational Methods

Filip Vanhavere, Mahmoud Abdelrahman, Pasquale Lombardo

Framework for individual monitoring: why is dosimetry needed

Individual monitoring of workers

Control occupational exposure

Dose limits and ALARA principle

Inform workers of their exposure

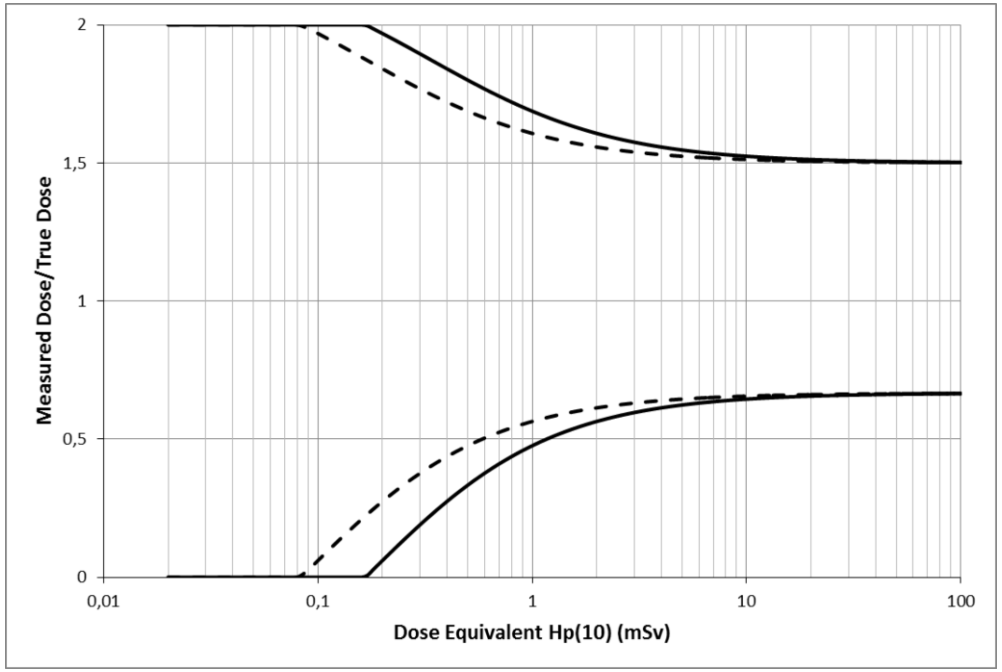
Dose	Annual Limit
Effective Dose	20 mSv
Eye Lens	20 mSv
Extremities	500 mSv/year

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

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….
- Loosing dosemeter: all data lost…
- Not wearing correctly
  - Dependent on homogeneity of the field

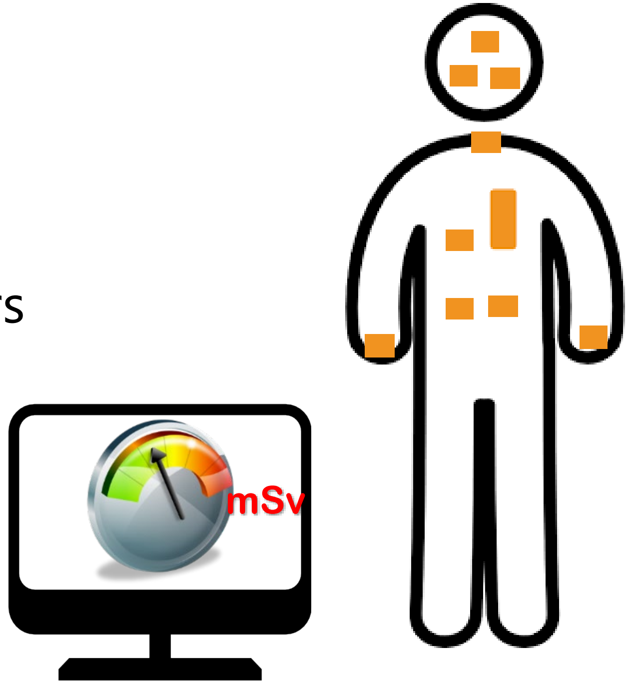


Factor 1.5 in either direction for doses near the limit
Factor 2.0 for lower doses (ICRP 75)

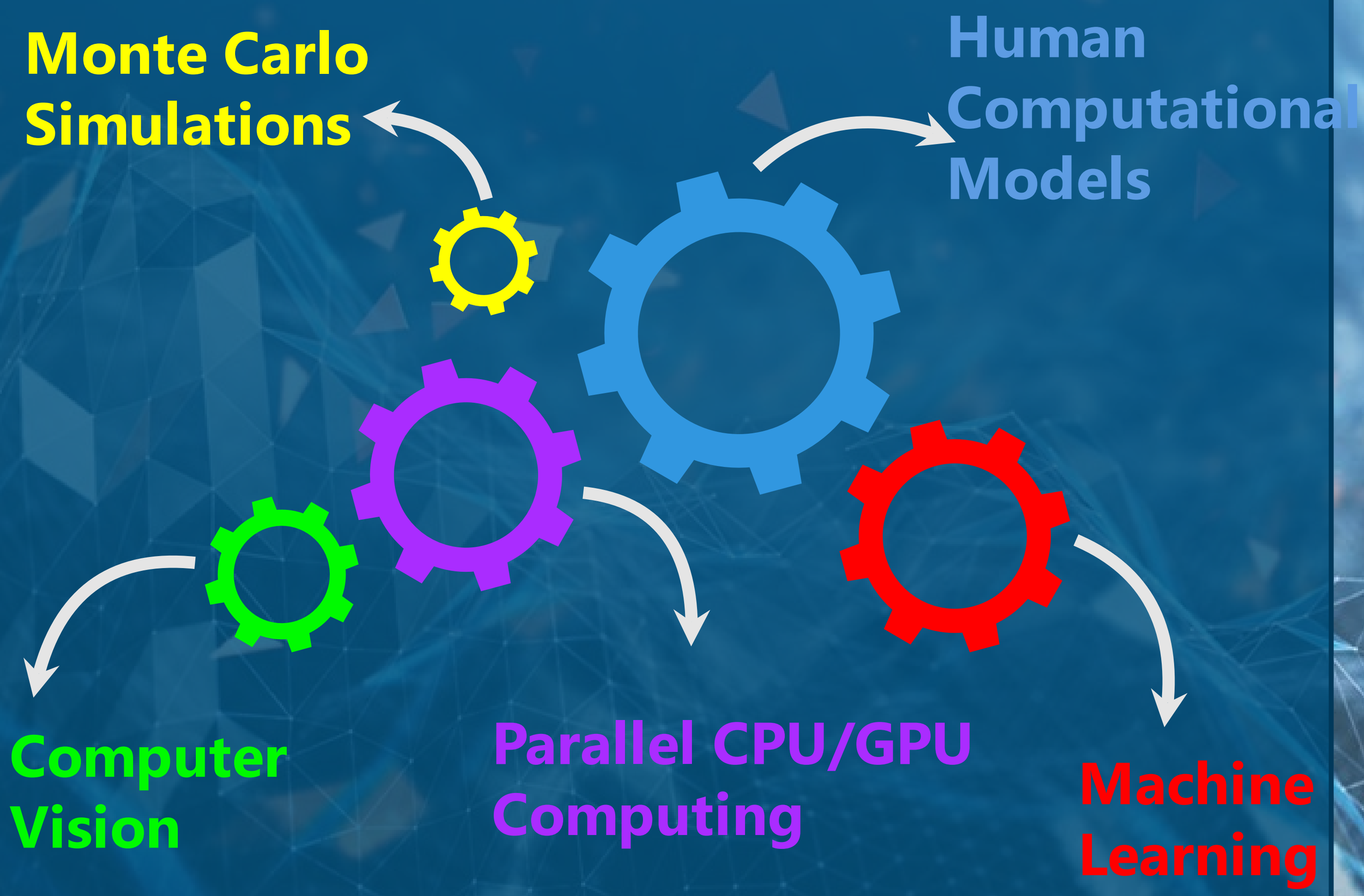
Personal Dosimetry: what brings the future?

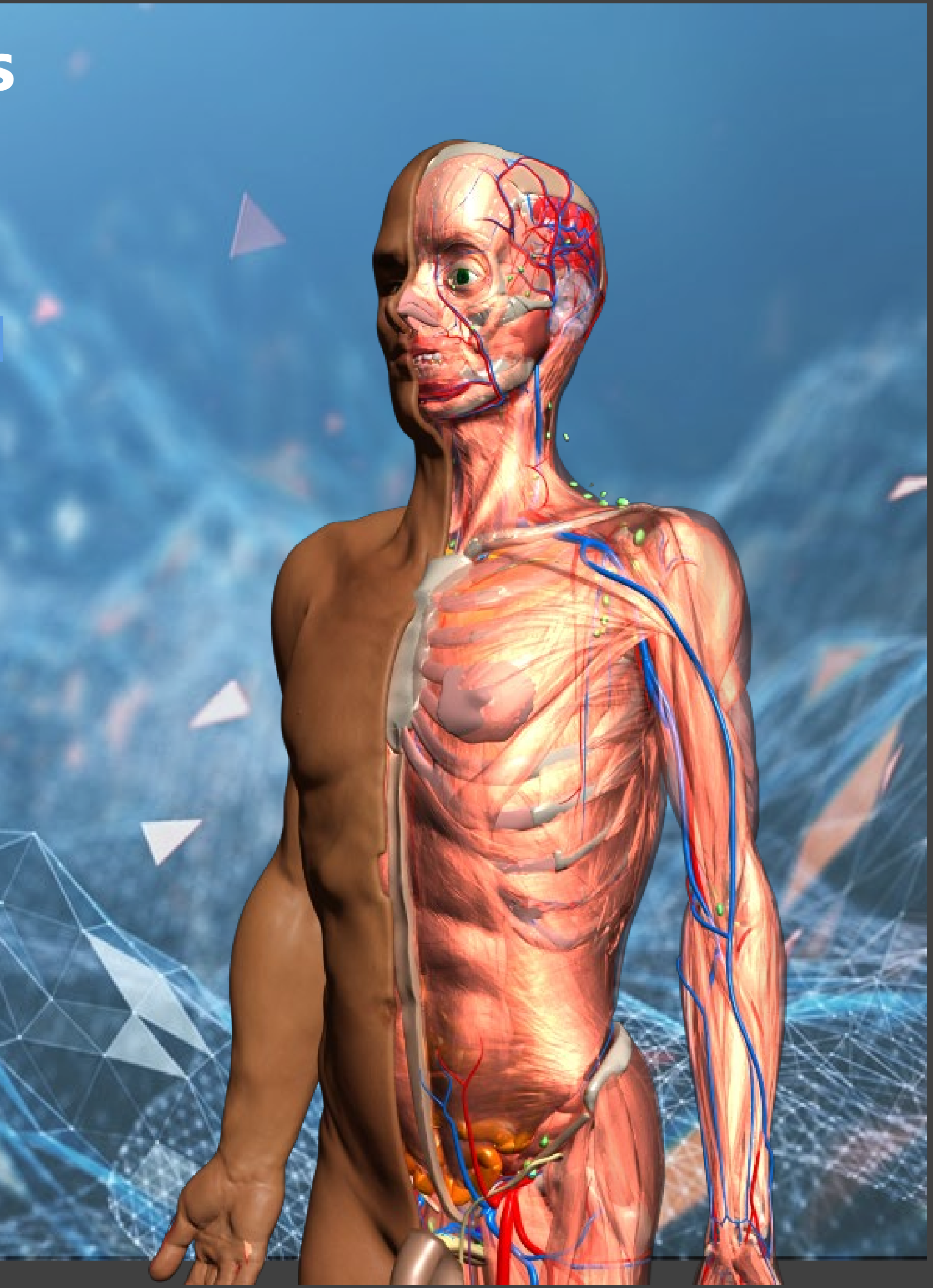
- More use of active personal dosemeter: direct feedback

- 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
  - ....



