External exposure from nuclear medicine patients: a computational approach to assess risk at very short distances

Peter Covens
EURADOS WG13: Dosimetry in Nuclear Medicine

SIG RADIONUCLIDE INTERNAL DOSIMETRY
EURADOS European Radiation Dosimetry Group
EFOMP EUROPEAN FEDERATION OF ORGANISATIONS FOR MEDICAL PHYSICS

Introduction: EURATOM BSS

- Molecular Radiotherapy in the clinic requires patient release criteria and instructions
- Related to the requirements of EURATOM BSS:
  Member states shall ensure
  the establishment of:
  - Dose constraints for public exposure
  - Dose constraints for medical exposure
    → protection carers/comforters/volunteers

Council Directive 2013/59/Euratom of 5 December 2013 laying down basic safety standards for protection against the dangers arising from exposure to ionising radiation, and repealing Directives 89/618/Euratom, 90/641/Euratom, 96/29/Euratom, 97/43/Euratom and 2003/122/Euratom

Introduction: heterogeneity of release criteria

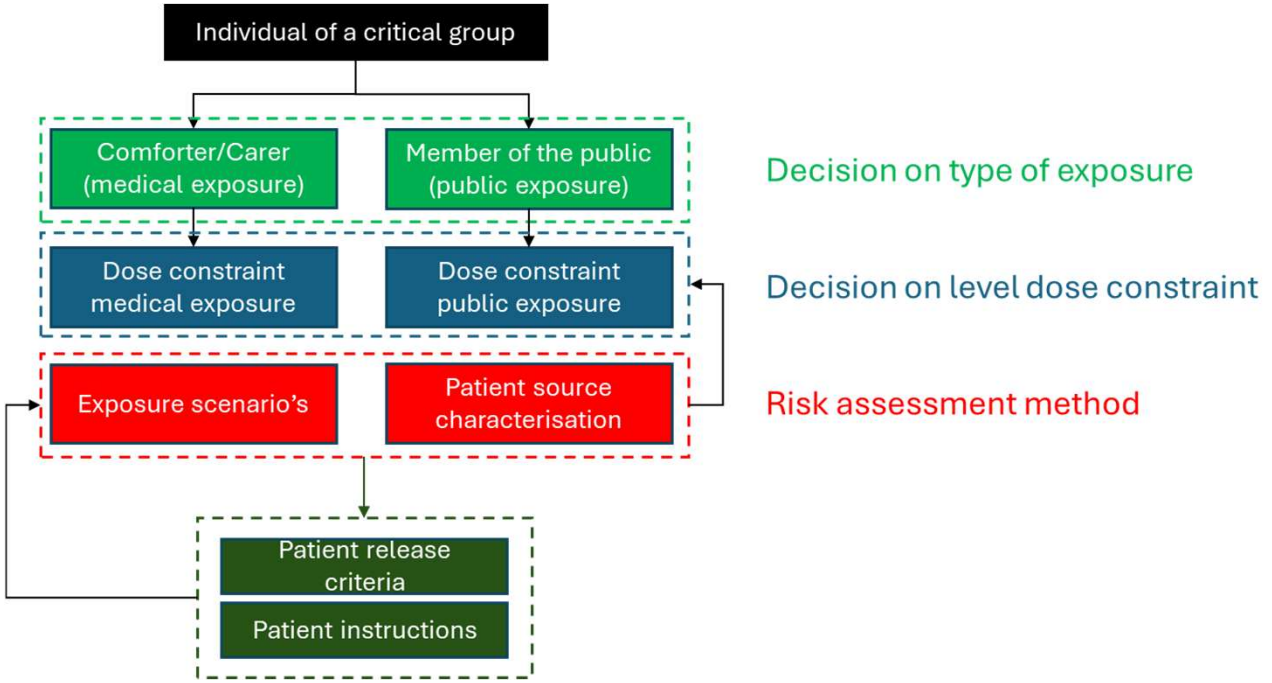
- Considerable heterogeneity in release criteria and dose constraints among member states
- Responsibility for setting dose constraints and release criteria varies across member states
- Different decision levels can influence the setting of release criteria and instructions

SAMIRA Study on the Implementation of the Euratom and EU Legal Bases with Respect to the Therapeutic Uses of Radiopharmaceuticals

