

External Dose Rates from Nuclear Medicine Patients to Specific Patient-Caregiver(s) Geometries

—

A computational Approach

EURADOS

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Background

- In recent years, a number of new radiopharmaceuticals have been used routinely in NM departments
 - The contribution of radionuclide therapy to patient treatment is widely accepted
- ⇒ The amount of activity administered to patients has increased
- ⇒ Necessitates investigating the potential **radiation hazard to staff/caregivers** from these patients
- The extent of radiation protection required by caregivers is still **a matter of debate**
 - **Guidelines** vary among countries and institutions in the same country



Background

- Guidelines for the release of nuclear medicine patients

- ICRP, Publ. 103/105/140
- IAEA SSG-46/SRS-63

Exposed group	Dose constraints
Family members, caregivers (except pregnant women) helping the patient	5mSv per episode/treatment
Other family members	1mSv per episode/treatment and 5mSv in 5 years
General public	0,3mSv per episode/treatment and 5mSv in 5 years

- Assessment of external exposure level

- Based on dose rate measurements at specified distances (0,1 – 1m)
- Extrapolation to infinity using the effective / physical half-life
- Contact time scenario's

Mettler <i>et al.</i> (2012)	Dose rate @ 1m < 25 μ Sv/h
Lee <i>et al.</i> (2015)	Dose rate @ 1m < 70 μ Sv/h
Pant <i>et al.</i> (2006)	Dose rate @ 1m < 30 μ Sv/h
U.S. NRC (1997)	Dose rate @ 1m < 70 μ Sv/h
National regulations Mexico	Dose rate @ 1m < 50 μ Sv/h
National regulations Germany	Dose rate @ 2m < 3,5 μ Sv/h



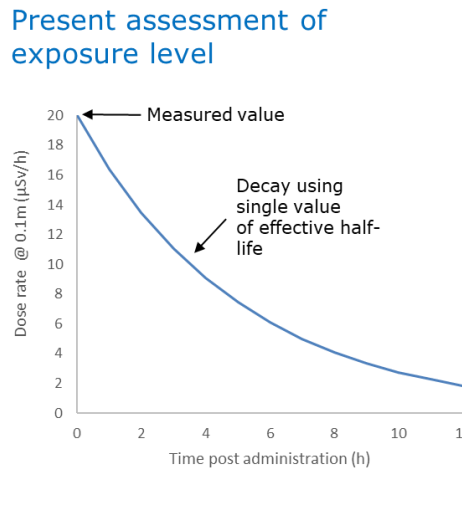
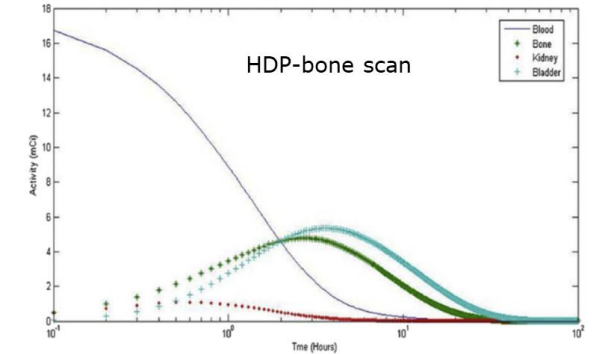
Background

- Recommendations/restrictions are rarely available
- Diagnostic procedures
 - No special restrictions necessary
 - Mostly verbal instructions in daily routine (young children, pregnant women)
 - No consensus, acceptable?
- Therapeutic procedure
 - Mostly focused on I-131 treatment for hyperthyroidism or thyroid cancer
 - Restrictions related both to external exposure and internal contamination



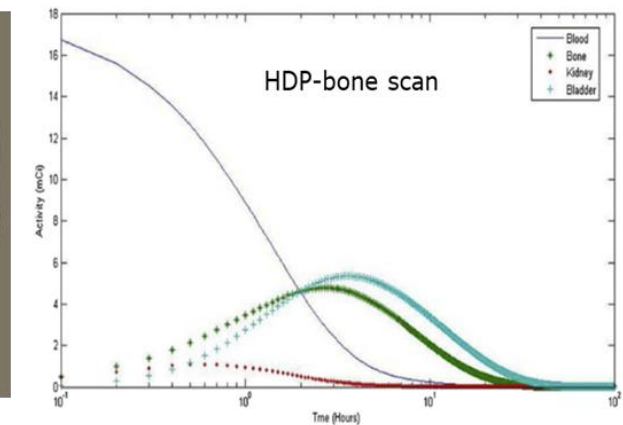
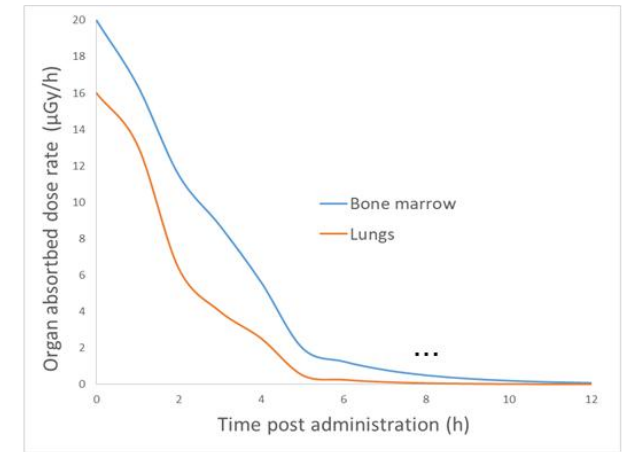
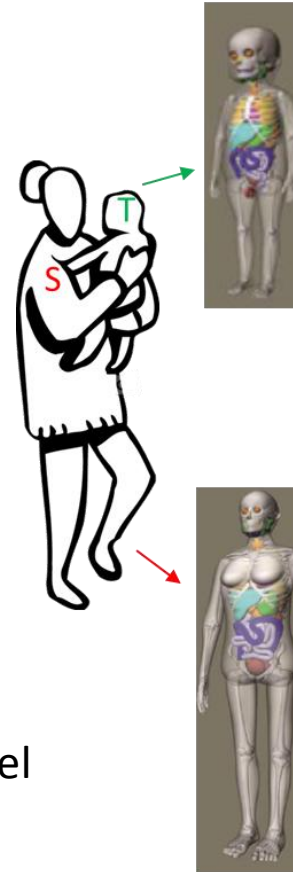
Background

- Nuclear medicine patient as a radiation source
 - Physically a **large source**
 - **Non-standard biokinetics** (diseases, medications, timing, ...) and **changes of activity distribution over time**
 - At short distances: combination of point measurements and a unique effective half-life can result in large errors for typical **'close-contact' scenario's**



Aim of the study

- Improve the assessment of external exposure with **a computational approach**
- Input
 - **Anthropomorphic computational models**, both for patient and staff/caregiver(s)/family member(s)
 - **Time activity curves** from each relevant source organ in the patient
- Output
 - **Organ absorbed dose rates over time** for the target model



Design of the study

- Collaboration between EANM and EURADOS
 - EANM Radiation Protection Committee
 - EURADOS WG6 on 'Computational Dosimetry'
 - EURADOS WG7 on 'Internal Dosimetry'
 - EURADOS WG12 on 'Dosimetry for Medical Imaging'
- Design of the computational framework
 - Benchmarking the different Monte Carlo codes used by the participants
 - Benchmarking the simulation results against experimental data
 - Built it up in a gradual approach in terms of complexity
- Literature review on dose rate measurements at certain distances and time points p.i.