Exploiting most advanced technologies





PODIUM: Personal Online DosImetry Using computational Methods

- CONCERT 2nd Call
- EC project

- 24 months, start January 2018

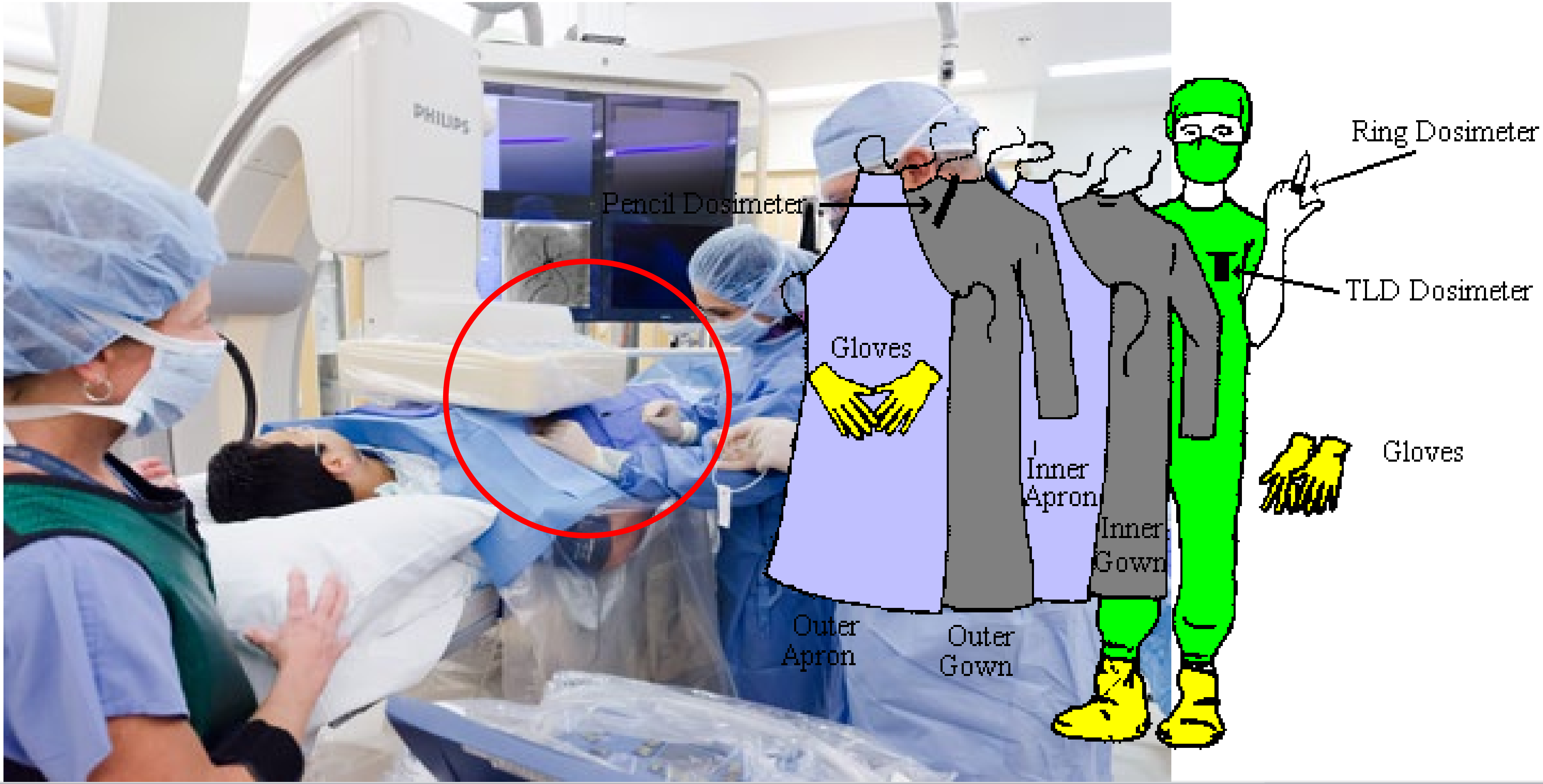
- 7 partners: SCK•CEN (Belgium), UPC (Spain/Catalunya), HMGU (Germany), LU (Sweden), PHE (UK), EEAE (Greece), SJH (Ireland)

PODIUM Objectives

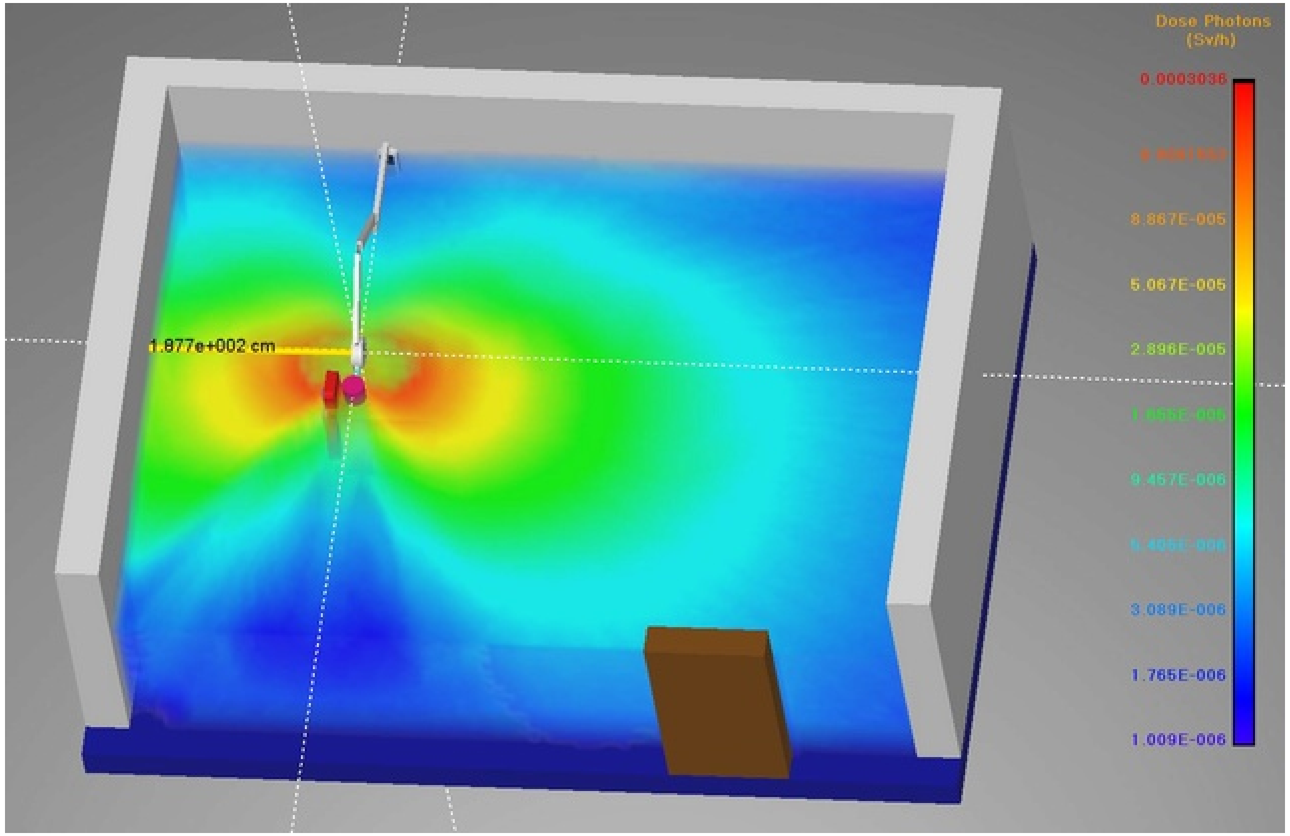
- **Improve occupational dosimetry** via an online dosimetry application using computer simulations: without the use of physical dosemeters
- **Develop an online application** in which we will calculate individual occupational doses
- **Apply and validate** the methodology for two situations where improvements 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

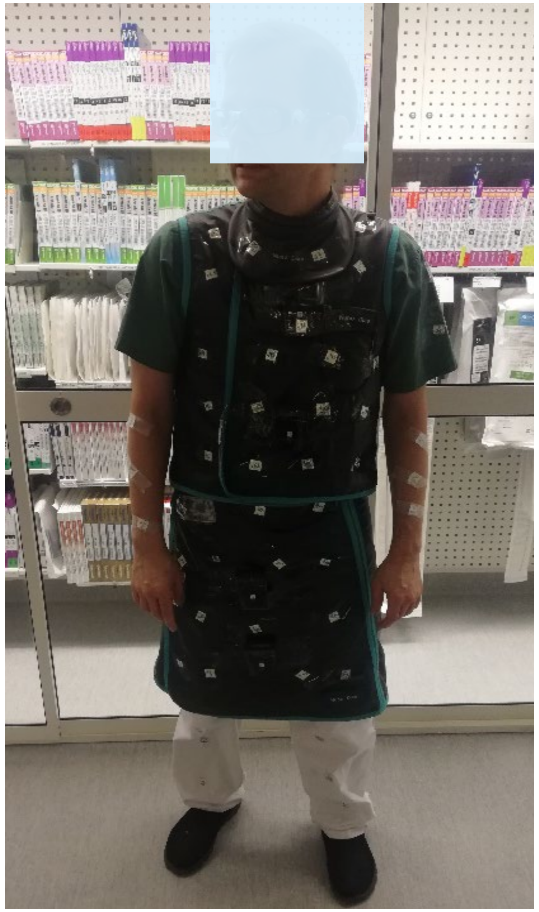
→ **FEASIBILITY STUDY**

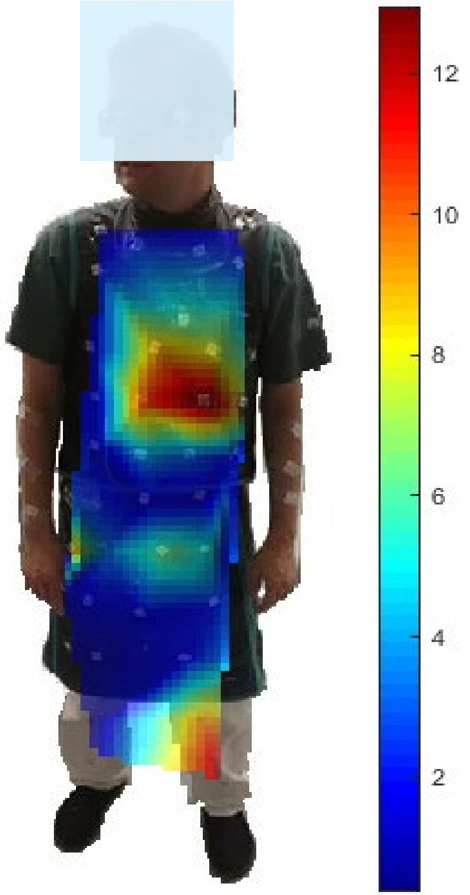
Personal Dosimetry: Interventional Radiology