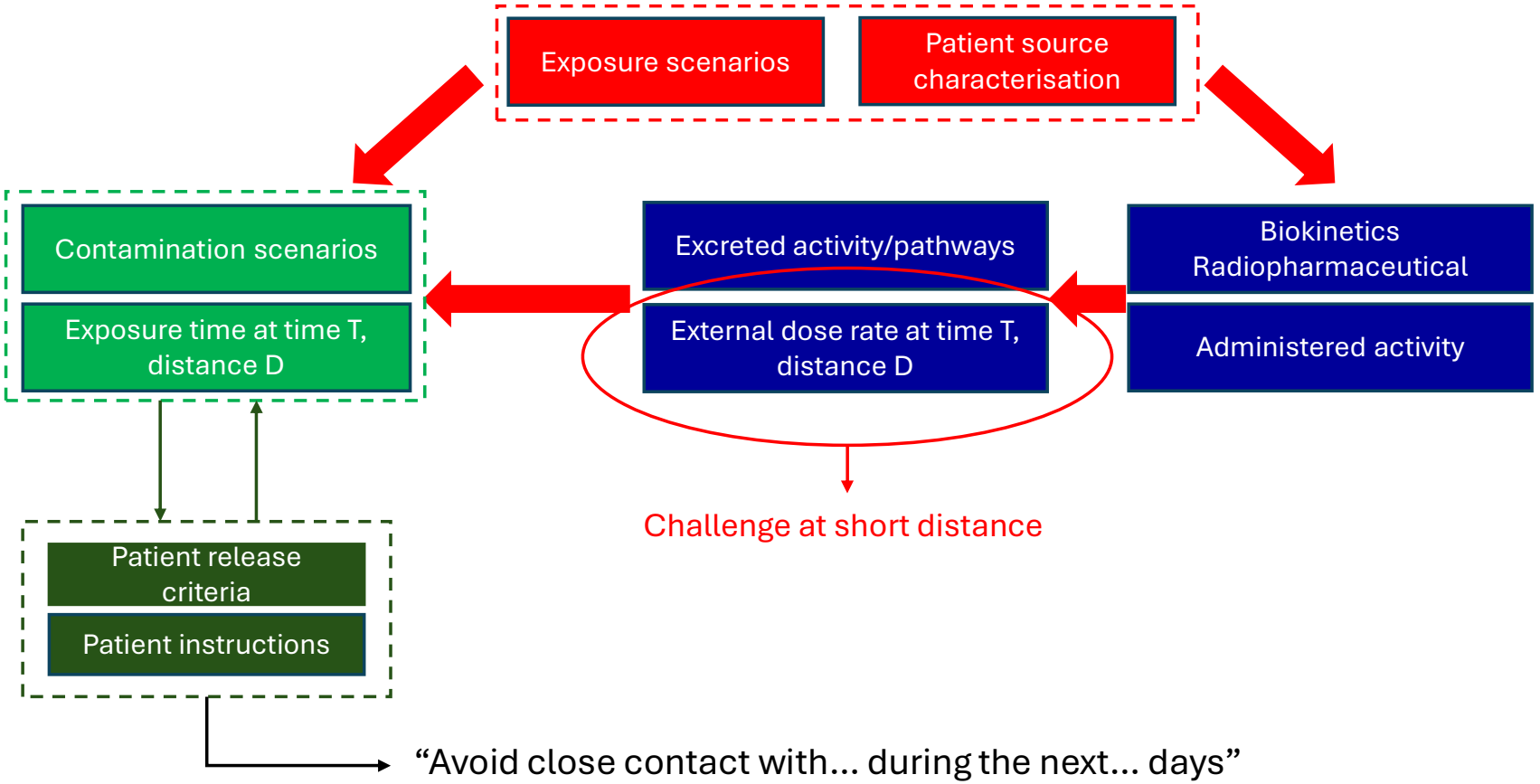
Simplerad

Complex setting of dose constraints release criteria

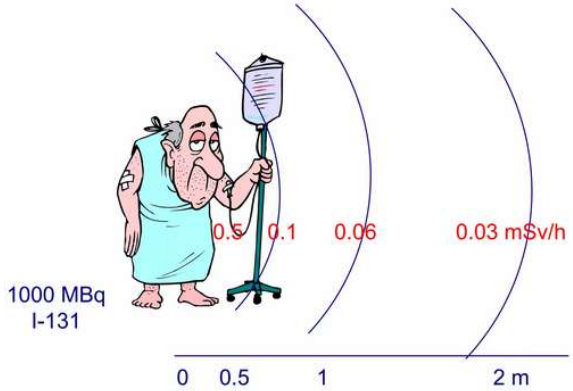
- Setting patient release criteria/instructions
  - Complex
  - Influenced by different decision levels
  - Some decisions can have political dimensions
  - Member states may adopt different interpretations



Risk assessment challenge



Current risk assessment methods and limitations

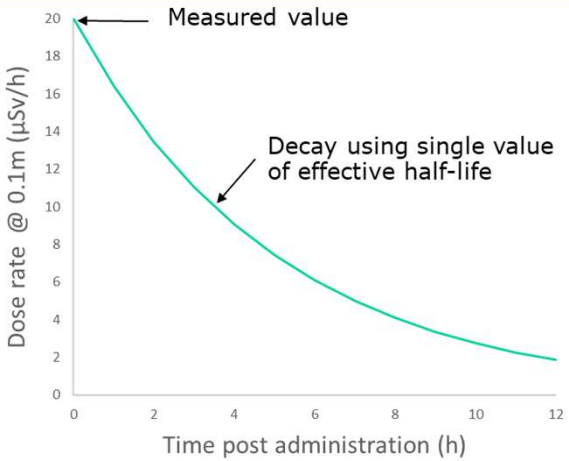


Typically H*(10) measurement

Extrapolation for close contact scenarios:

- Point-to-point inverse square law model
- Point-Line source model (Broggio, 2022)

⇒ Extrapolated $\dot{H}^*(10)$ = $\dot{E}$ exposed individual



Nuclear medicine patient as a radioactive source!

- Physically large source
- Patient-specific biokinetics change the activity distribution over time
  - Isotope- and pharmaceutical-specific
- Combination of 'point measurement' and 'unique effective half life'

⇒ can result in errors for typical 'close-contact scenarios' when assessing an Effective dose for an individual of a critical group

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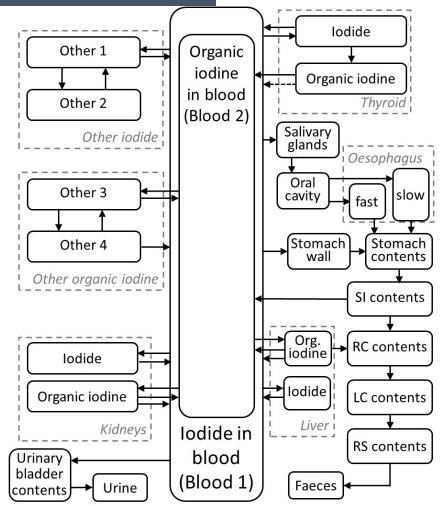
Joint EURADOS-EANM initiative computational approach