• ^{99m}Tc -HDP/MDP, ^{18}F FDG, Na^{131}I

For benchmarking purposes

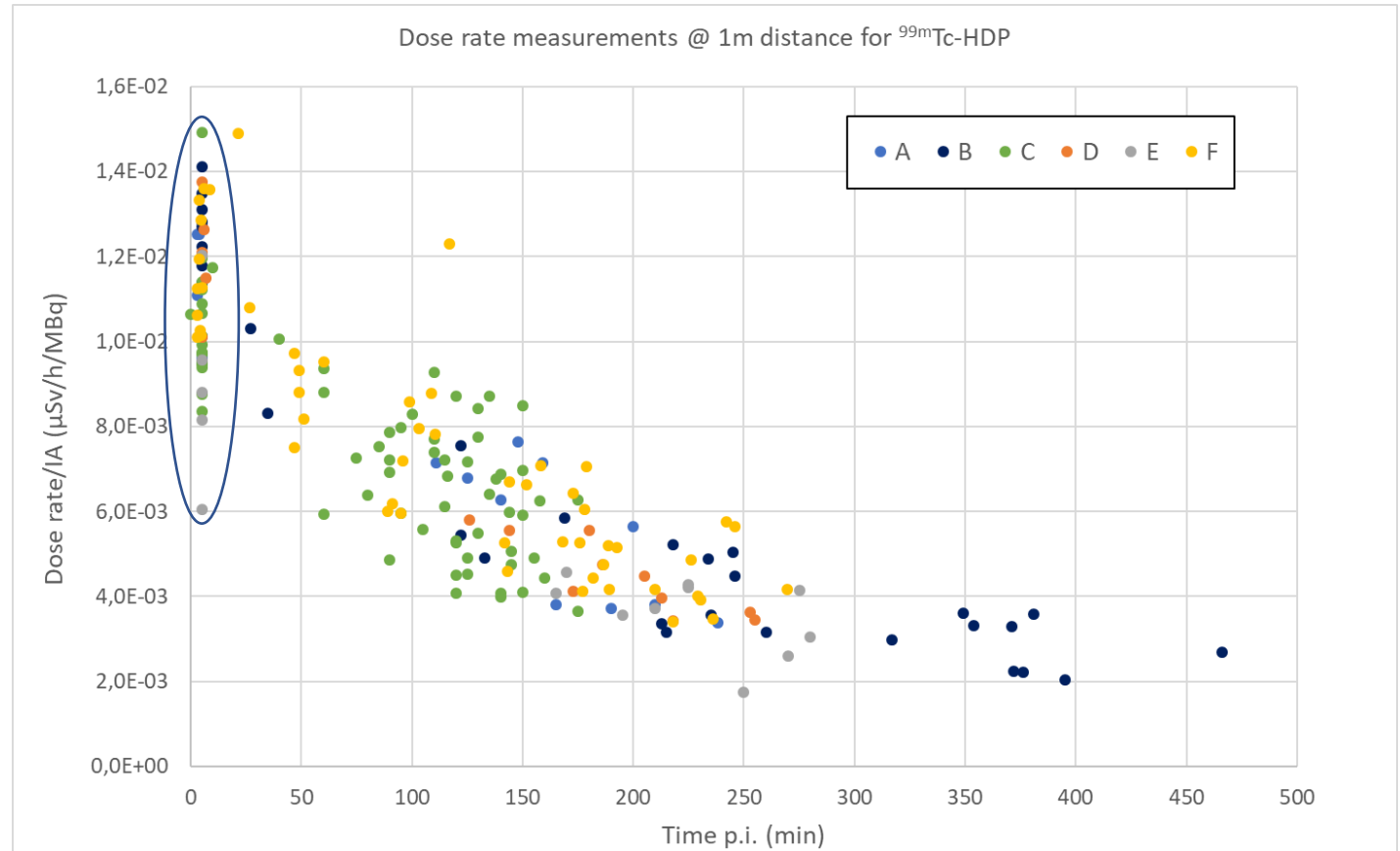


Dose rate measurements – ^{99m}Tc -HDP

- 6 centers
- 58 patients
- Cross calibration of measurement equipment
- Record
 - Injected activity
 - Remaining activity in the syringe
 - Time point p.i. of measurement
 - Patient body mass and height
- Large variation @ first time point

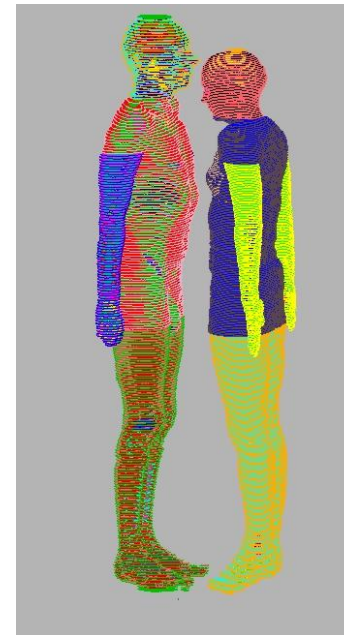
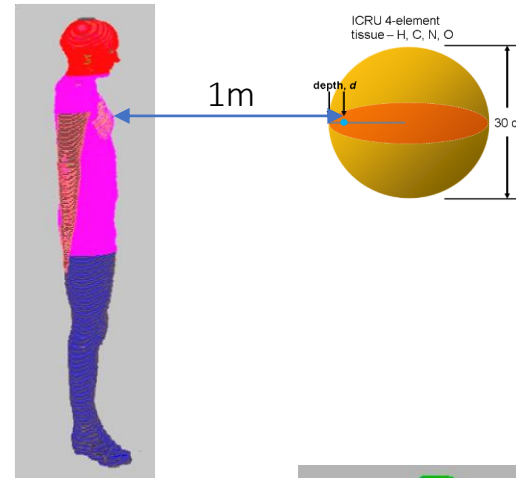
Centre	Normalised dose rate ($\mu\text{Sv/h/MBq}$)
A	2,44E-02
B	2,32E-02
C	1,60E-02
D	1,22E-02
E	1,80E-02
F	2,54E-02