Personal Dosimetry: Inhomogeneous fields

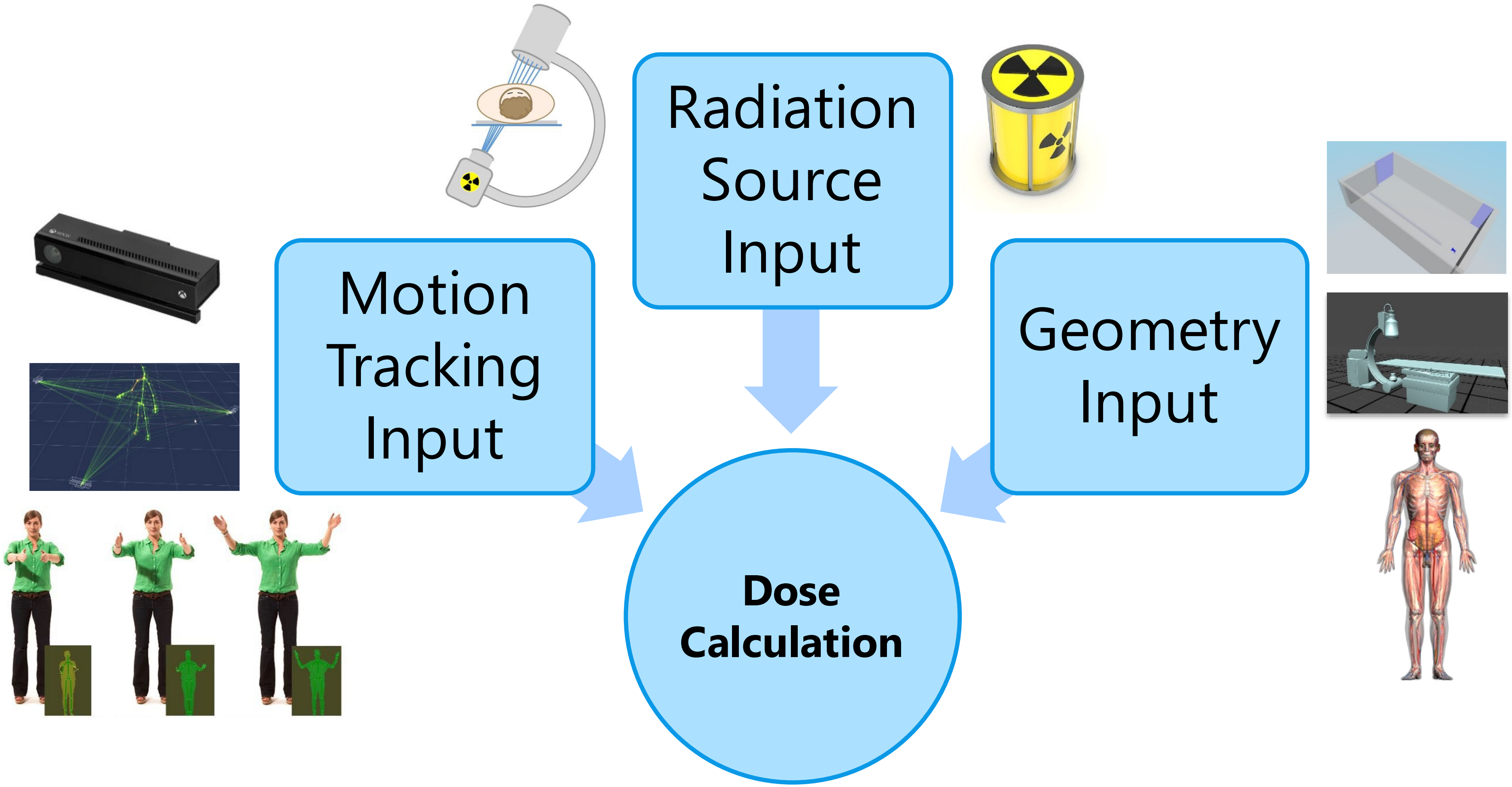






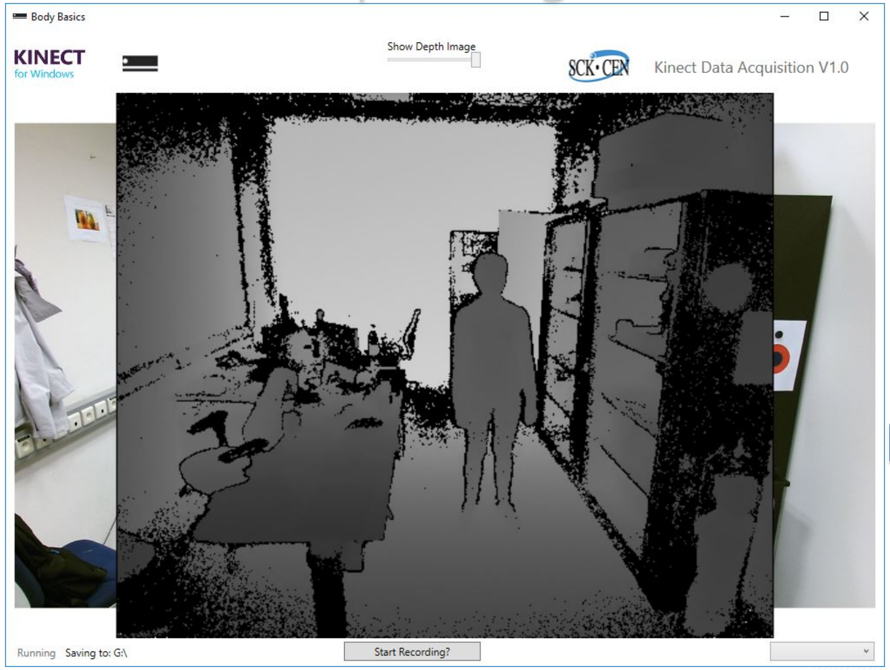
Dose Simulations Input

Staff movement monitoring and Radiation field mapping

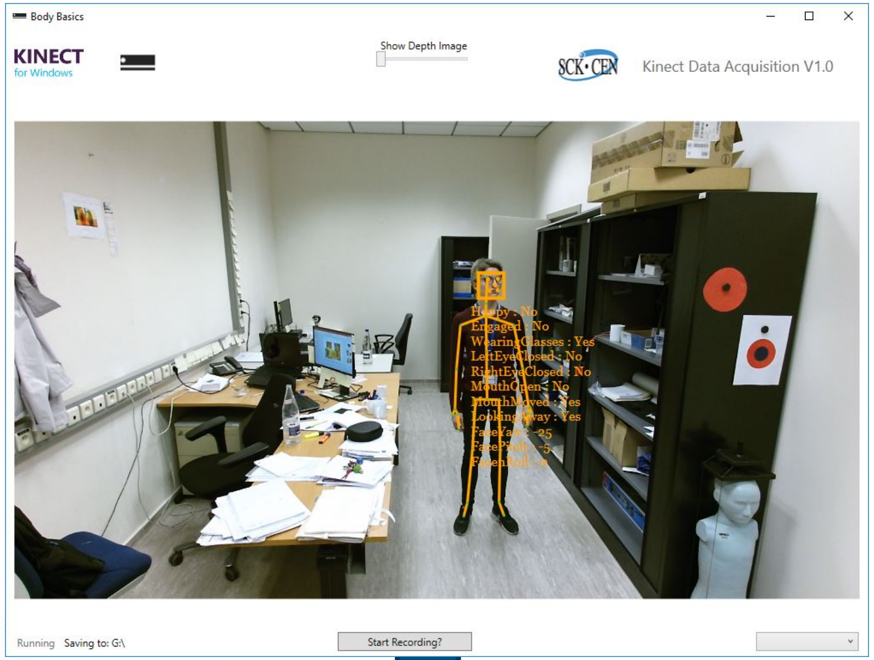


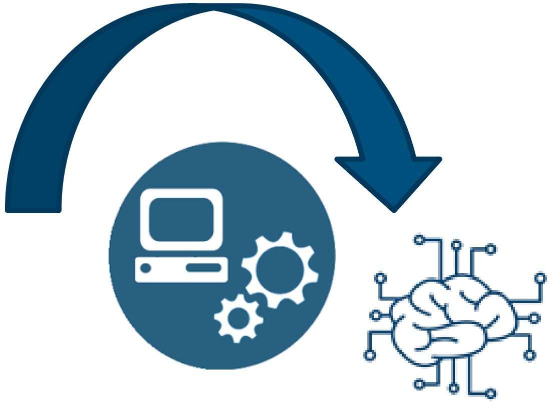
Tracking system based on single depth camera

Depth Image

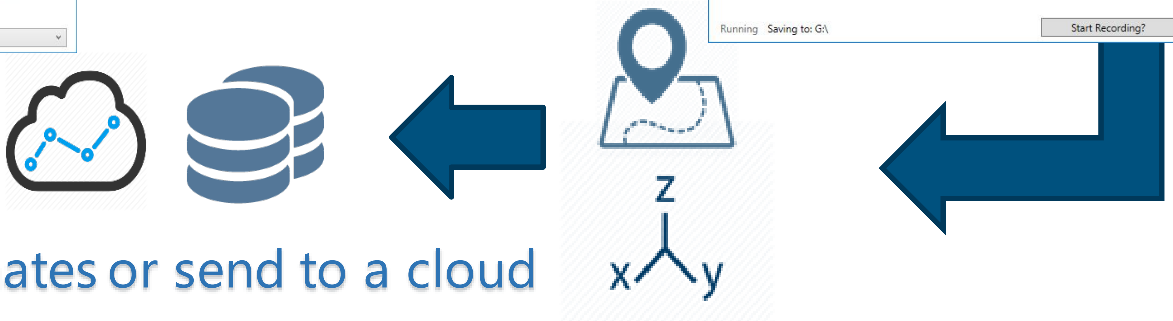


Skeleton Tracking





Real-time processing



Storing XYZ coordinates or send to a cloud

RAF: Realistic Anthropomorphic Flexible Phantom

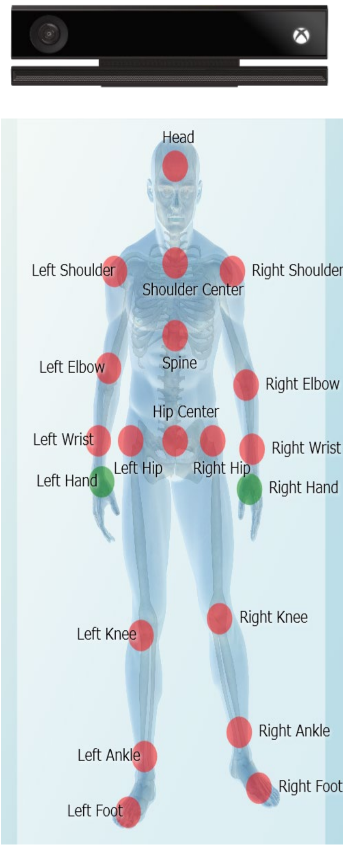
- Polygonal Mesh Boundary Representation
- Organ and tissue masses adjusted according to ICRP 89
- Computational model with 2900 tissues segmented
- Dosimetric validation in comparison with ICRP 116

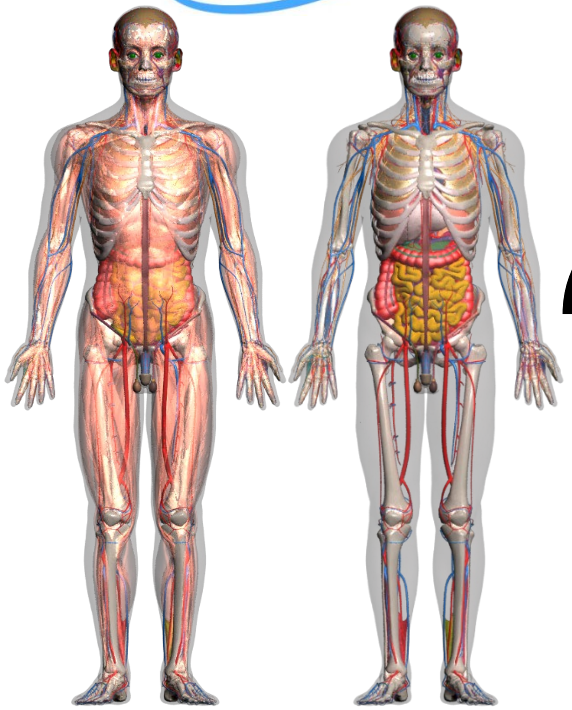
Development and Validation of the Realistic Anthropomorphic Flexible (RAF) Phantom

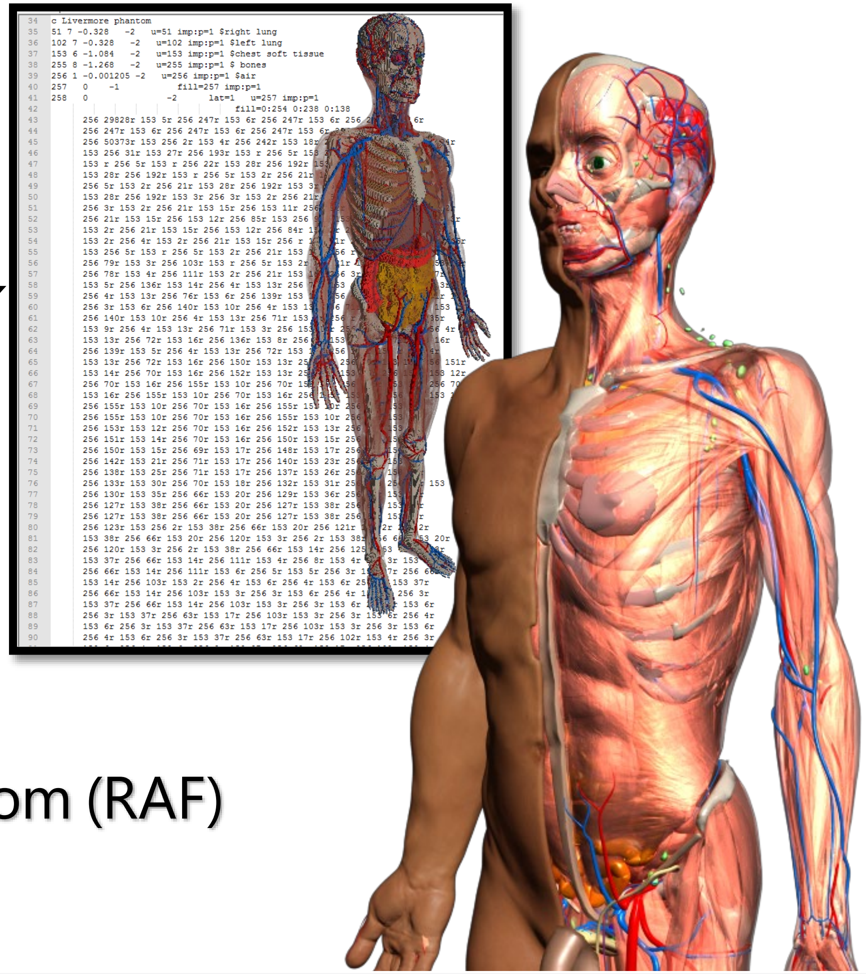
Lombardo, Pasquale A.; Vanhavere, Filip; Lebacq, Anne L.; Struelens, Lara; Bogaerts, Ria

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

Tracking to computational phantom

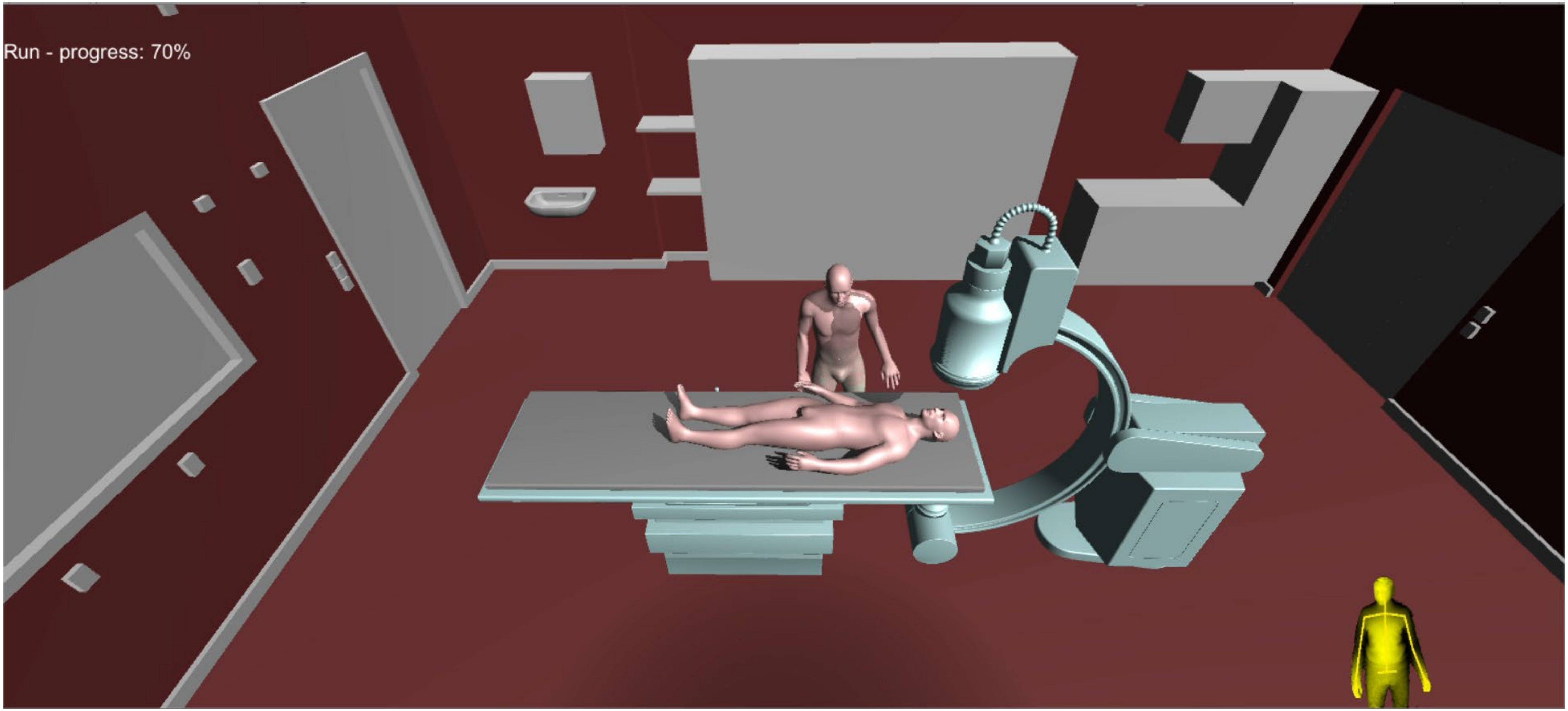






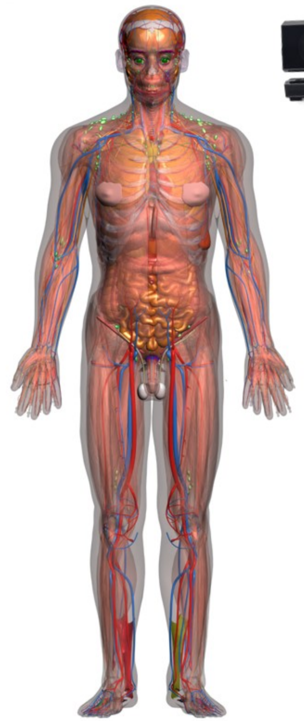
Realistic Anthropomorphic Flexible Phantom (RAF)