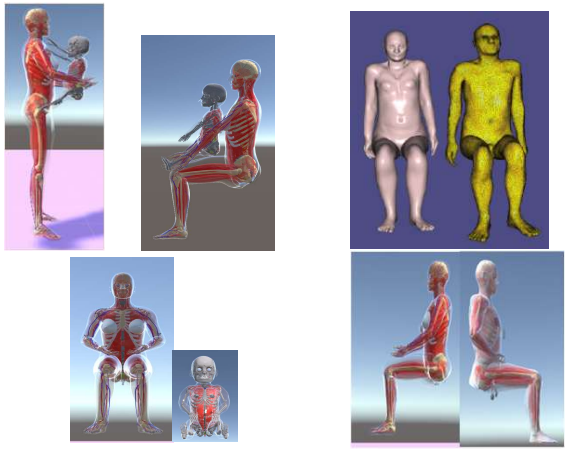
[1]ICRP Publication 128 (2015)
[2]Kamp A, et al. (2023)
[3]Taprogge J, et al. (2021)
[4]Siebinge H, et al. (2024)

[4]ICRP Publication 145 (2020)
[5]Lombardo P, et al. (2018)

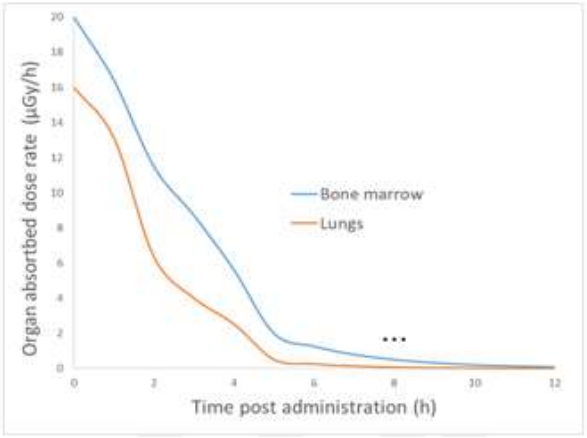
Patient Biokinetic models



Flexible mesh-based computational models for both patient and exposed individual (typical contact postures)



Individual organ absorbed dose rate of the exposed individual at time T for a specific contact posture ⇒ Ė



Monte Carlo modelling

- ICRP reference Biokinetic models[1,2]
- Biokinetic data based on patient data[3,4]

- ICRP reference phantoms[4]
- In-house developed phantoms[5]
- Incl. software to change the posture

- Monte Carlo codes
  - MCNP-X
  - PHITS
  - GATE
  - GEANT4
  - TRIPOLI-4

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Strategy

Benchmark of the computational framework

- Comparison between different Monte Carlo codes
- Comparison with H*(10) measured patient data (1m distance)

Choice of contact postures

- Everyday life (Adult/Child)
- Preliminary simulations diagnostic/therapeutic radiopharmaceuticals

Case study: Adult (patient)→Child (exposed individual)

- ^{177}Lu-PSMA-617, Na^{131}I (Hyperthyroidism)
- Influence of uncertainties in biokinetics
- Comparison with existing extrapolation methods
- Impact on cumulated dose using specific exposure scenarios

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Benchmark of the computational framework

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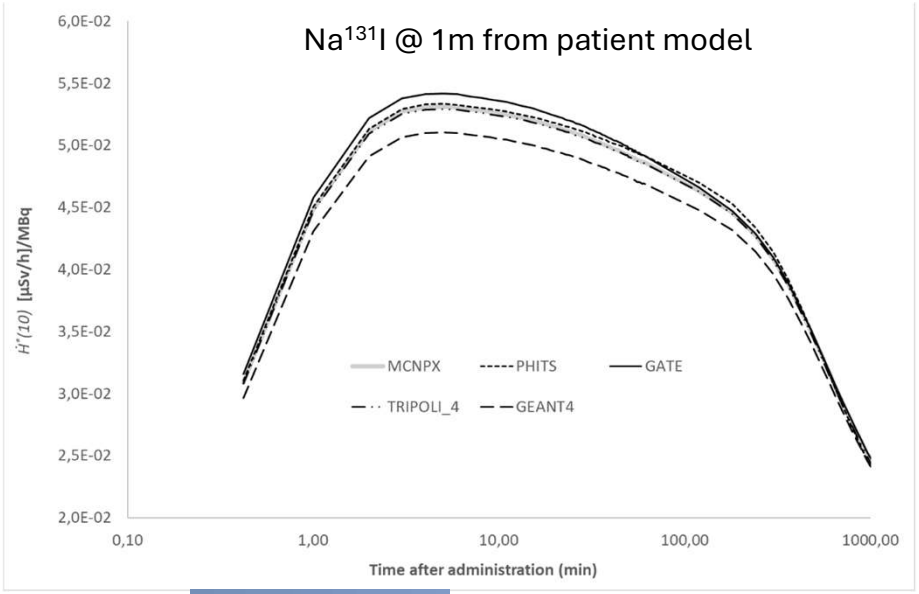
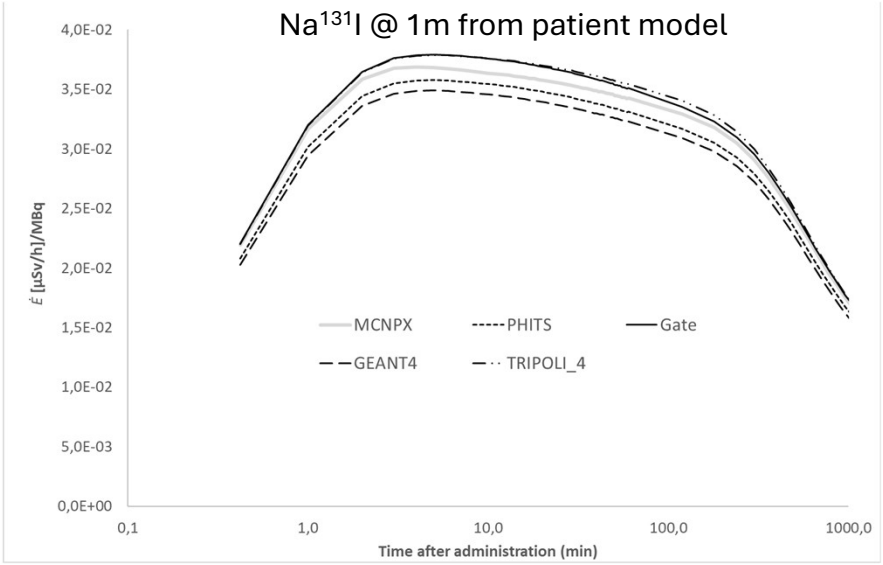
Comparison between different MC-codes