Calibration of measurement equipment



Monte Carlo simulations

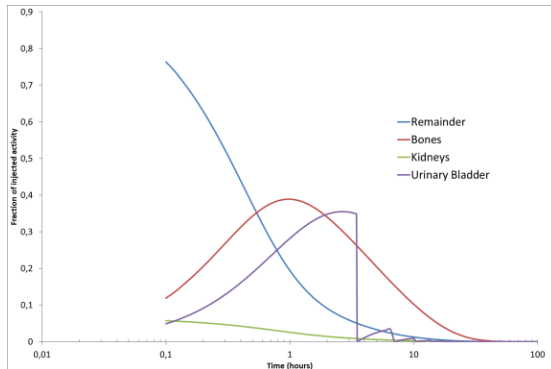
1. Dose rate in a point, in terms of $H^*(10)$ @ 1m distance from patient model (chest level)
⇔ Compare against measurements
2. Time-dependent absorbed organ dose rates of the target computational model
 - 2 voxel models (straight posture)
 - Changing distances
 - Changing orientation
3. Time-dependent absorbed organ dose rates of the target computational model
 - Flexible computational mesh models
 - Representation of close-contact scenario's



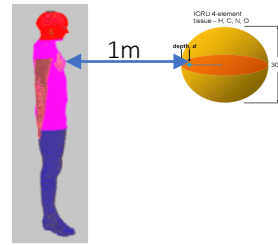
Monte Carlo simulations – ^{99m}Tc -HDP

Dose rate in a point

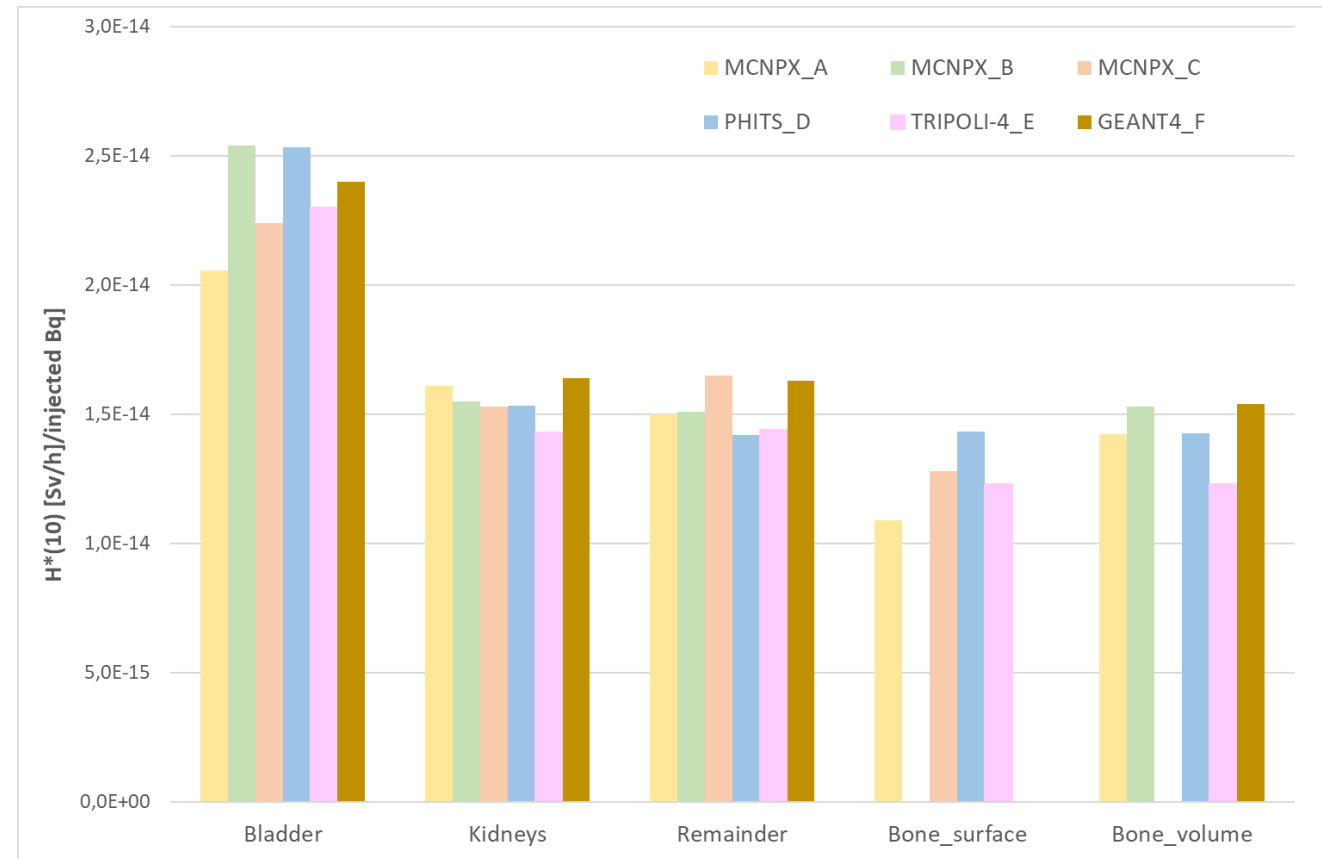
- 6 institutes
- 4 codes: MCNP-X, PHITS, TRIPOLI-4, GEANT4
- Source organs
 - According to [ICRP-53 biokinetic data](#)
 - Urinary bladder, kidneys, bones, remainder



- Calculation uncertainty (one sigma) < 10%
- Variation of 5-11% between different codes
 - Mainly from small differences between the tallied position



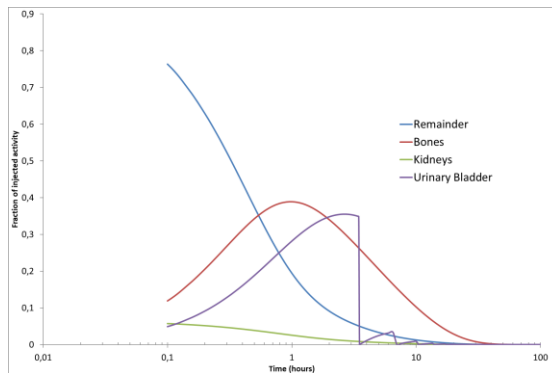
Comparison for each source organ separately:
 $H^*(10)$ per emitted source particle