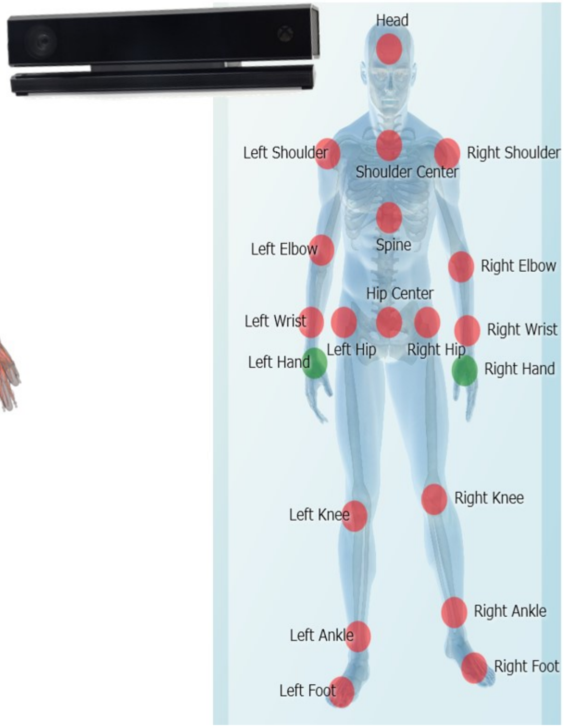
Animation of RAF phantom

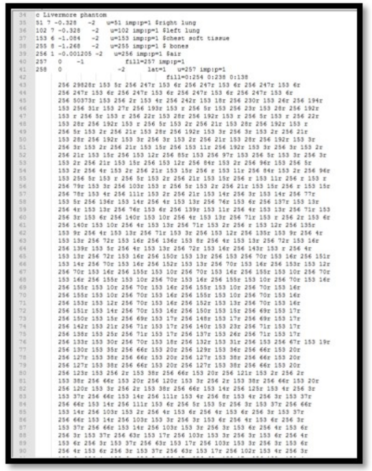


Computational phantom framework

RAF mesh phantom → Pose capture → Voxelization → MCNPX







Geometry Input

- Define of the workplace geometry for the calculations

Geometrical input

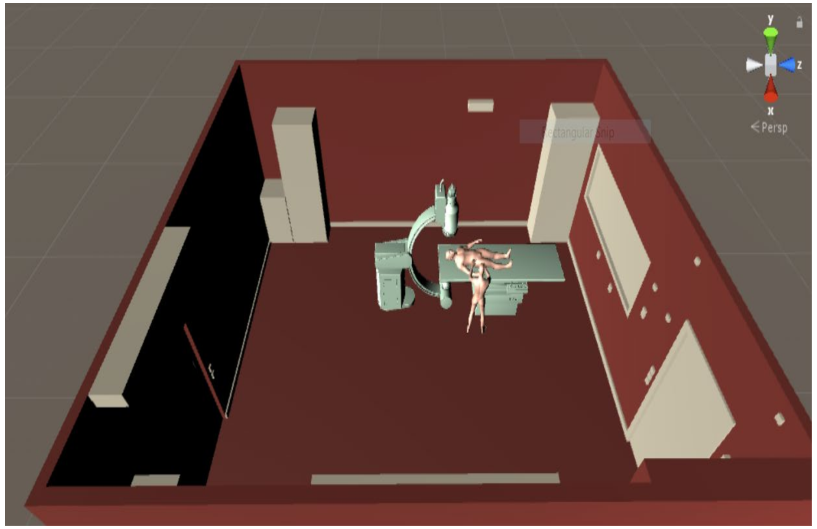
From Technical Drawings
Survey Techniques
Photogrammetry
Laser Scanning

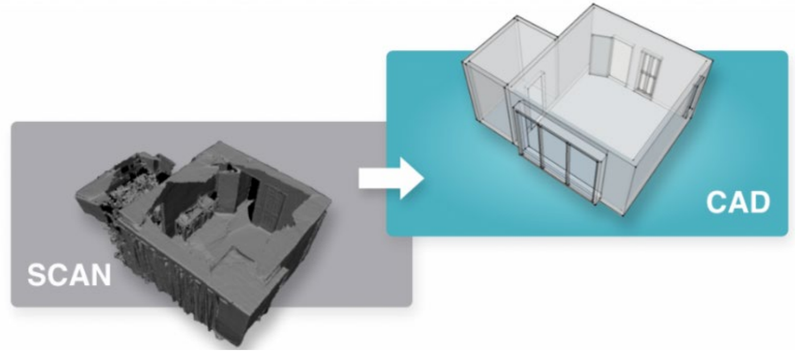
Primitive Volumes

Material input

Technical Data
Experts on site

Material Dataset





- Complex geometries can be prepared by:
  - ❑ Scanning of the workplace
  - ❑ Converting CAD files to different formats
- Modeling and tracking of important moving objects (**shielding**) is also needed

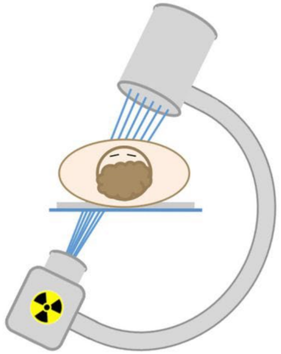
Radiation Source Input: Radiology Case

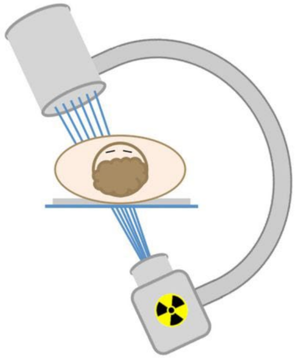
X-Ray spectrum

- 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


IPP - RAF phantom
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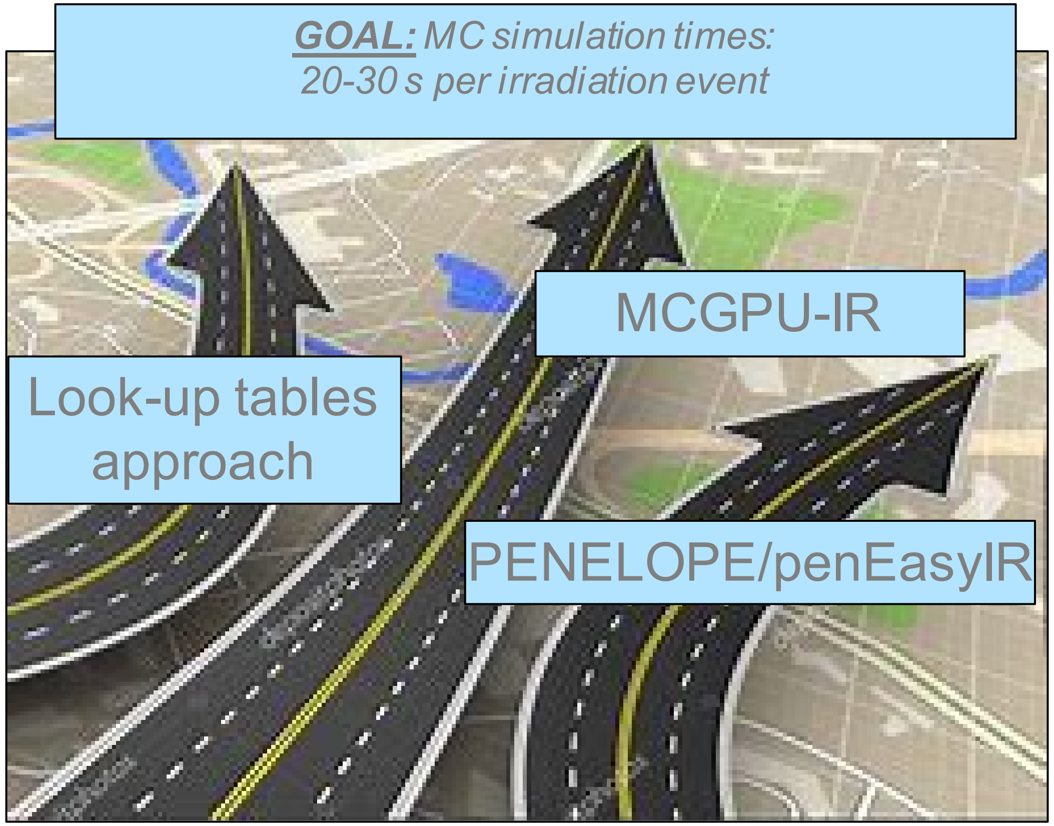
CENTRE D'ETUDE DE L'ENERGIE NUCLEAIRE
Standard position
No room
Selected EndEffector
Head
Inverse Kinematic
KINECT
IR Room definition
IR room
Rotate C-Arm
Move bed
effective dose [Sv/(Gy DAP)] * (voxel volume)
0.00011235715069231
Calculate Bounding Box
Res x
Res y
Res z
256
512
256
(-43.07, 121.76, 51.51)
load MCNP PTRAC
Batch mode (seconds)
30
KINECT angle (degs)
-10
Source position
PNG stack for VoxelVis
VoxelVis
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
High Res? cut legs!
PP graphics
OBJ
ASCII STL
BINARY STL
Export Mesh for Geant4
Voxelize on GPU
launch MCNP sim

Computational dosimetry … the solution?

Challenge: Make Monte Carlo calculations fast enough



Fast Monte Carlo methods for interventional procedures

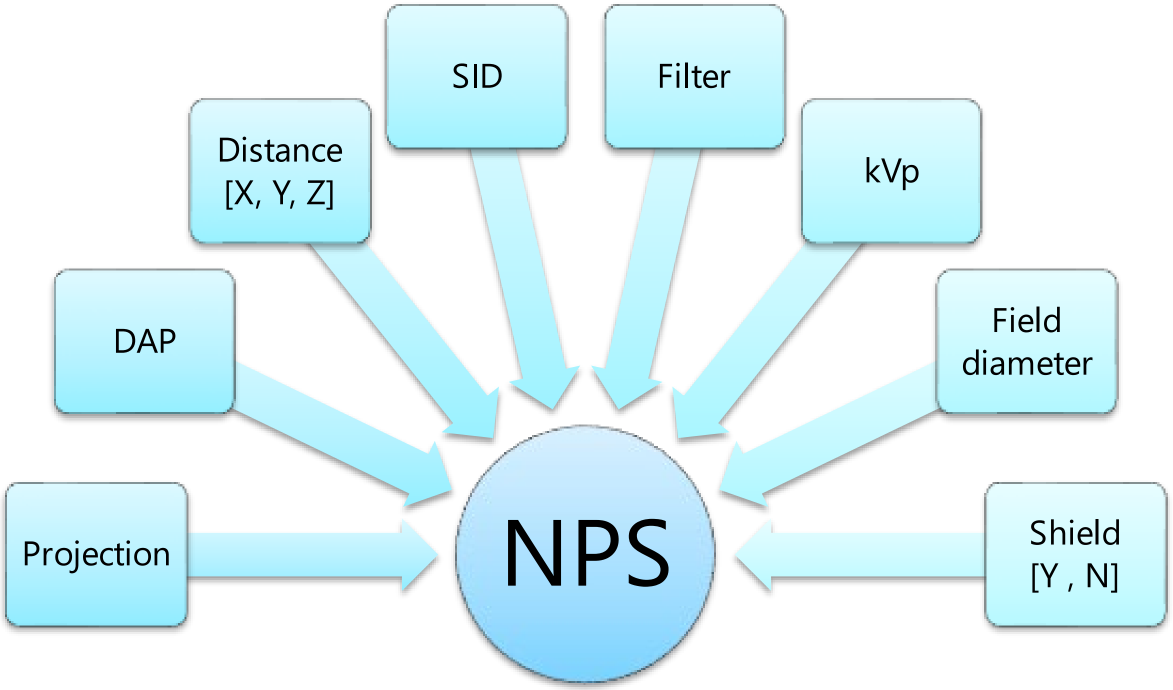
MCGPU-IR

Based on MC-GPU (2009) a MC code for the simulation of photon transport in restricted geometrical set-up's