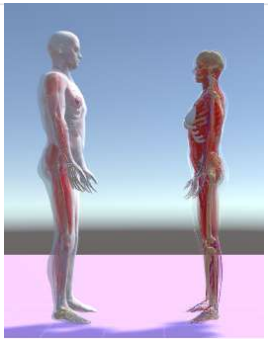
ICRP128 biokinetic data
hyperthyroidism
Patient: ICRP ref female voxel phantom

Ambient dose equivalent rate $\dot{H}^*(10)$





Effective dose rate Ė



ICRP128 biokinetic data
hyperthyroidism
Patient: ICRP Ref female voxel phantom
Exposed individual: average of female/male ICRP ref phantoms

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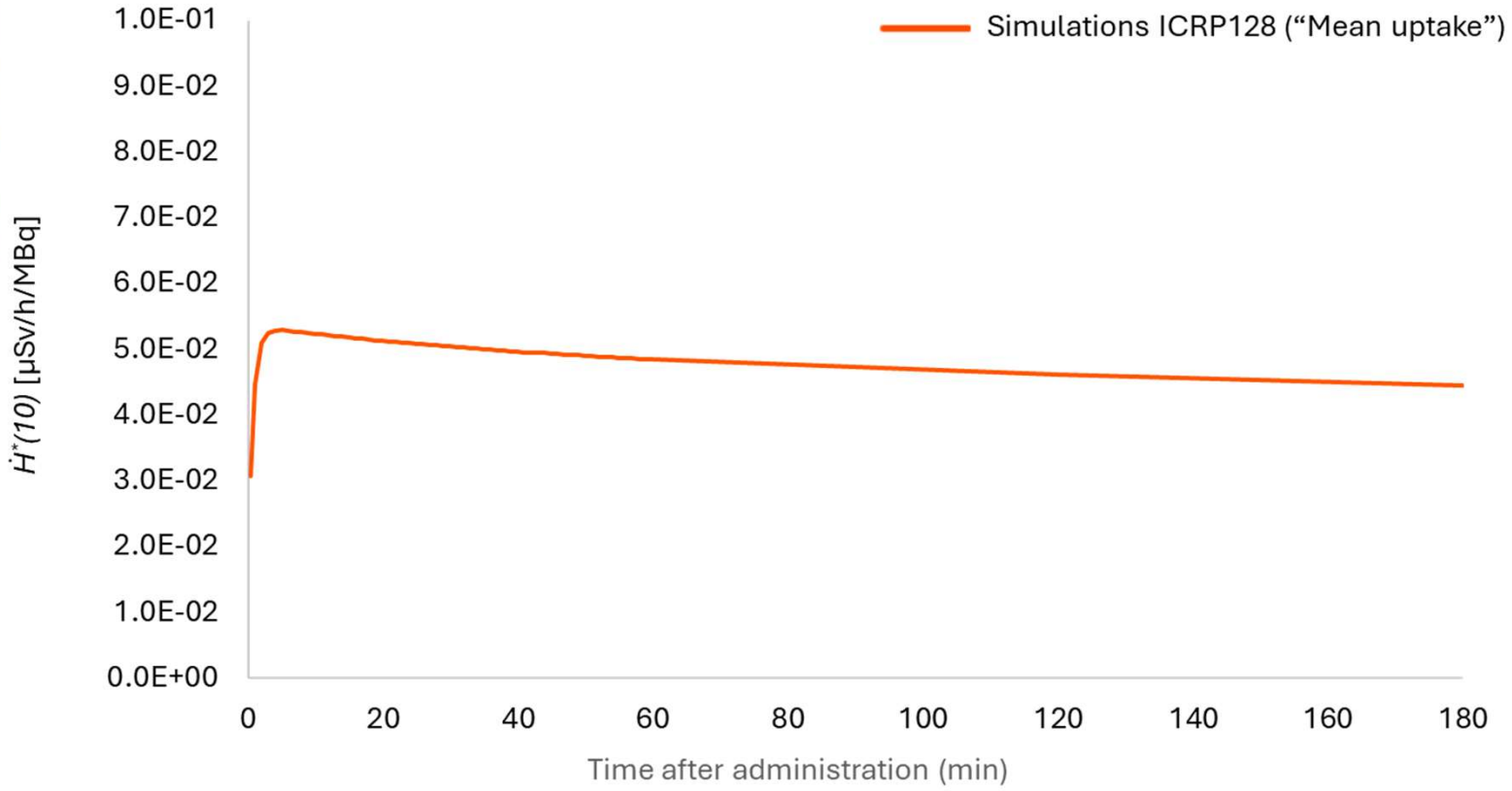
H*(10) comparison Hyperthyroidism $Na^{131}I$ data