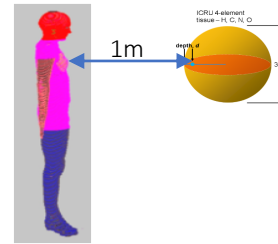
Monte Carlo simulations – ^{99m}Tc -HDP

Dose rate in a point

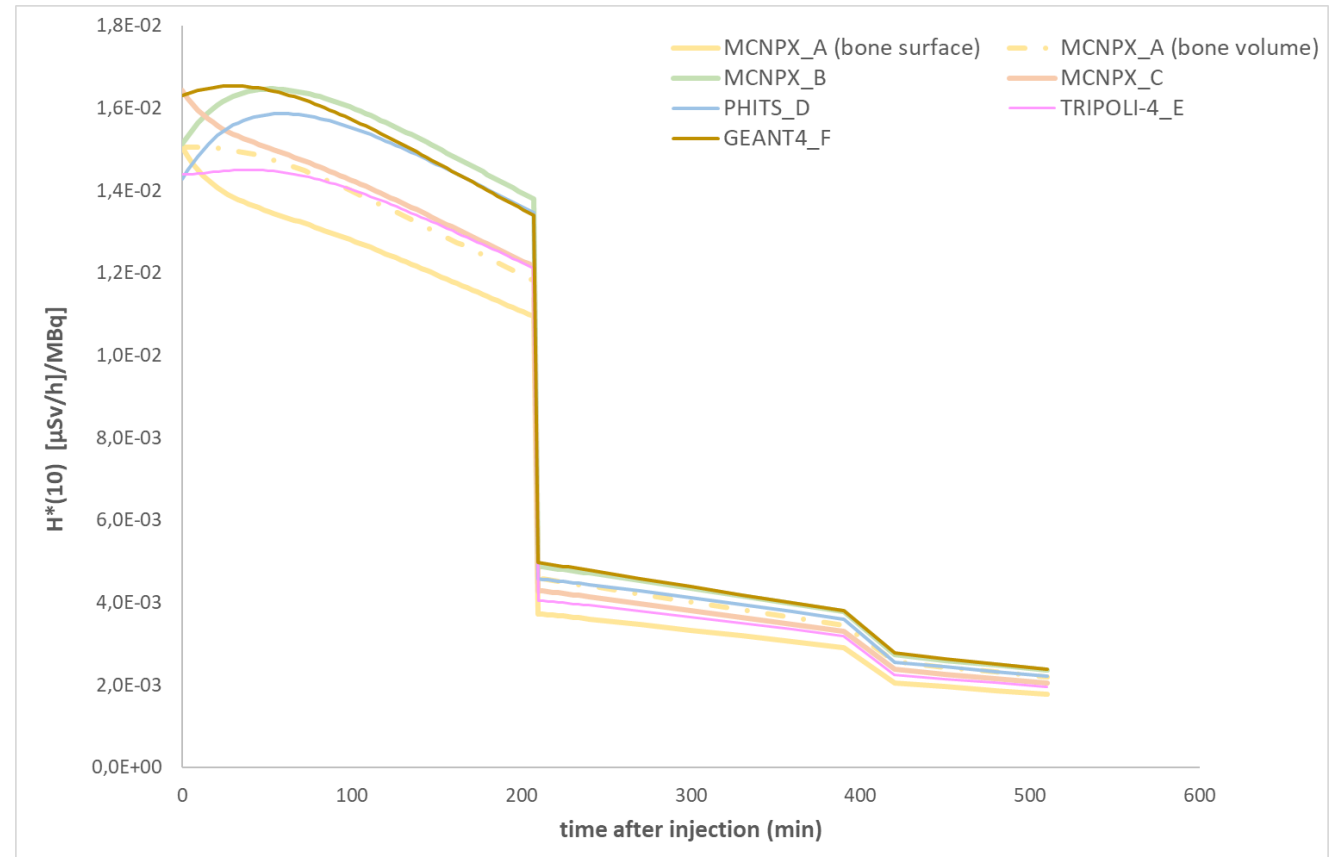
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Multiplication with corresponding time-activity curves:
cumulated $H^(10)$ per injected activity*

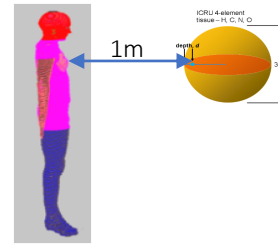
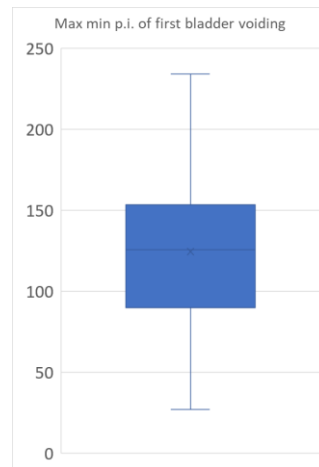


Monte Carlo simulations \Leftrightarrow measurements

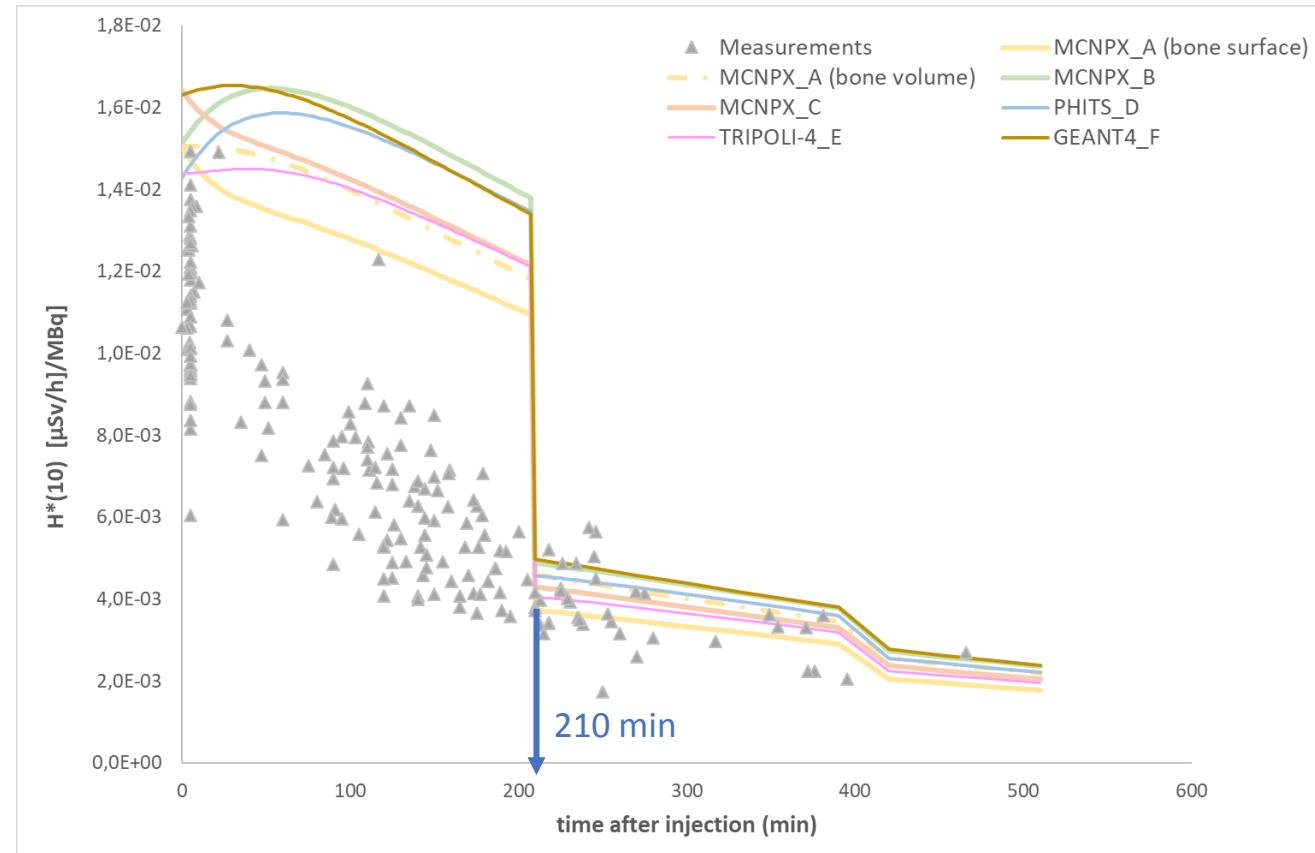
- Large overestimation from simulations
 - ICRP-53 TAC: bladder voiding intervals every 210 min p.i.
 - Estimated mean first bladder voiding time p.i. from measurements: 125 min