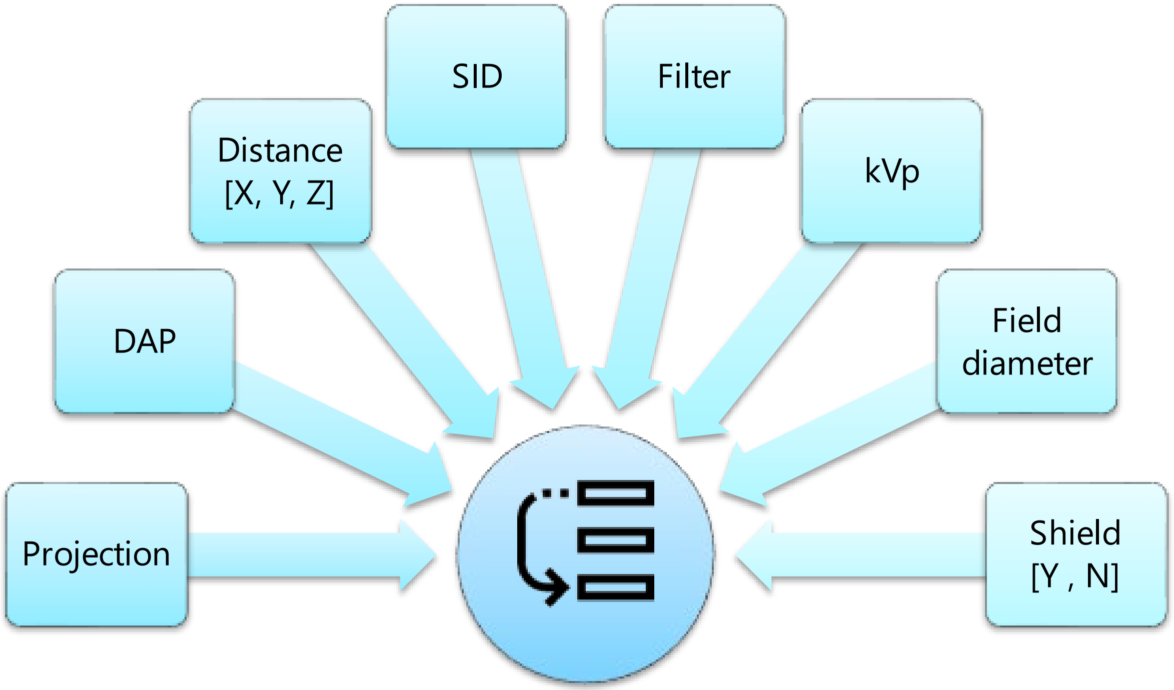
PENELOPE/penEasyIR

Based on PENELOPE v2014, a standard multi-purpose MC code

Optimization Algorithm

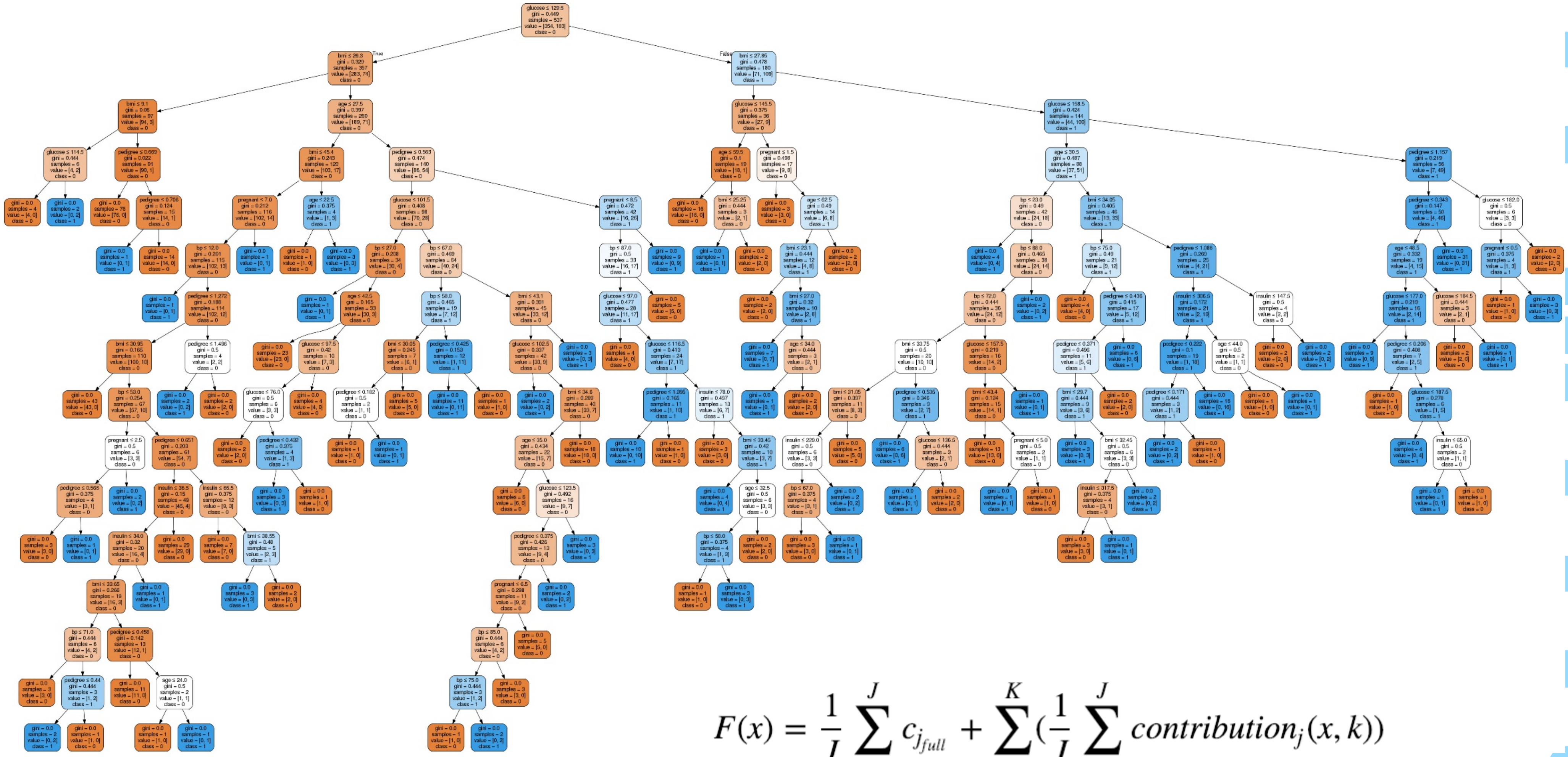


Optimized simulation time
NPS: number of simulated particles

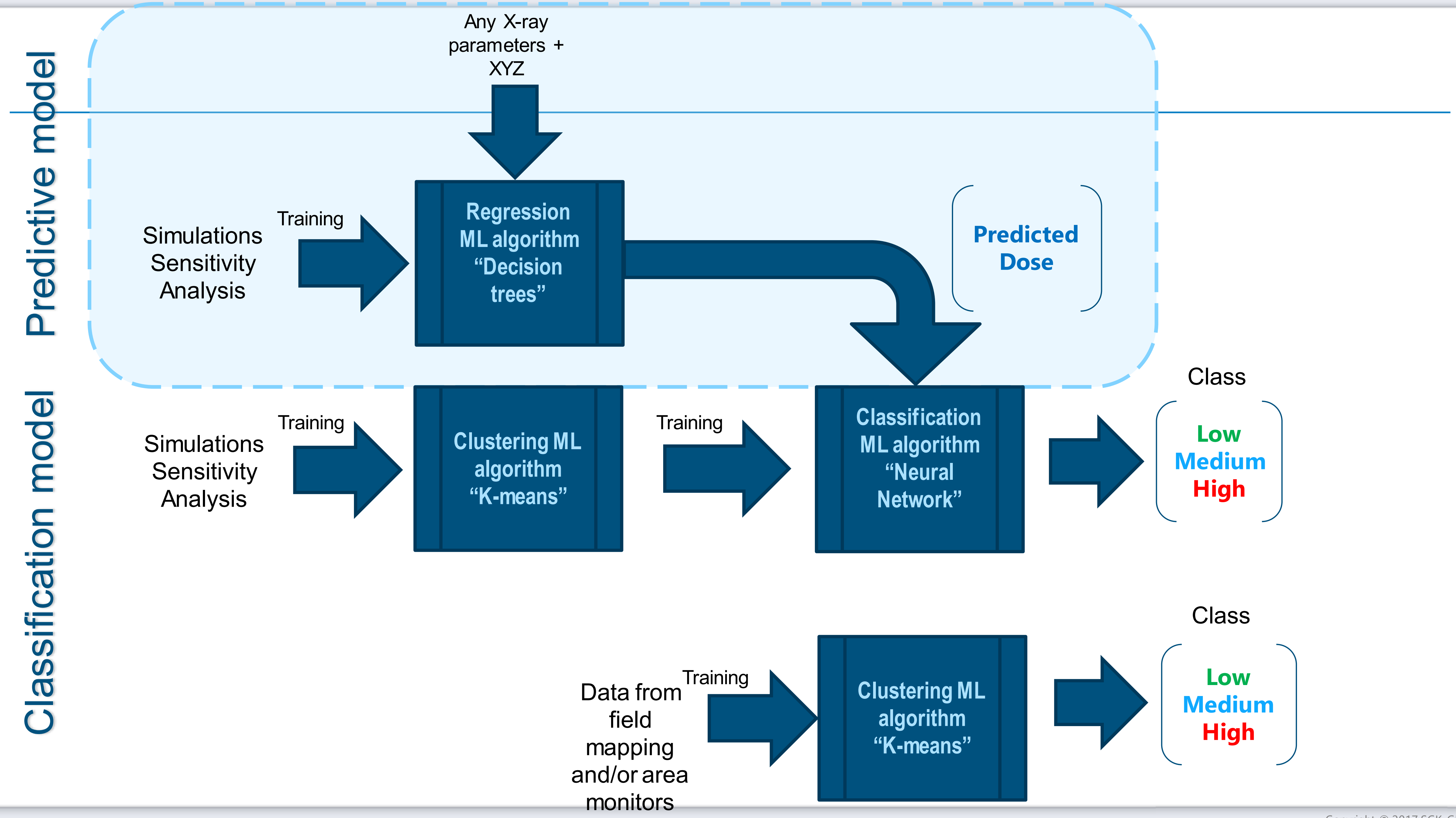


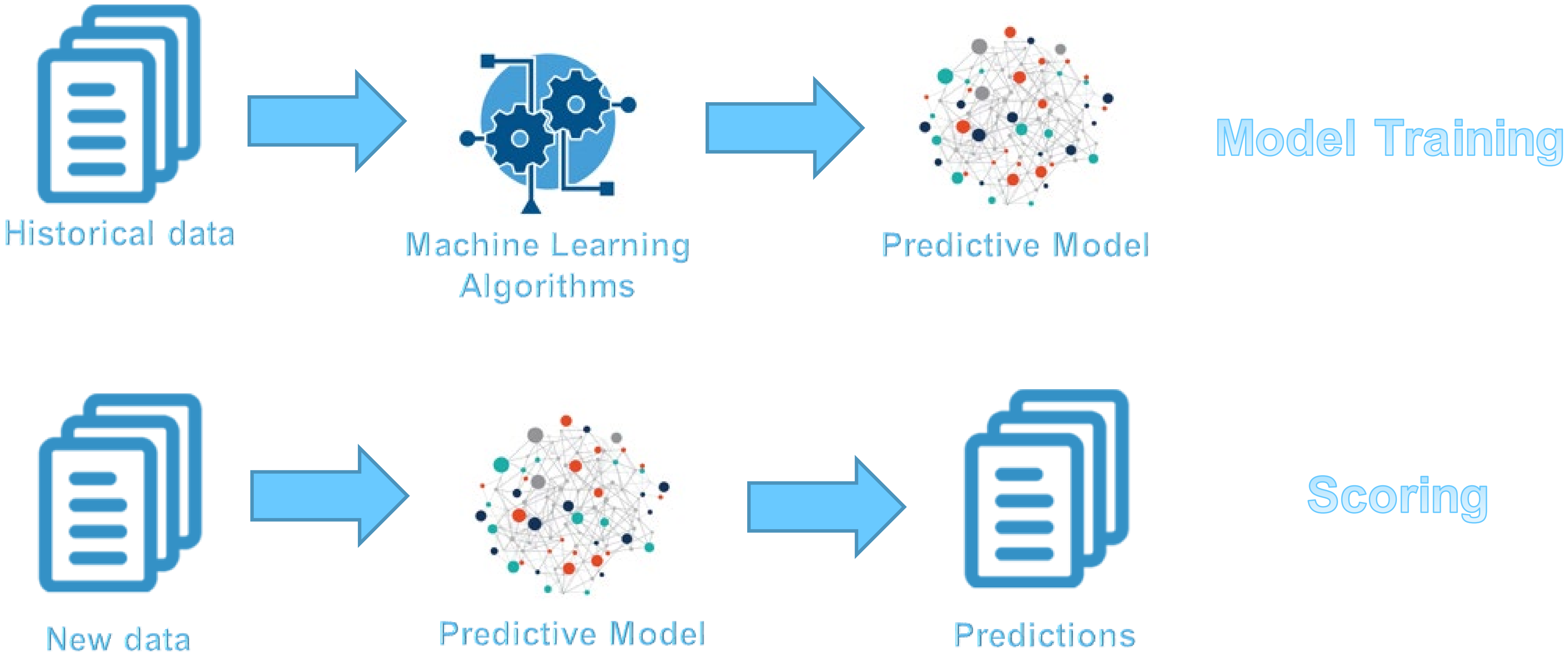
Prioritization of simulations
Irradiation event with high dose