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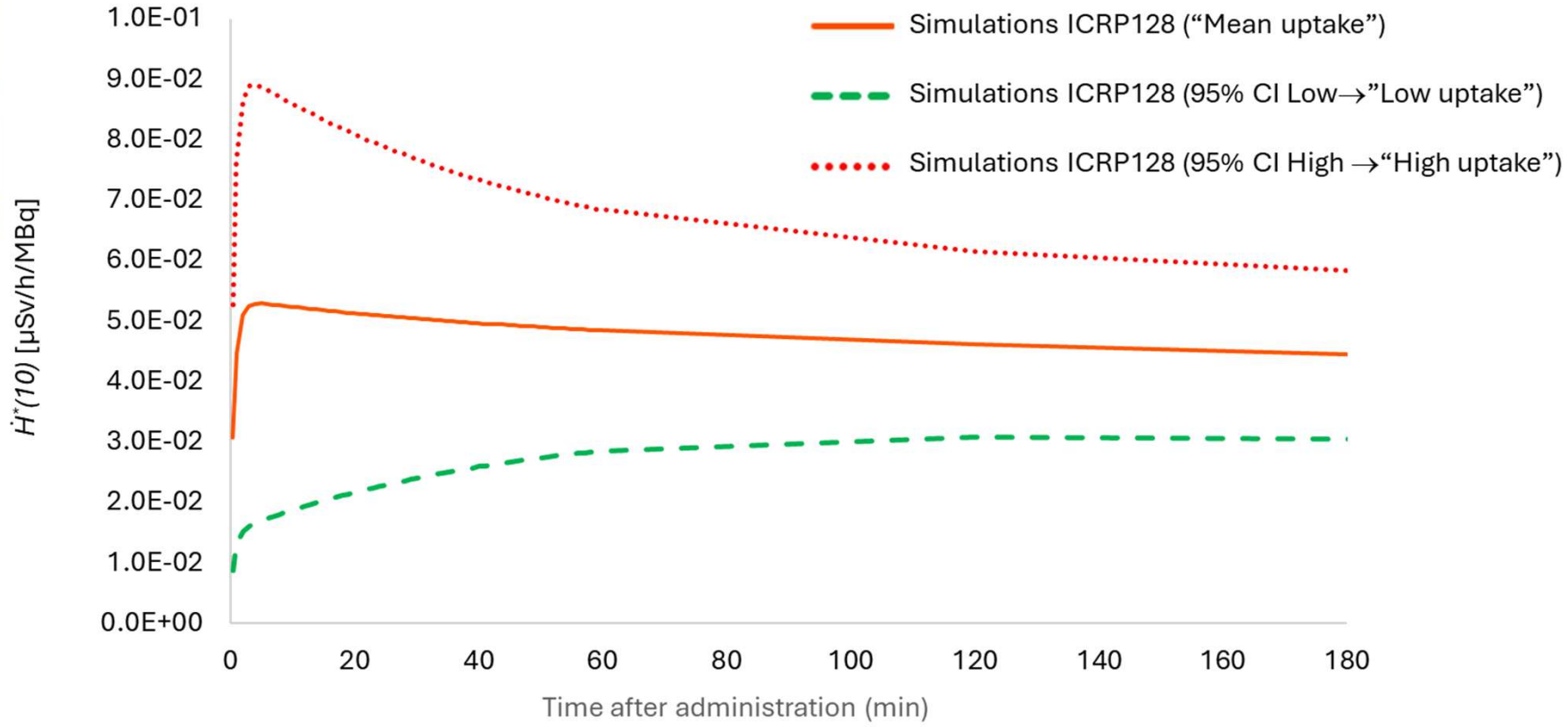
H*(10) comparison Hyperthyroidism $Na^{131}I$ data



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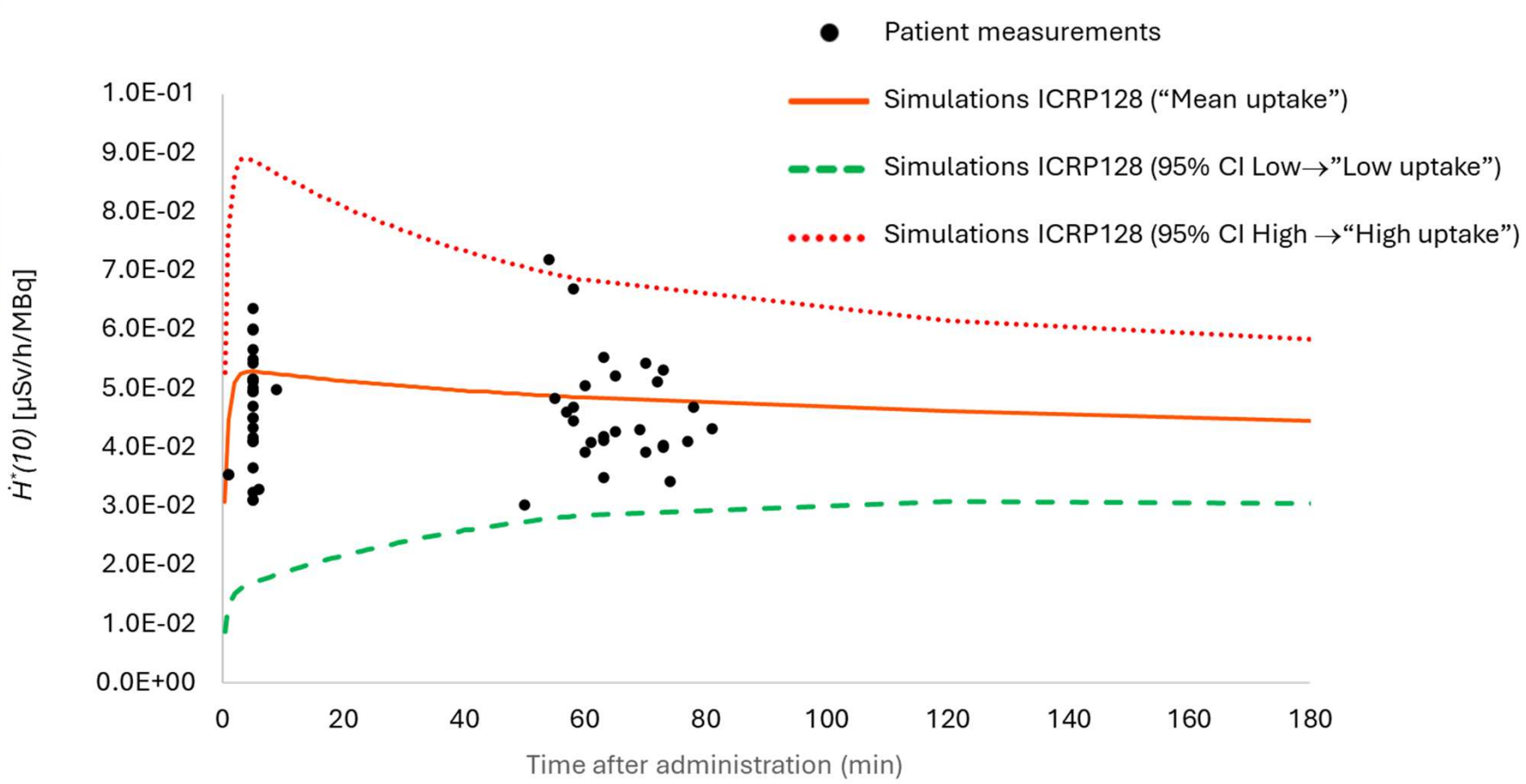