- Adjust model parameters of ICRP-53 for different bladder voiding intervals

\Rightarrow Impact on the results?



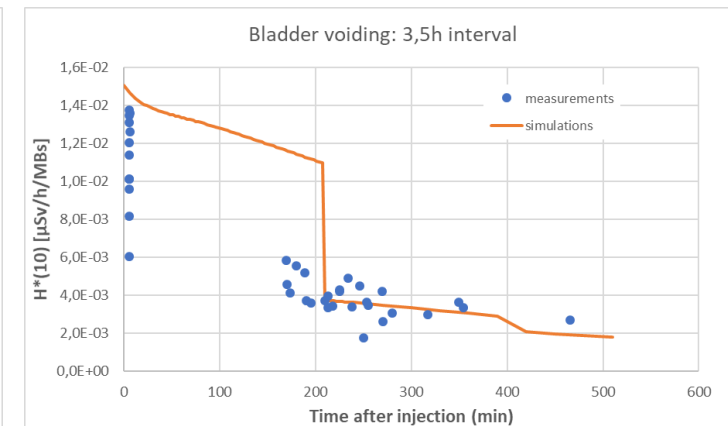
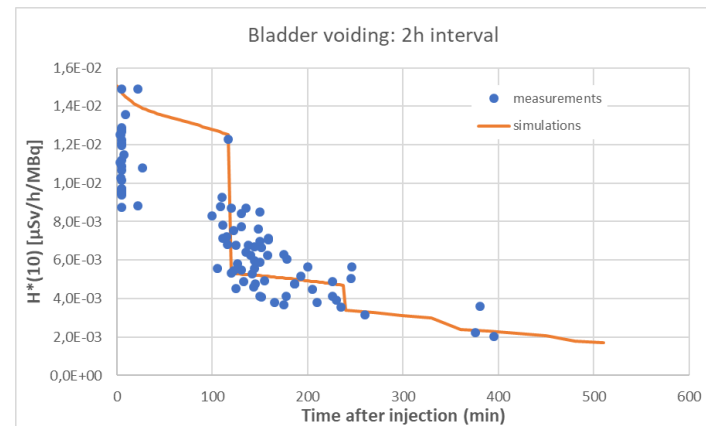
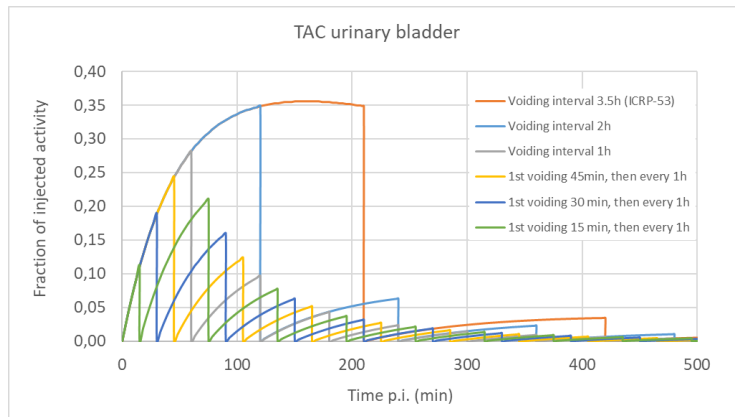
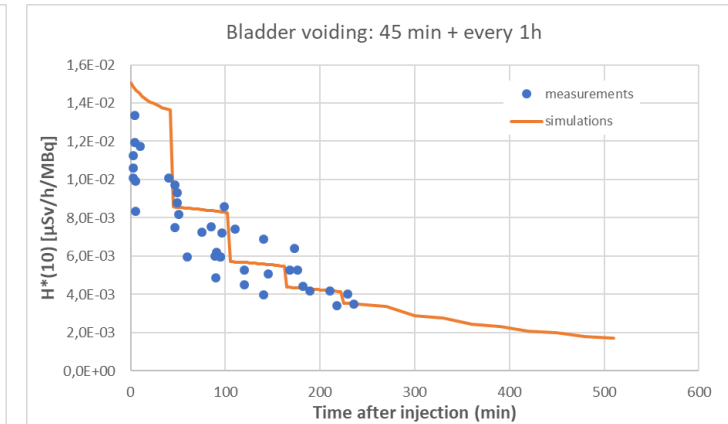
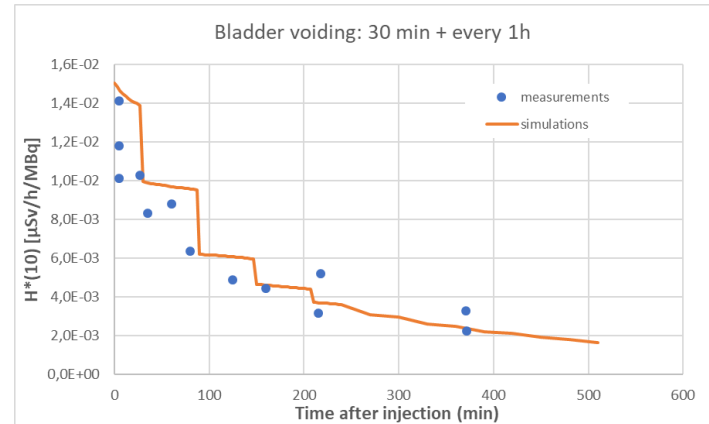
Multiplication with corresponding time-activity curves:
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Monte Carlo simulations \Leftrightarrow measurements

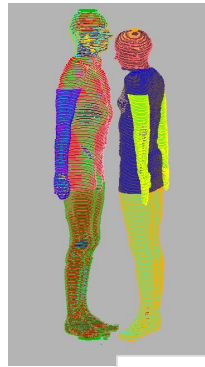
- Different voiding times and intervals
 - Voiding interval 3.5h (ICRP-53), 2h, 1h
 - 1st voiding @ 45min/30min/15min, then every 1h