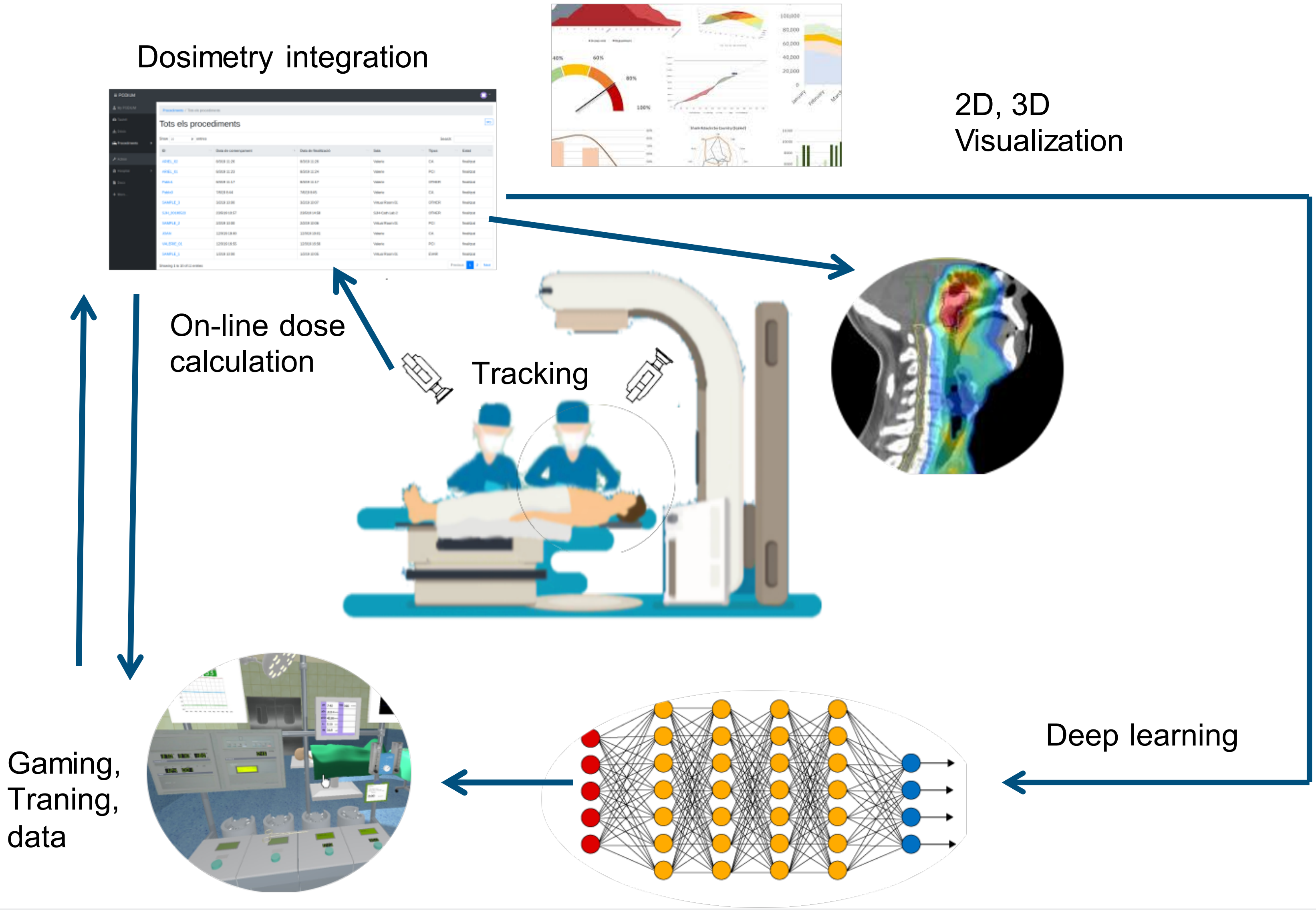
Data analysis: Random forest regressor



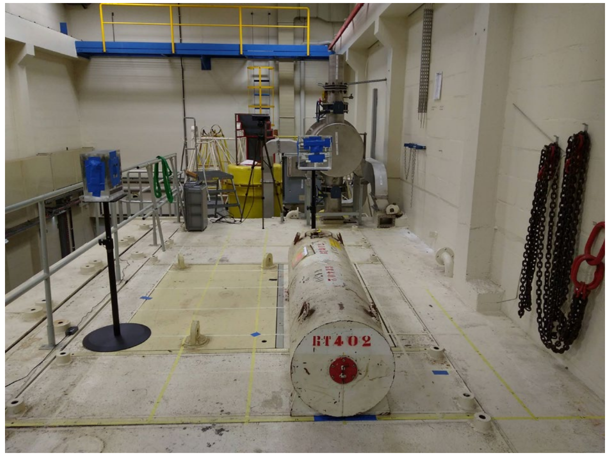
$$F(x) = \frac{1}{J}\sum_{j=1}^{J} c_{j_{full}} + \sum_{k=1}^{K}\left(\frac{1}{J}\sum_{j=1}^{J} contribution_j(x,k)\right)$$


Predictive model
Classification model
Any X-ray parameters + XYZ
Simulations Sensitivity Analysis
Training
Regression ML algorithm "Decision trees"
Predicted Dose
Simulations Sensitivity Analysis
Training
Clustering ML algorithm "K-means"
Training
Classification ML algorithm "Neural Network"
Class
Low
Medium
High
Data from field mapping and/or area monitors
Training
Clustering ML algorithm "K-means"
Class
Low
Medium
High


Historical data
Machine Learning Algorithms
Predictive Model
Model Training
New data
Predictive Model
Predictions
Scoring


Dosimetry integration
Tots els procediments
2D, 3D
Visualization
On-line dose
calculation
Tracking
Gaming,
Traning,
data
Deep learning

Validation

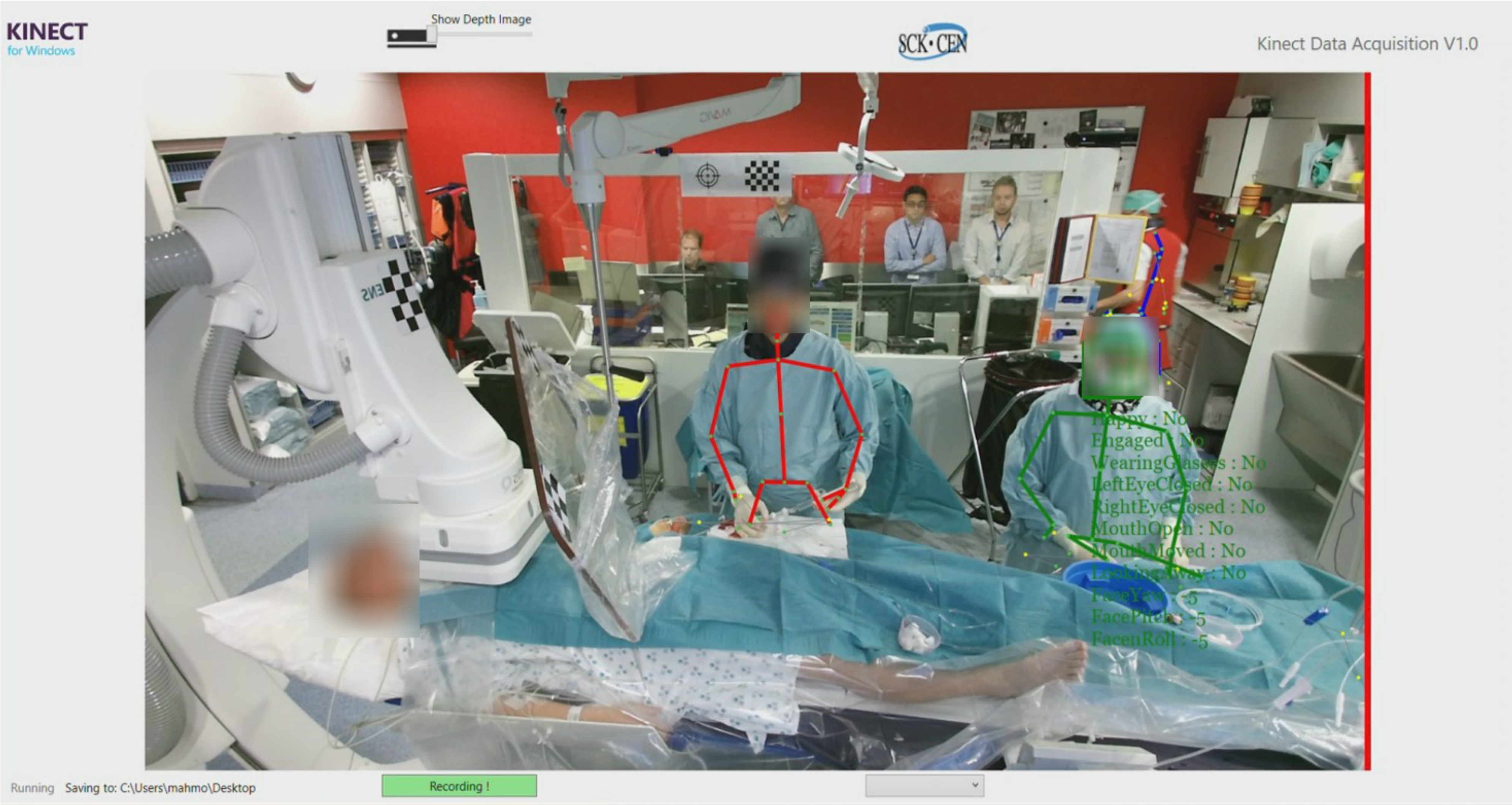


PODIUM
Personal Online Dosimetry
Using computational Methods

CONCERT

Universitair
Ziekenhuis
Brussel

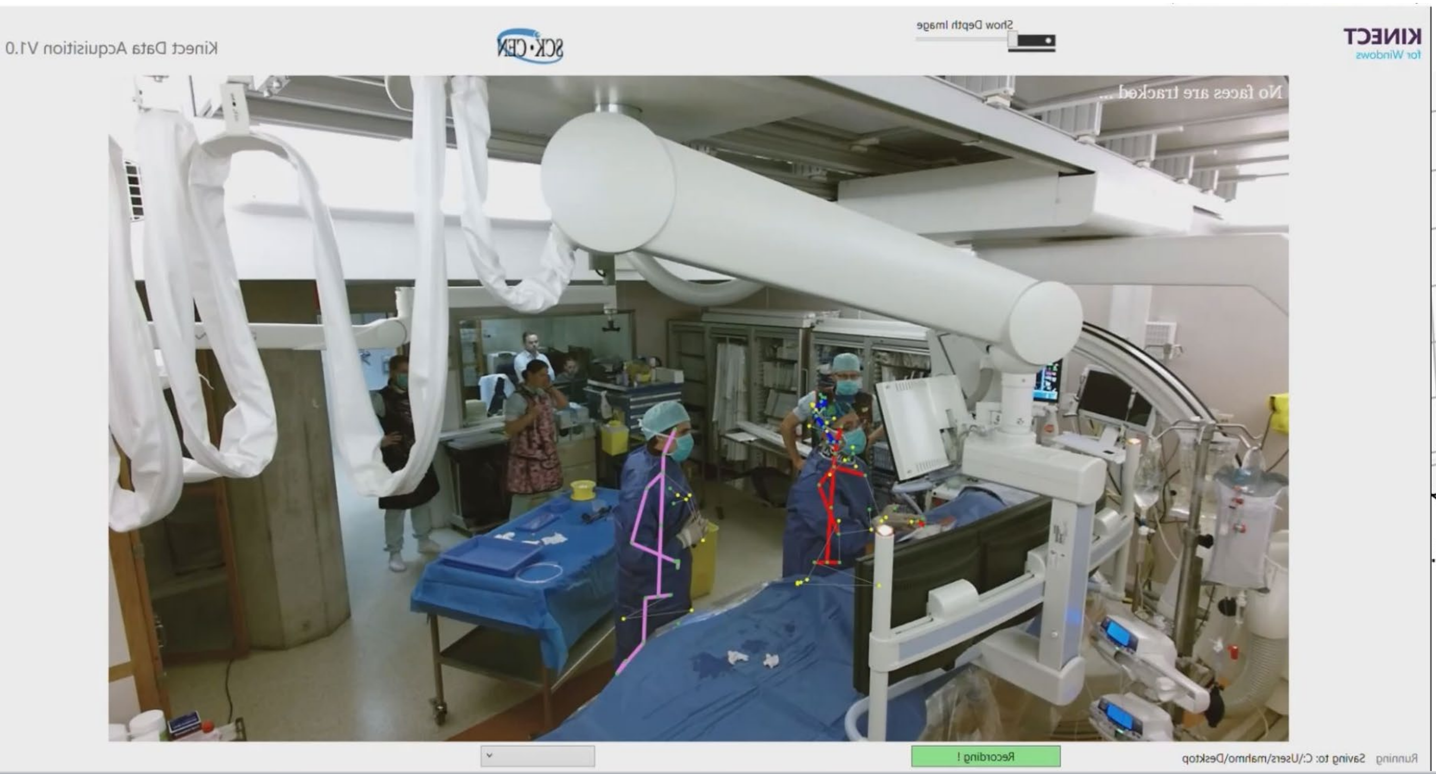
Test at UZ-VUB - Brussels

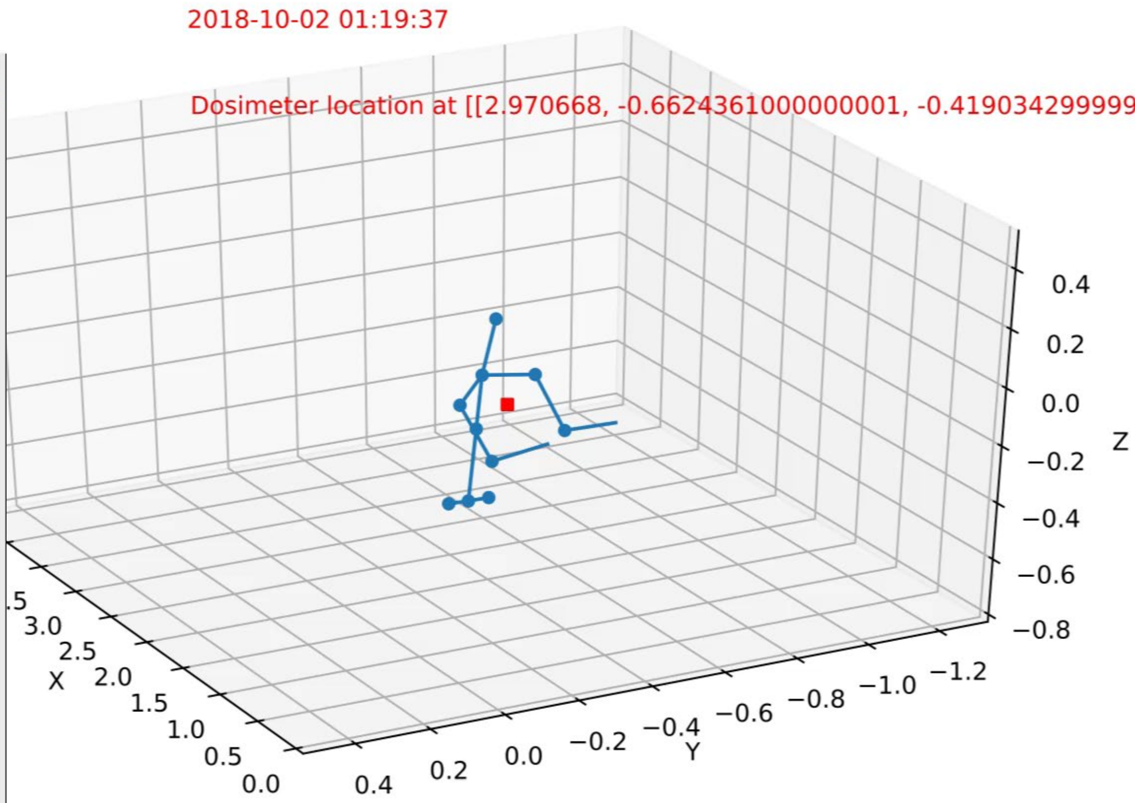


Test at CHU-Liège

Validation Case: Angioplasty Procedure

- Measurement of accumulated dose $H_p(10)$ of operators with Thermo EPD Mk2.3
- Estimation of dosimeter location by the tracking system