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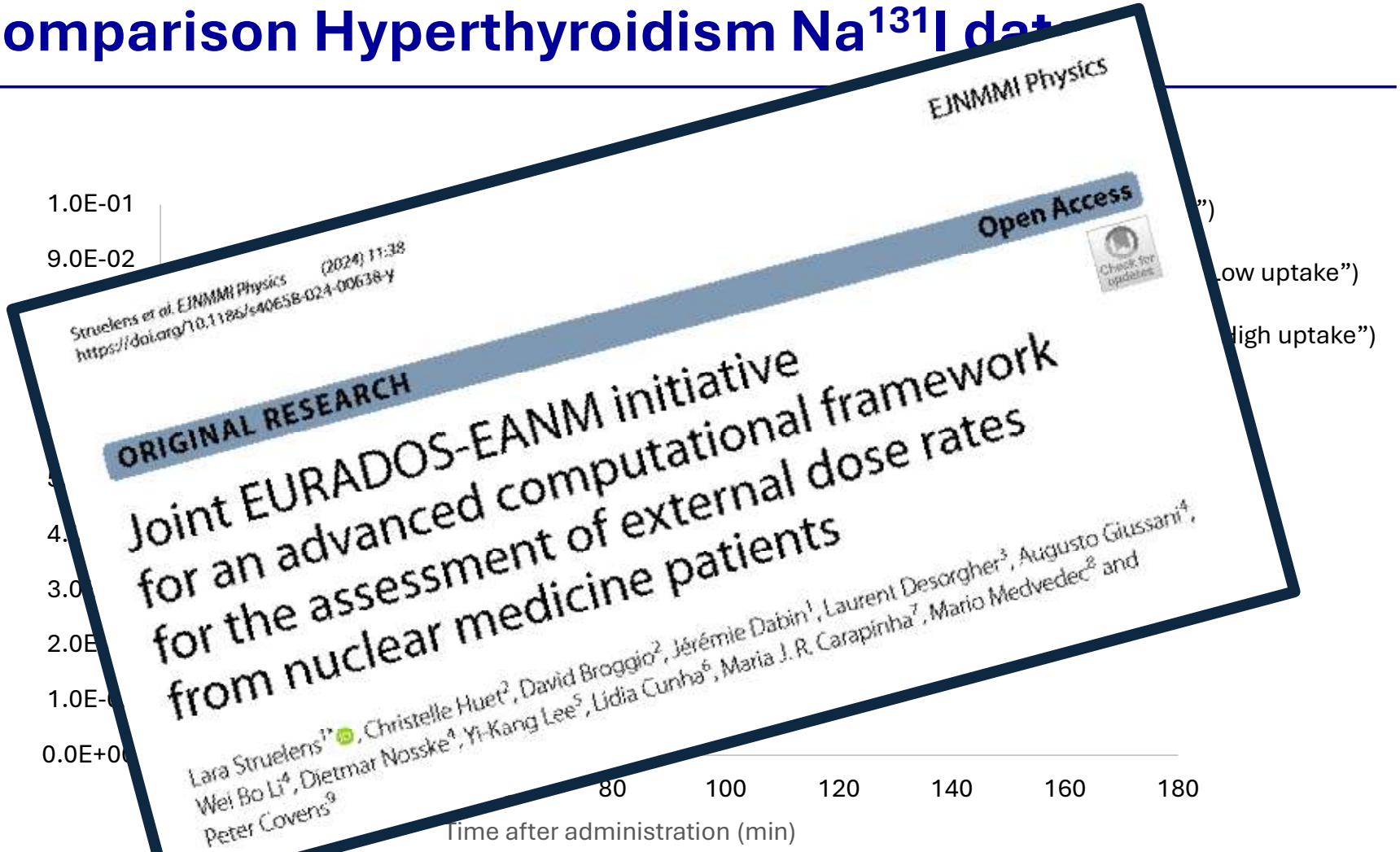
H*(10) comparison Hyperthyroidism $Na^{131}I$ dat



Struelens et al. EJNMMI Physics (2024) 11:38
https://doi.org/10.1186/s40658-024-00638-y

EJNMMI Physics

Open Access

ORIGINAL RESEARCH

Joint EURADOS-EANM initiative for an advanced computational framework for the assessment of external dose rates from nuclear medicine patients

Lara Struelens[1*], Christelle Huet[2], David Broggio[2], Jérémie Dabin[1], Laurent Desorgher[3], Augusto Giussani[4], Wei Bo Li[4], Dietmar Nosske[4], Yi-Kang Lee[5], Lídia Cunha[6], Maria J. R. Carapinha[7], Mario Medvedec[8] and Peter Covens[9]