Measured data organized according to estimated 1st bladder voiding time

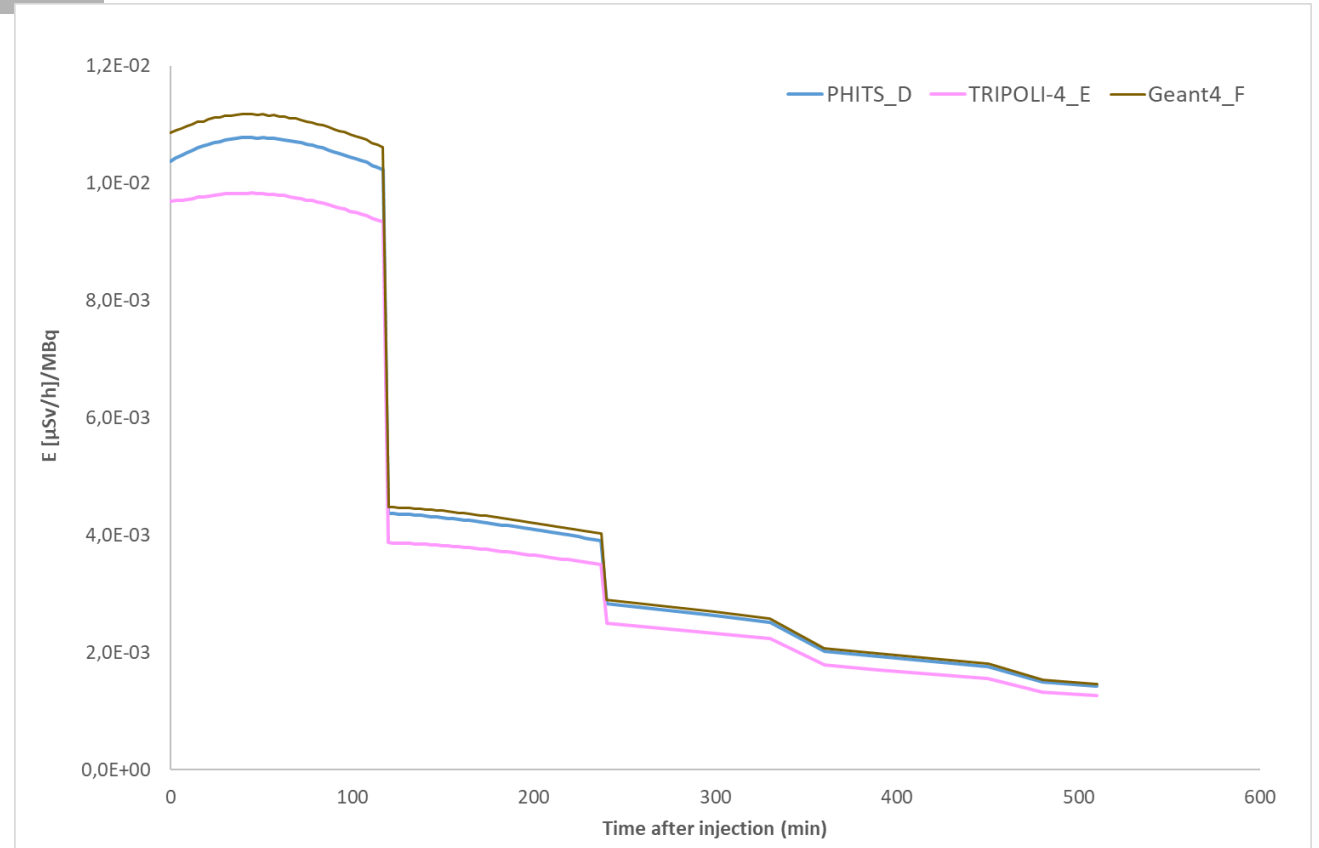


Monte Carlo simulations – ^{99m}Tc -HDP

Effective dose



- 3 institutes
- 3 codes: PHITS, TRIPOLI-4, Geant4
- Models facing each other @ 1m distance
- Bladder voiding interval of 120 min selected
- Calculation uncertainty (one sigma) < 2%
- **Good agreement** (<20%) between different Monte Carlo codes



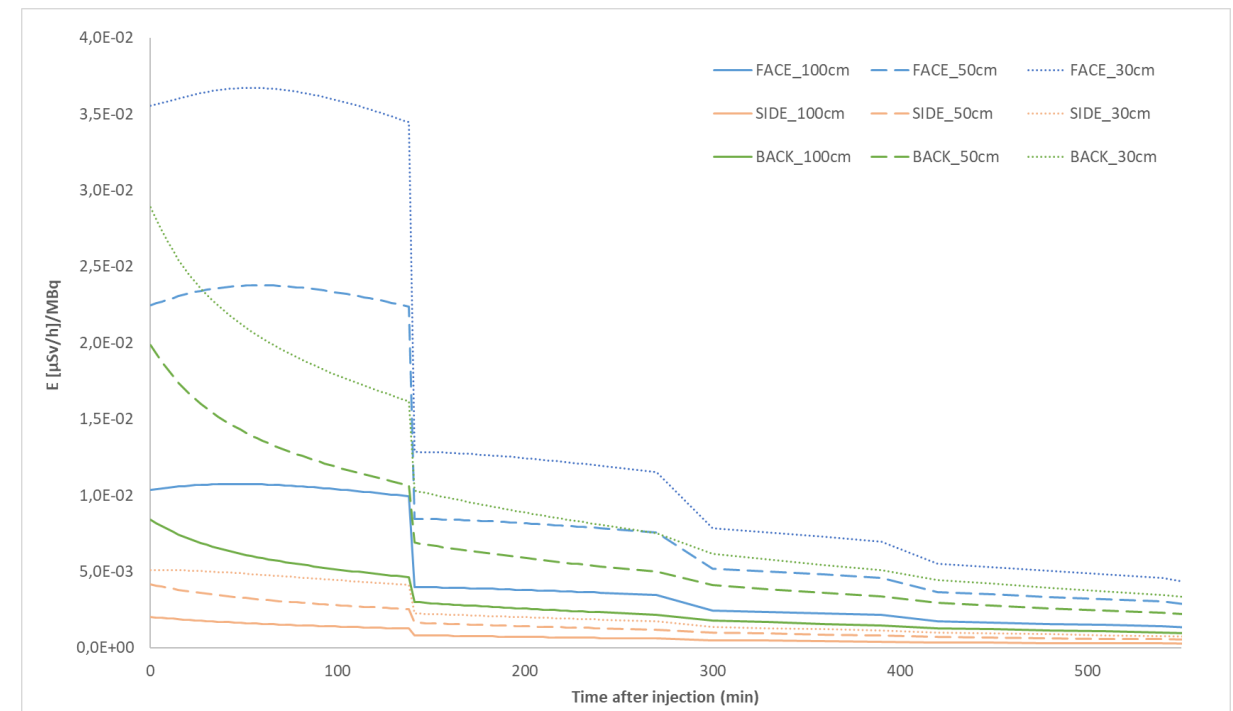
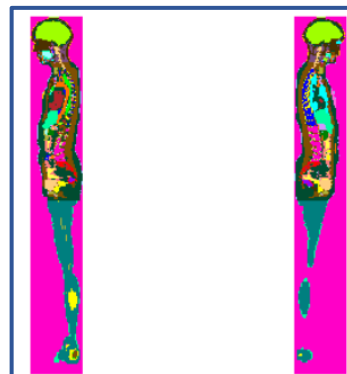
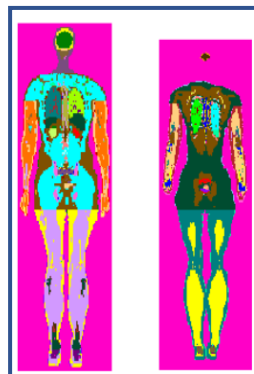
Exposure to staff/caregivers