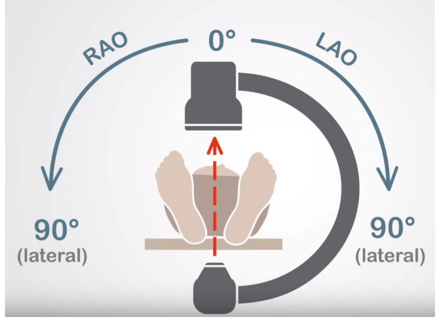


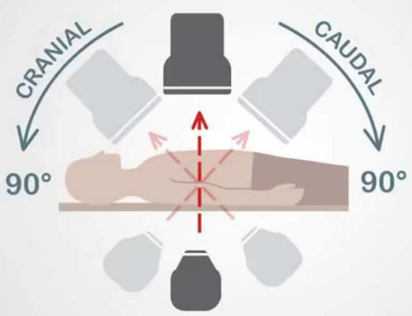


Procedure Dose Report

Procedure parameters:

- kVp:
- 80 – 125 kVp
- DAP:
- 15935.6 µGy.m2
- Projections:
- 0LAO / 0CRA
- 75RAO / 0CRA
- 27RAO / 0CRA





Patient Position: HFS   02-Oct-18 12:55:45

1	DSA		FIXED	VCS					7s	2F/s	02-Oct-18	13:17:02	
A	80kV	284mA	160.5ms	500CL	small	0.1Cu	32cm	536.5µGym²	47.6mGy	0LAO		0CRA	13F
2	DSA		FIXED	VCS					6s	2F/s	02-Oct-18	13:19:36	
A	125kV	295mA	199.6ms	******	large	0.0Cu	32cm	1655.2µGym²	217mGy	75RAO		0CRA	11F
3	DSA		FIXED	VCS					6s	2F/s	02-Oct-18	13:20:41	
A	125kV	295mA	199.6ms	******	large	0.0Cu	32cm	1647.7µGym²	216mGy	75RAO		0CRA	11F
4	DSA		FIXED	VCS					5s	2F/s	02-Oct-18	13:26:03	
A	125kV	295mA	199.6ms	******	large	0.0Cu	32cm	1347.0µGym²	177mGy	75RAO		0CRA	9F
5	DSA		FIXED	VCS					6s	2F/s	02-Oct-18	13:26:41	
A	125kV	295mA	199.6ms	******	large	0.0Cu	32cm	1646.9µGym²	216mGy	75RAO		0CRA	11F
6	DSA		FIXED	VCS					6s	2F/s	02-Oct-18	13:27:08	
A	125kV	295mA	199.6ms	******	large	0.0Cu	32cm	1647.1µGym²	216mGy	75RAO		0CRA	11F
7	DSA		FIXED	VCS					6s	2F/s	02-Oct-18	13:28:58	
A	125kV	295mA	199.6ms	******	large	0.0Cu	32cm	1646.7µGym²	216mGy	75RAO		0CRA	11F
8	DSA		FIXED	VCS					5s	2F/s	02-Oct-18	13:29:34	
A	125kV	295mA	199.6ms	******	large	0.0Cu	32cm	1496.8µGym²	196mGy	75RAO		0CRA	10F
9	DSA		FIXED	VCS					6s	2F/s	02-Oct-18	13:30:46	
A	82kV	536mA	160.6ms	******	large	0.0Cu	32cm	1090.2µGym²	143mGy	27RAO		0CRA	11F

Accumulated exposure data   02-Oct-18 14:42:19

Phys: HENROTEAUX DENIS   Exposures: 9

TotalFluoro: 5.4min   Total: 15935.6µGym² 1990mGy

Results from CHU-Liège case 4

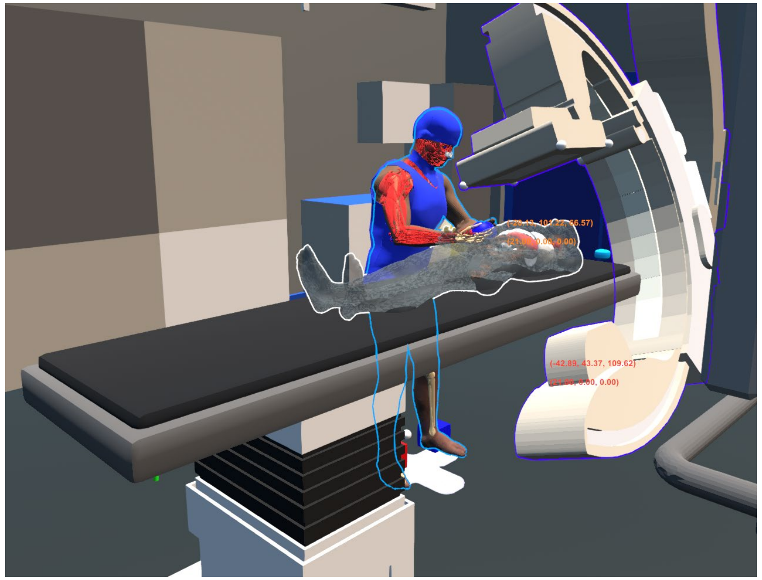
Validation Case	Simulations Accumulated $H_p(10)$	Measured EPD Accumulated $H_p(10)$
EndoVasc CHU-Liège Case 4 (PCI)	39 µSv	23 µSv

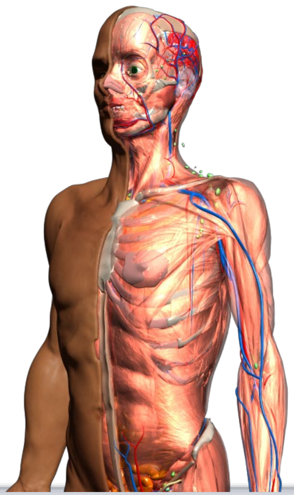
Event	FL1	FL2	FL3	FL4	FL5
Time (s)	7	6	6	5	6
RDSR DAP (µGy.m^2)	536.5	1655.2	1647.7	1347	1646.9
mGy	47.6	217	216	177	216
F6-REF (MeV/g/#)	6.55E-05	4.85E-05	4.85E-05	4.85E-05	4.85E-05
F6-DOS (MeV/g/#)	3.25E-09	9.27E-10	9.27E-10	9.27E-10	9.27E-10
$H_p(10)$ (µSv)	2.36	4.84	4.81	4.73	4.81
Event	FL6	FL7	FL8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

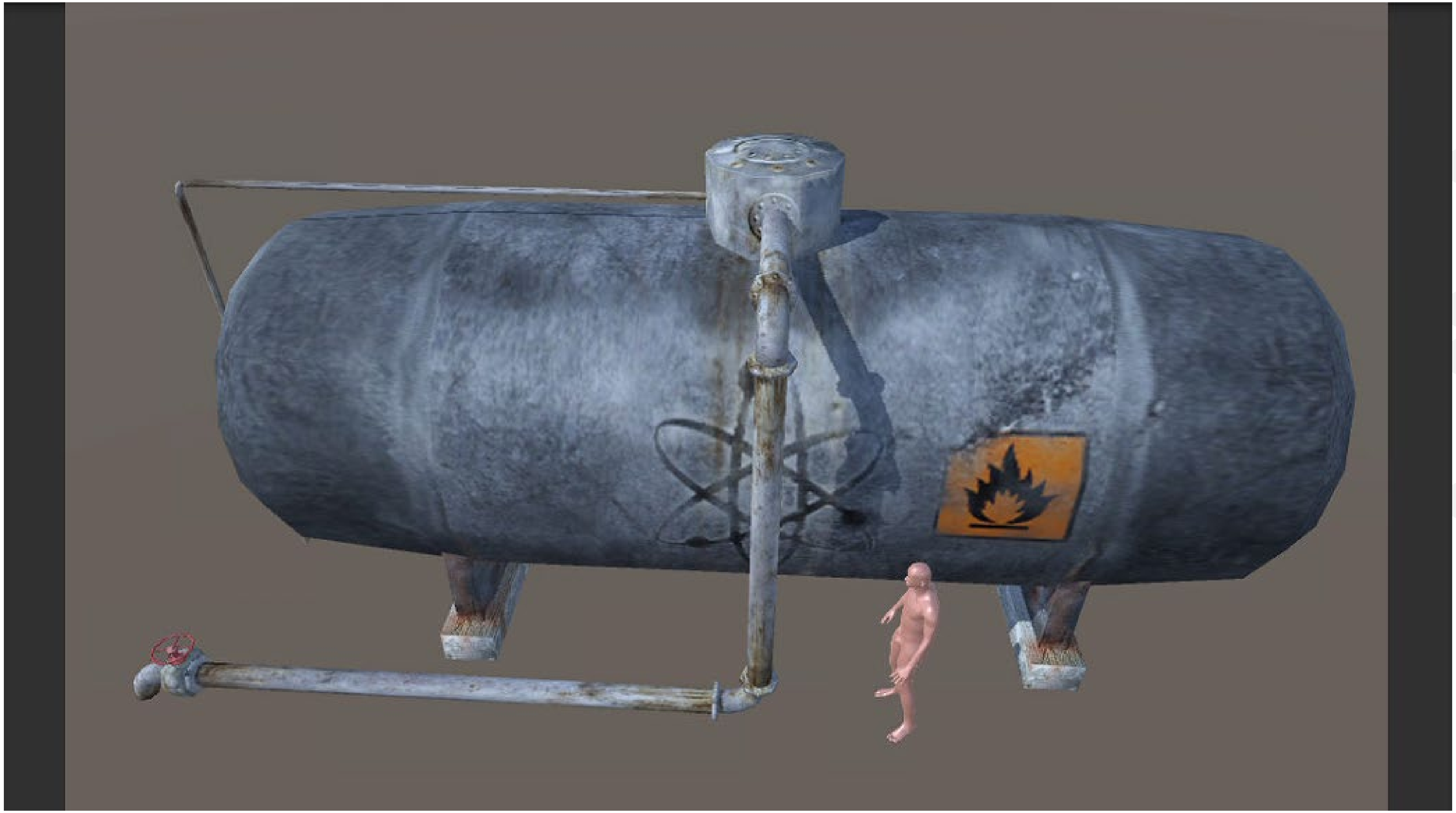
Conclusion

- Part of the future will be dosimetry without physical dosemeters
  - Although dosimeters still will exist for many applications
- Results show the validity of the method in interventional radiology and some neutron workplaces
- Still some challenges to be solved
  - Shielding tracking, worker identification
- Increasing contribution from AI and ML
  - "prediction" of doses instead of simulating….
- Important aspect of visualisation of radiation
  - ALARA and training tool
- Expanding to other applications