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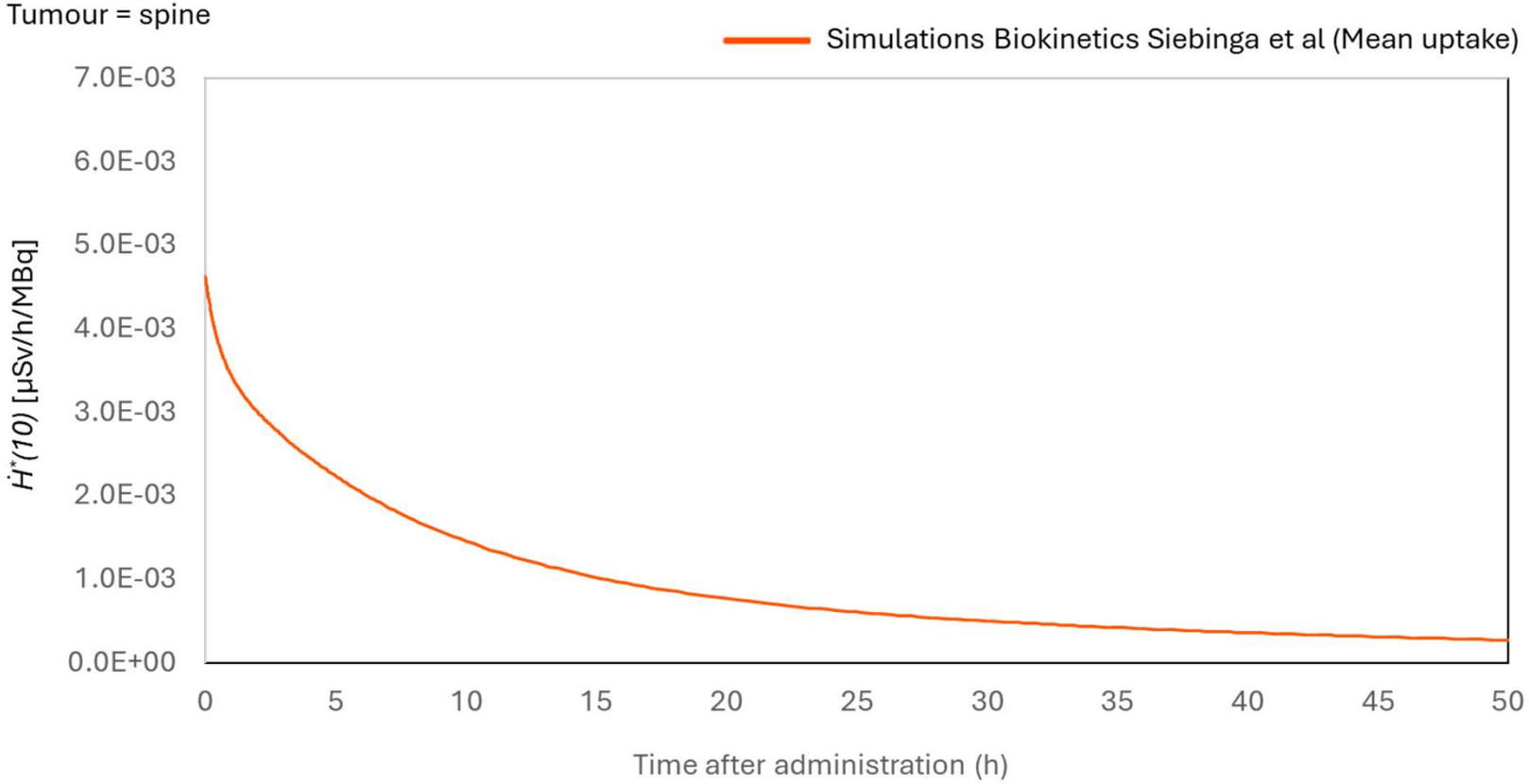
H*(10) comparison ^{177}Lu-PSMA-617 data