- Idea

- Built a **database of effective dose rate over time** for specific and relevant exposure geometries
- Combine with **contact time scenario's**

- First example with 2 computational models in straight position, for $^{99m}\text{Tc-HDP}$

- Orientation: face-to-face, side-by-side, back-to-back
- Varying distance: 30 cm – 50 cm – 100 cm

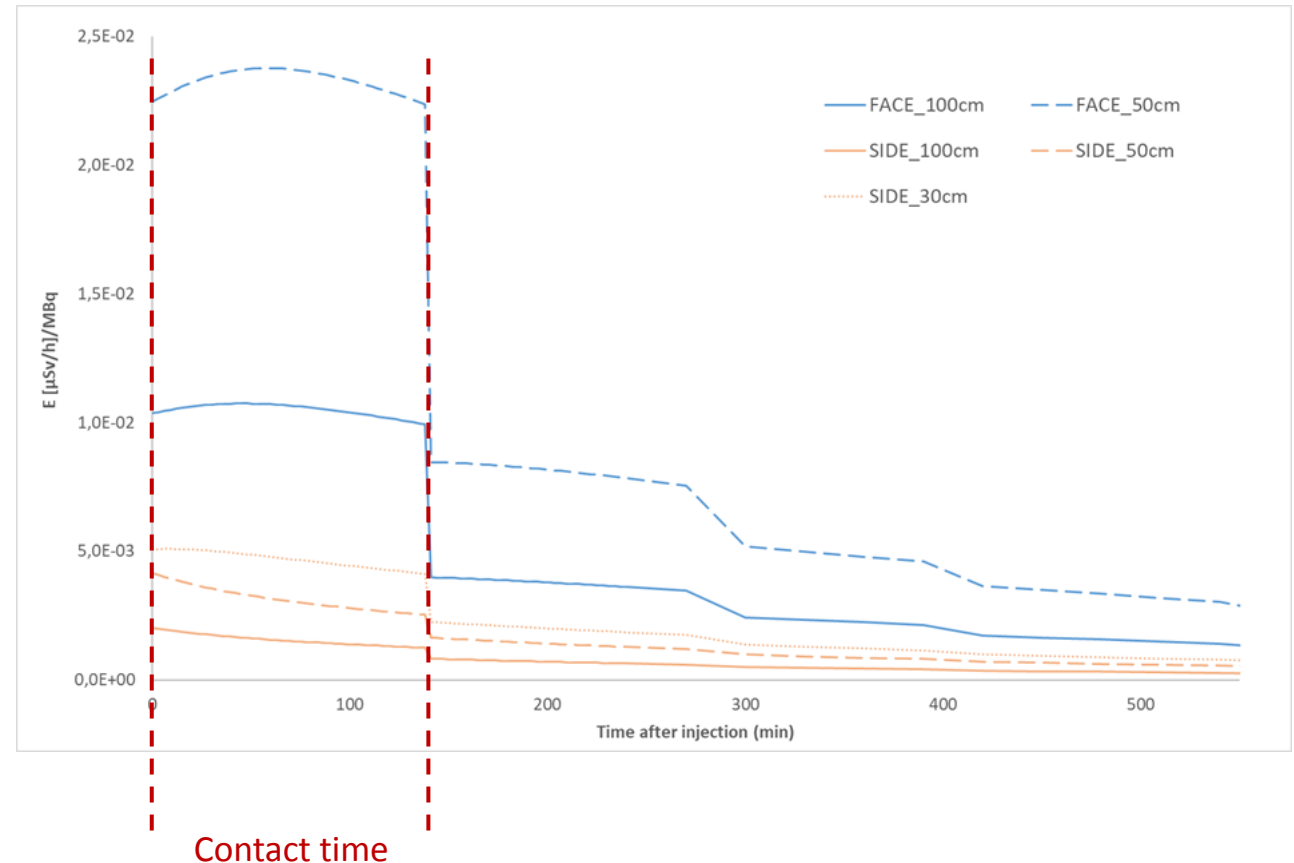


Exposure to staff/caregivers

Possible scenarios

1. Family member accompanying patient in hospital before SPECT examination (waiting room, cafeteria, ...)
 - SPECT examination 2.3h after injection
 - Injected activity: 740 MBq
 - Relevant scenarios:
 - face-to-face (50, 100 cm) ;
 - side-by-side (30, 50 and 100 cm)