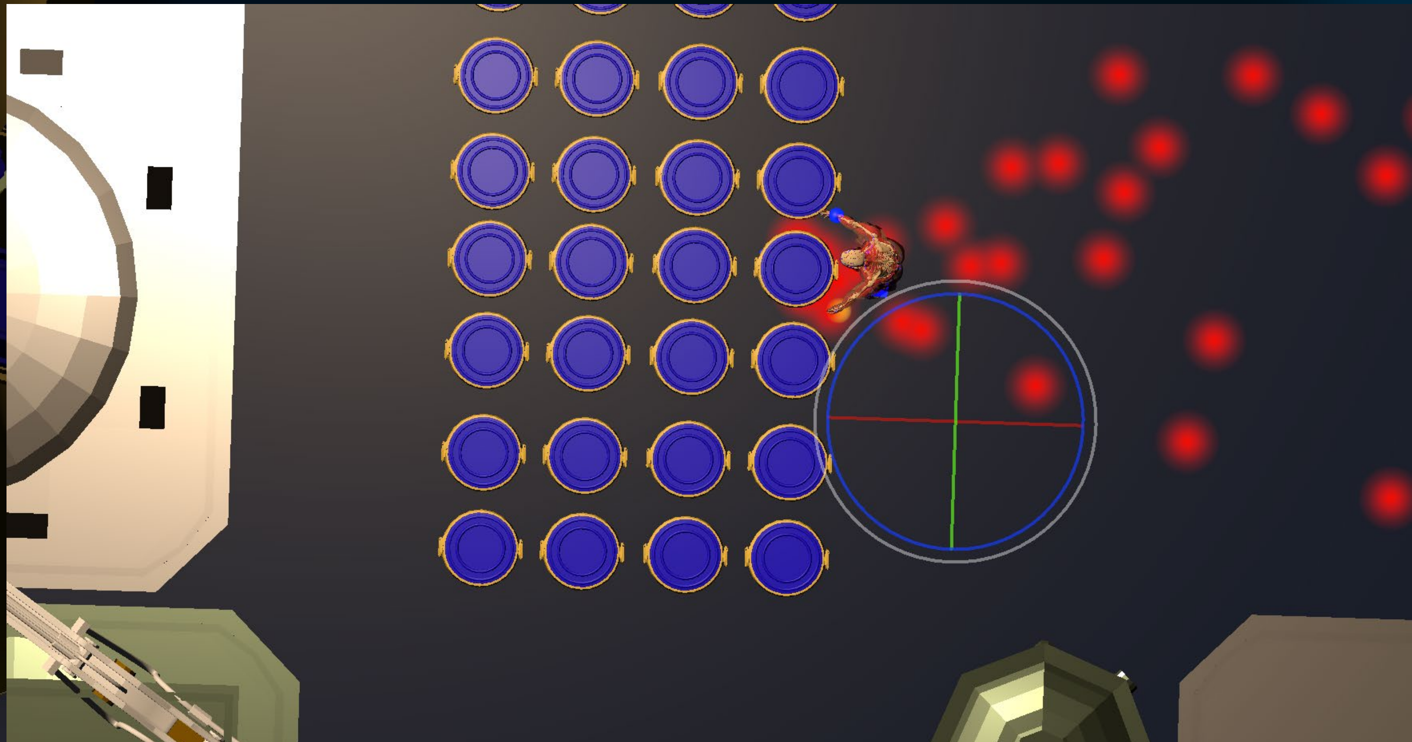


Other applications with RAF Phantom



ALARA planning and training tool

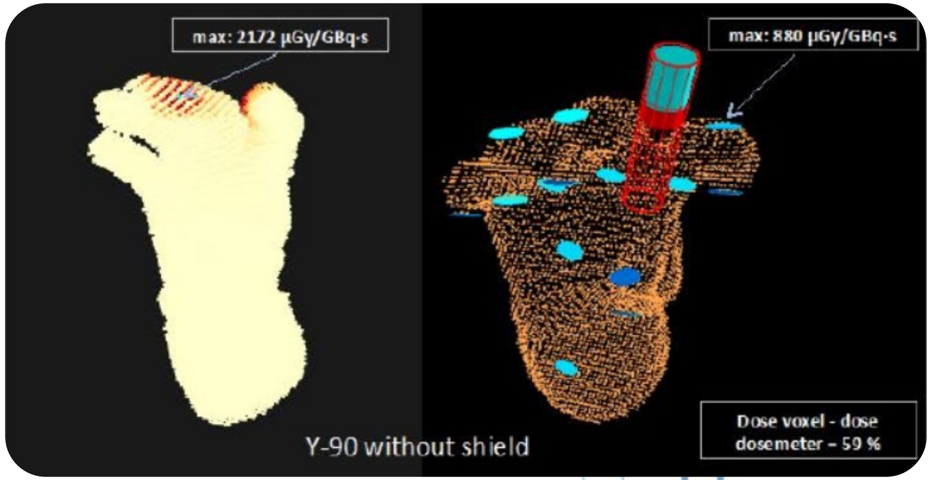
- **Accurate** MC simulations using flexible phantoms
- **Planning and analysis** dosimetry tool visualizing data in Virtual Reality environment
- **Neural Network** based framework for optimizing dose calculations



Why improve dosimetry service for **nuclear medicine** staff?

- 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 dosimeter is not enough to measure the whole hands dose
  - Wearing many ring dosimeters is uncomfortable
  - Multiple dosimeters will make dosimetry service more complex and expensive



Local data acquisition – object tracking

Tailor PODIUM data acquisition solution to fit NM requirements by **developing specialized** ML-based person, fingers and object tracking.

- We cannot rely on already available tracking algorithms especially for **tracking the radioactive source -> vials, syringes**

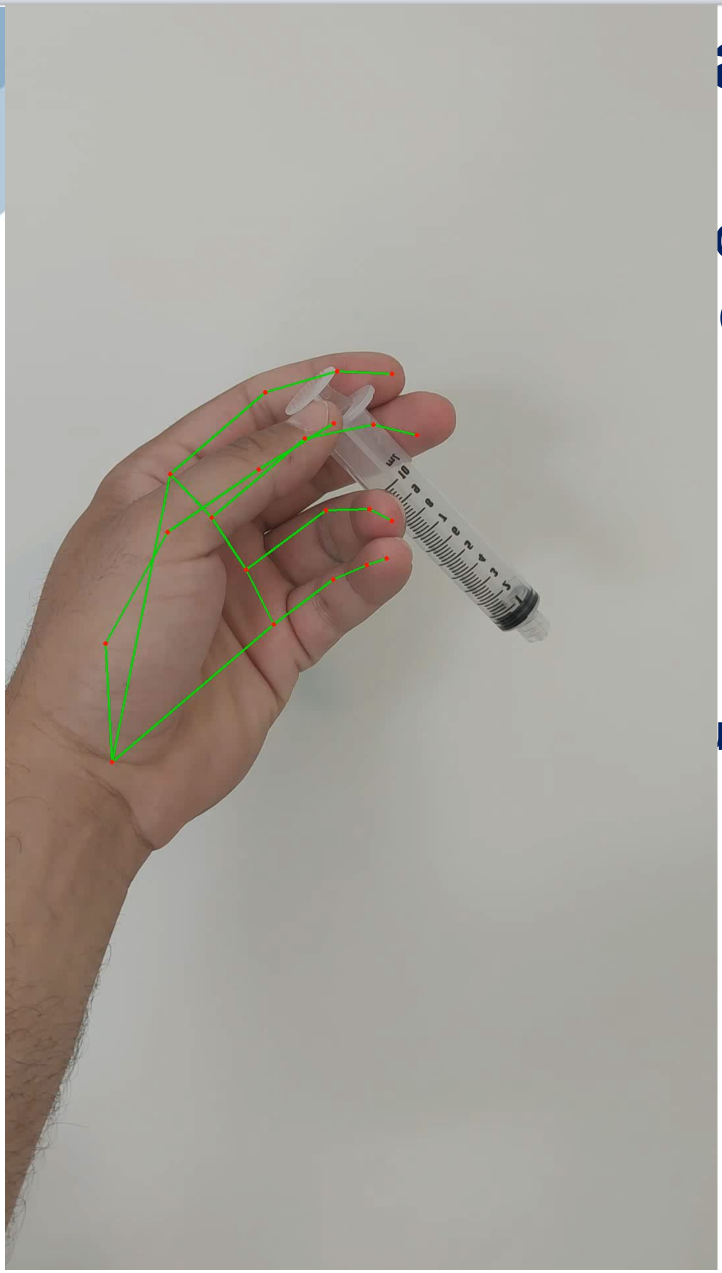
Train our own Convolutional Neural Network (CNN) using **Tensorflow**

OpenCV

TensorFlow

Caffe

SINFONIA



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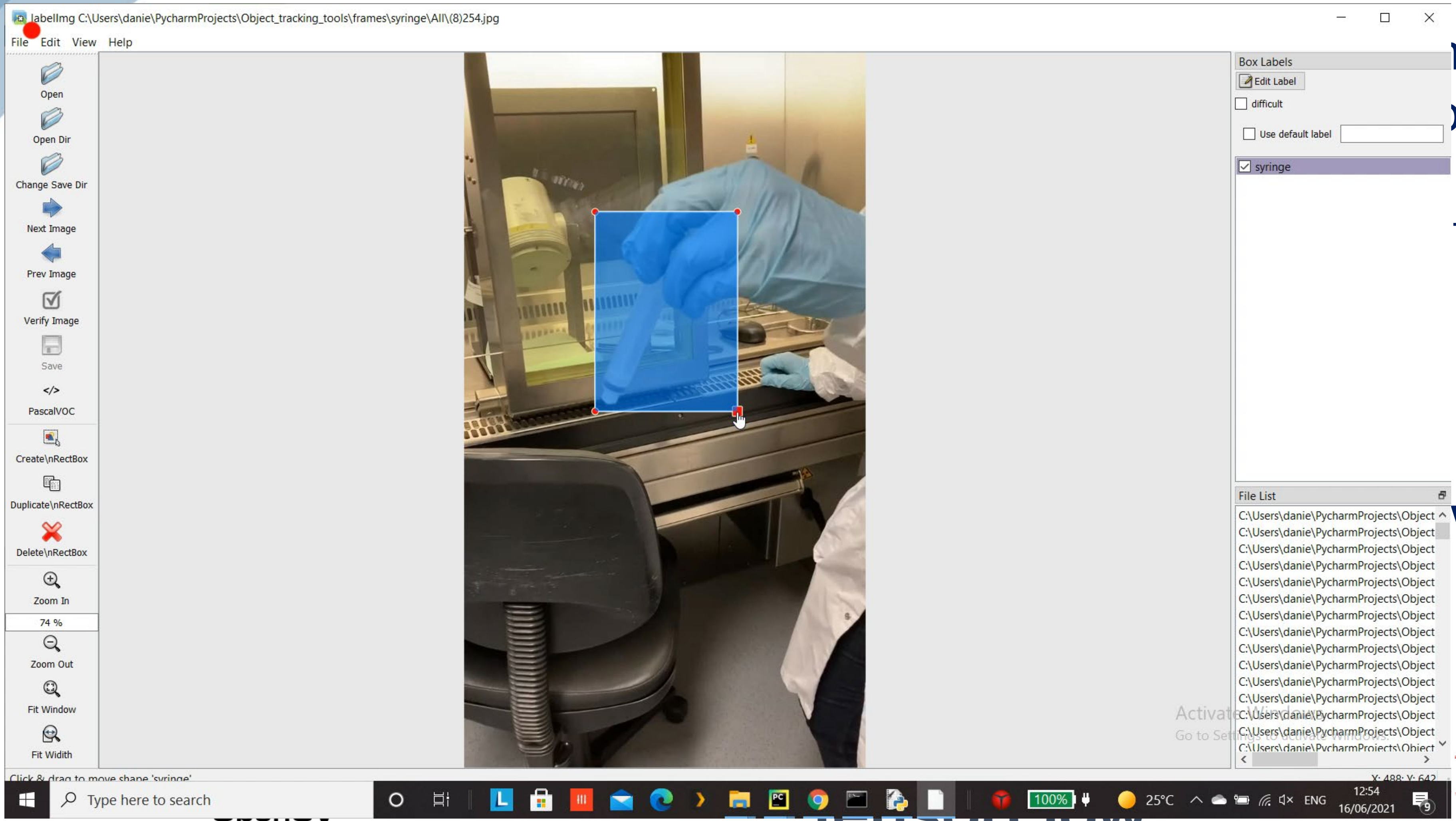

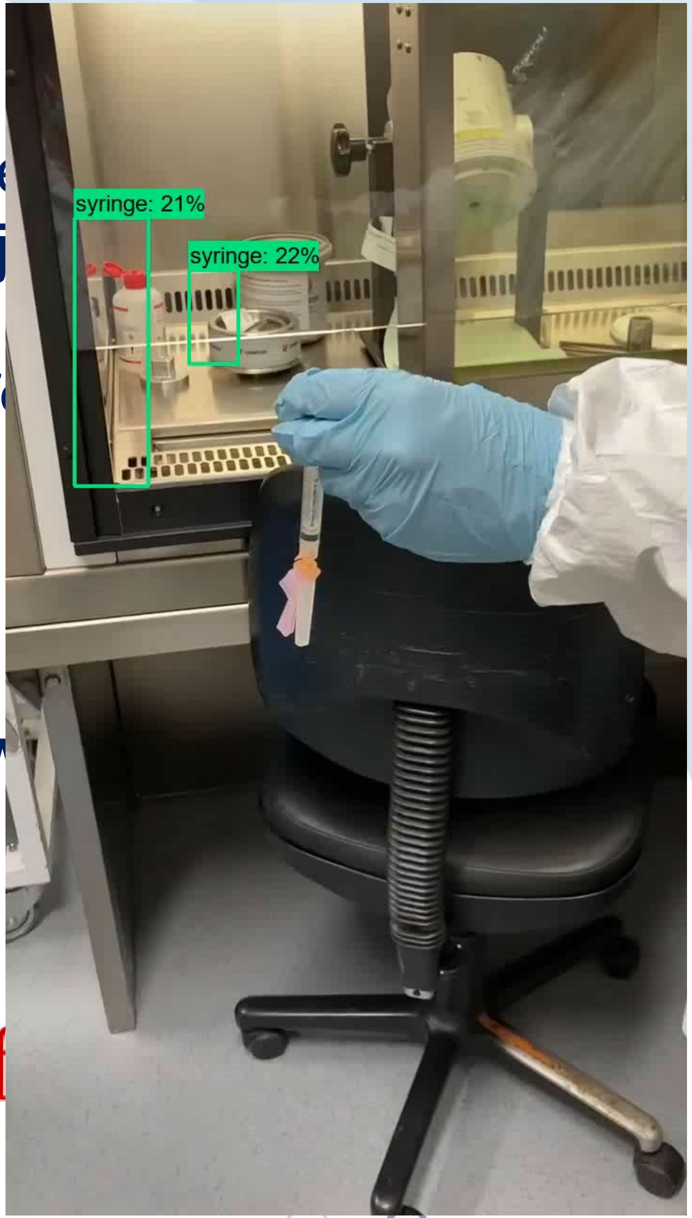

Thank you!

We are looking for projects and partners to apply this methodology for different applications!

Filip.vanhavere@sckcen.be

PODIUM
Personal Online Dosimetry Using computational Methods

CONCERT
European Joint Programme for the Integration of Radiation Protection Research

PODIUM Team

SCK•CEN

HelmholtzZentrum münchen
Deutsches Forschungszentrum für Gesundheit und Umwelt

Universitat Politècnica de Catalunya BarcelonaTech

St. James's Hospital Dublin . Ireland

Lund University

EEAE Ελληνική Επιτροπή Ατομικής Ενέργειας Greek Atomic Energy Commission

Public Health England

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