⇒ Effective dose: < 40 μSv
(2,3h contact time)
< 17 $\mu\text{Sv/h}$



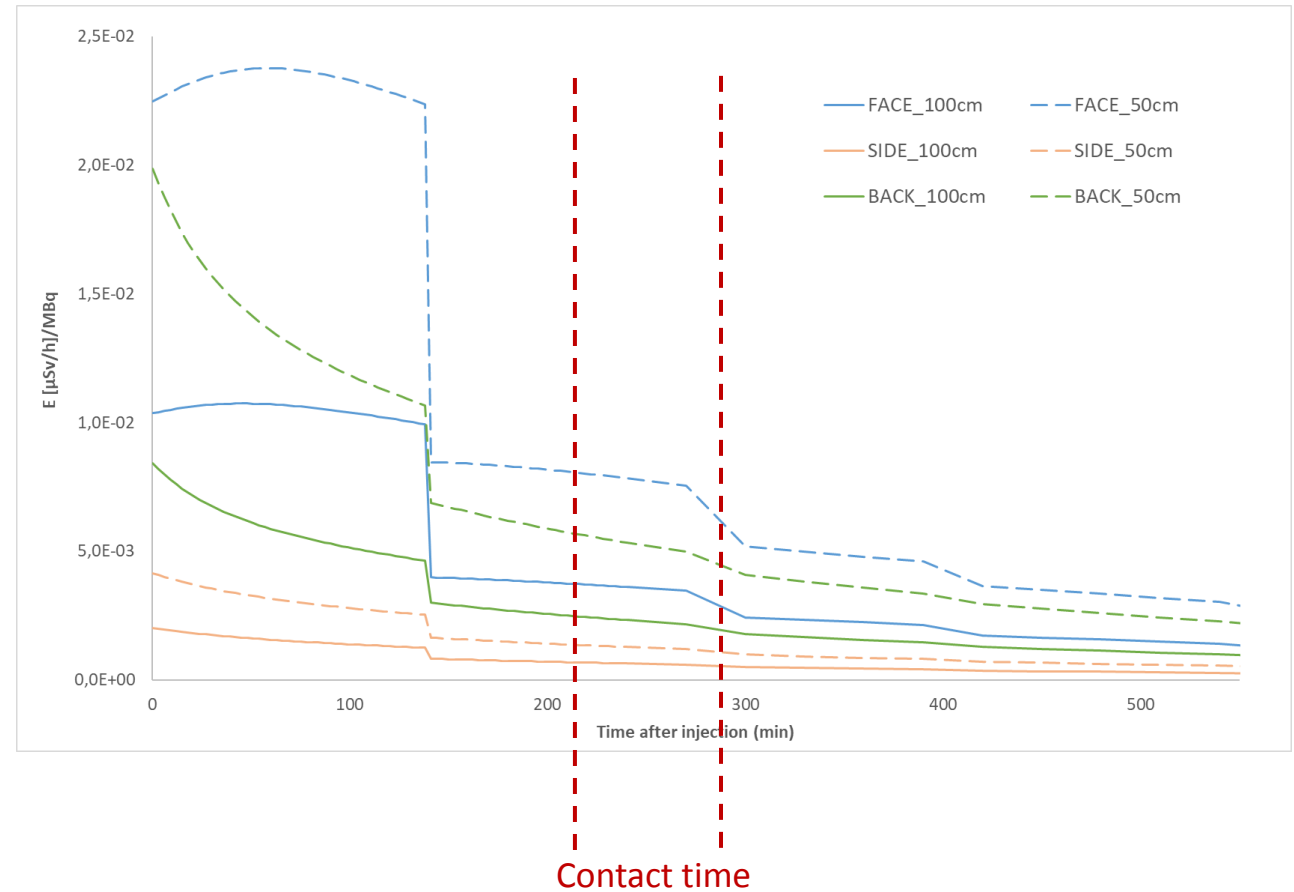
Exposure to staff/caregivers

Possible scenarios

2. Patient leaves the hospital 4h p.i. and travels home by bus

- Time of exposure: 240 to 300 min p.i. (duration: 1h)
- Injected activity: 740 MBq
- Relevant scenarios:
 - face-to-face (50, 100 cm) ;
 - side-by-side (50, 100 cm)
 - Back-to-back (50, 100 cm)

⇒ Effective dose < 7 μ Sv



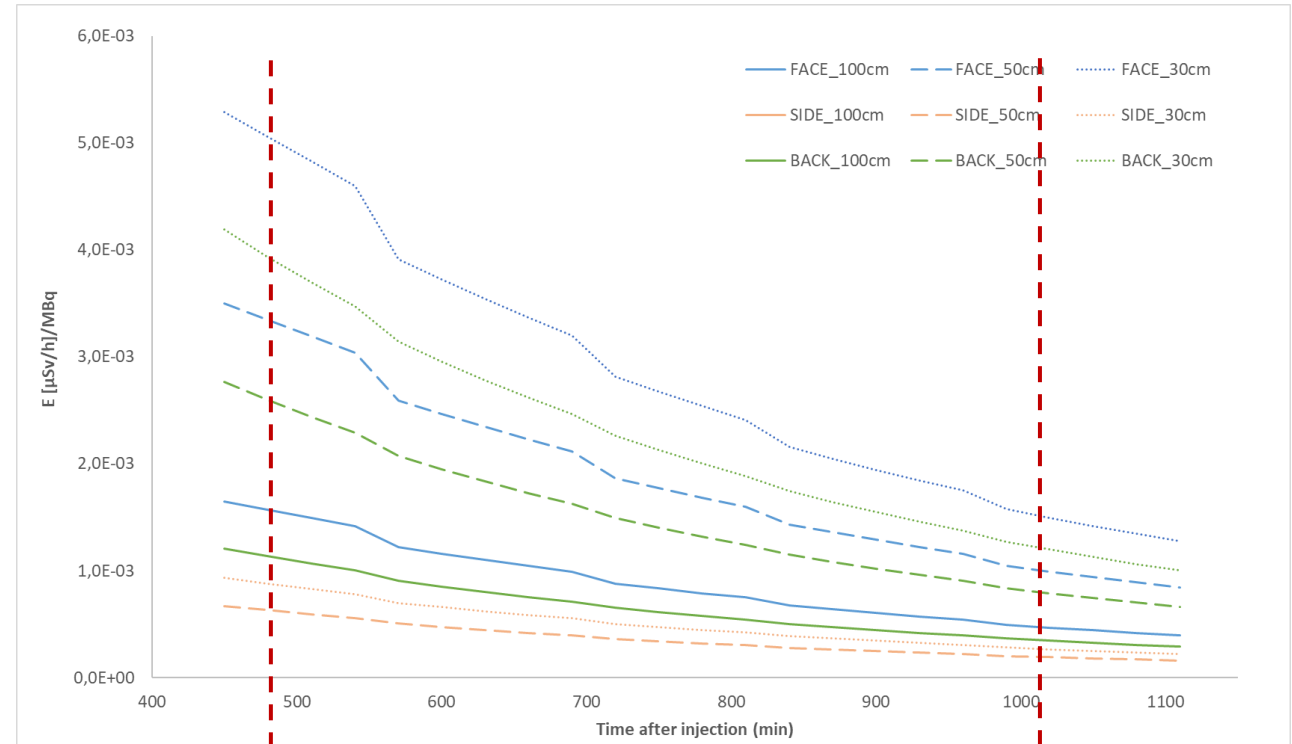
Exposure to staff/caregivers

Possible scenarios

3. Patient sleeps with partner @ home

- Injection at 14h
- Time of exposure: 22h to 8h
 - 480 to 1080 min p.i.
 - Duration 10h
- Injected activity: 740 MBq
- Relevant scenarios:
 - face-to-face (30, 50, 100 cm) ;
 - side-by-side (30, 50, 100 cm)
 - Back-to-back (30, 50, 100 cm)

⇒ Effective dose: 1-20 μSv



Contact time



Conclusions

- Computational approach to determine the external dose rates and subsequent exposure to caregivers/staff from nuclear medicine patient
- Current status:
 - Framework has been benchmarked against different codes and against experimental data for ^{99m}Tc -HDP
 - Very large influence from selected biokinetic data!!
 - Differs also between patients
- Next steps
 - Evaluate/confirm benchmarking for F-18 (FDG) and I-131 treatment
- Future work
 - Move towards high-risk close-contact scenario's
 - E.g. exposure of child from treated mother
 - Focus on radionuclide therapy (higher activities)
 - Needs the implementation of innovative flexible mesh models



Acknowledgement

To all EANM and EURADOS collaborators!



Thank you for your attention