Lu-PSMA-617
Tumour = spine



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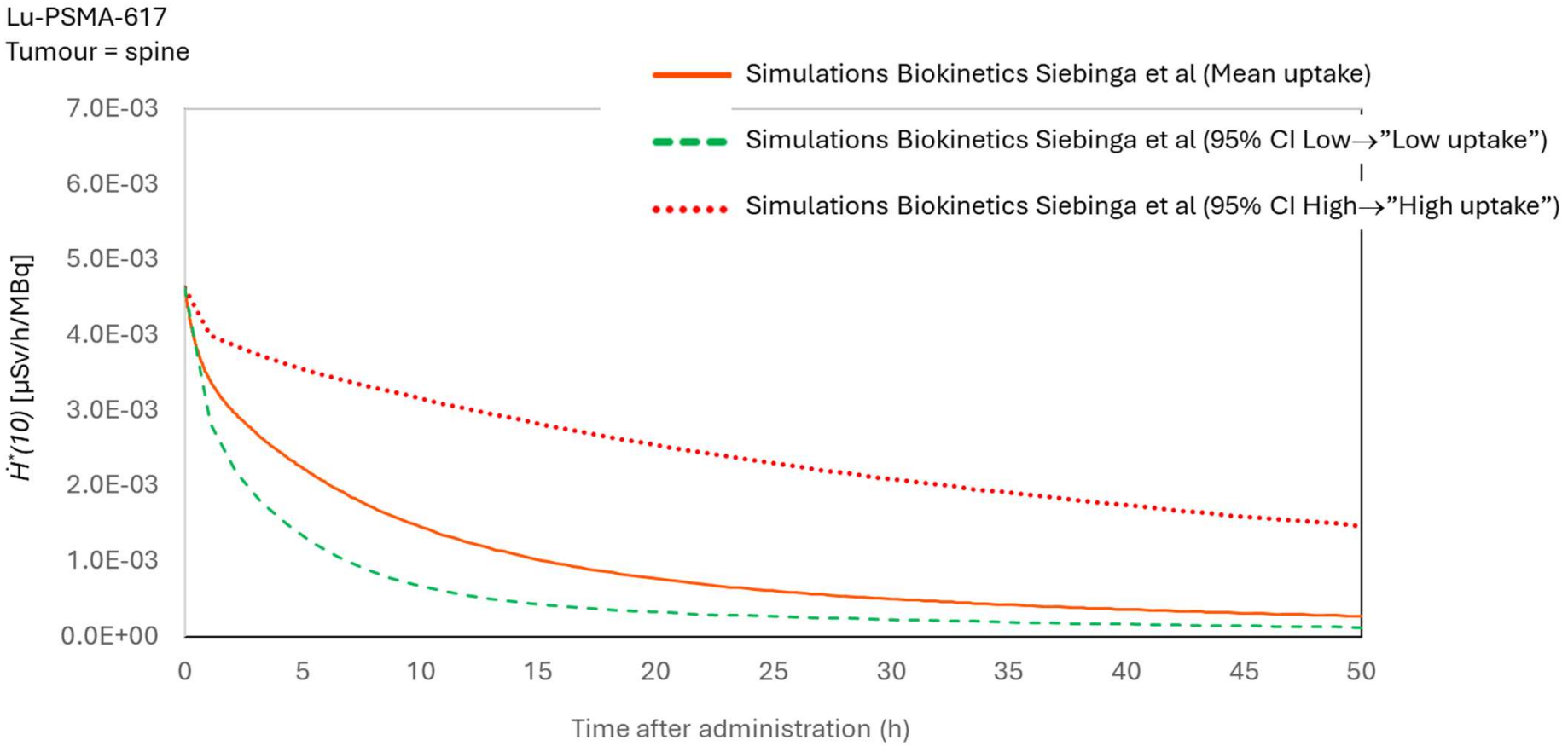
H*(10) comparison ^{177}Lu-PSMA-617 data



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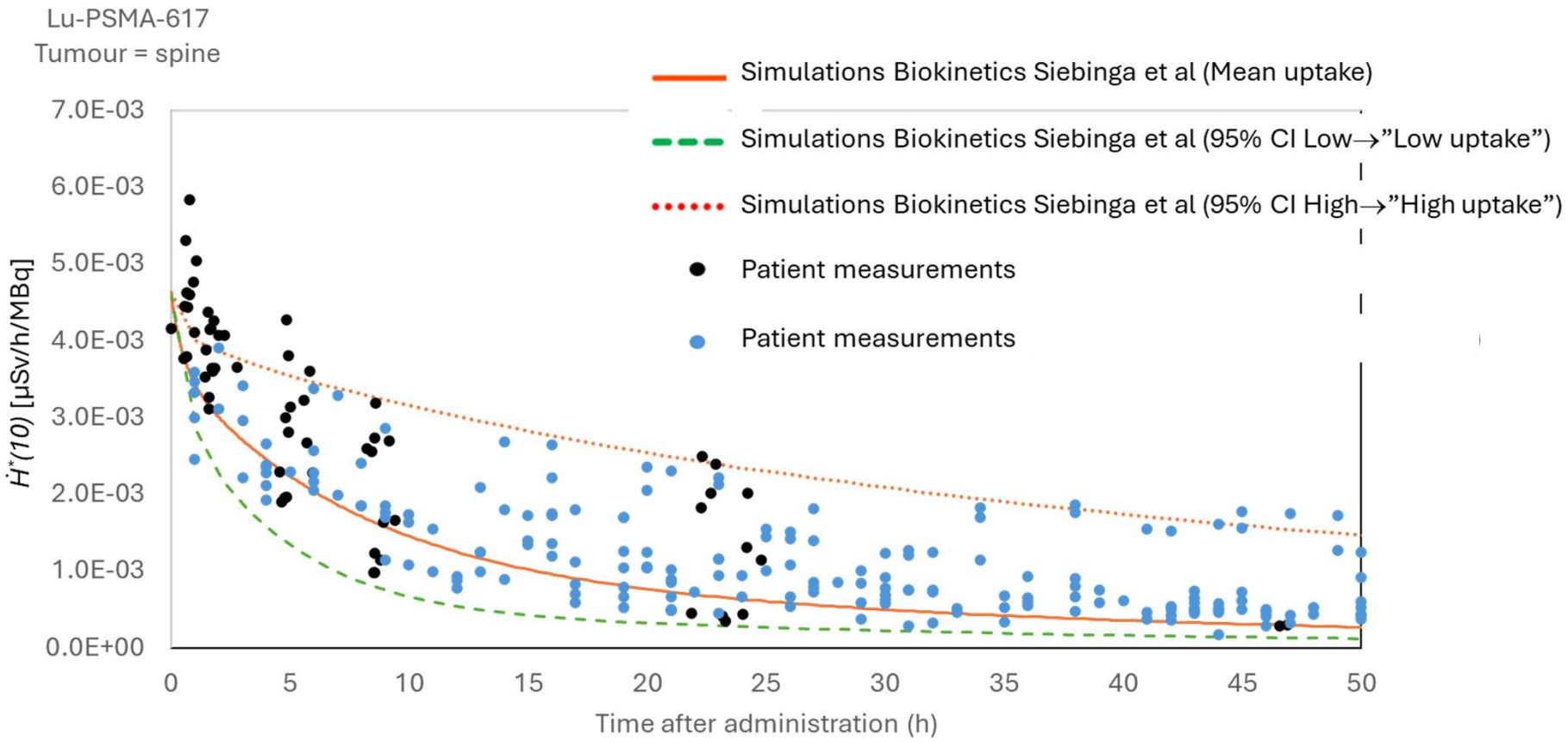
H*(10) comparison ^{177}Lu-PSMA-617 data



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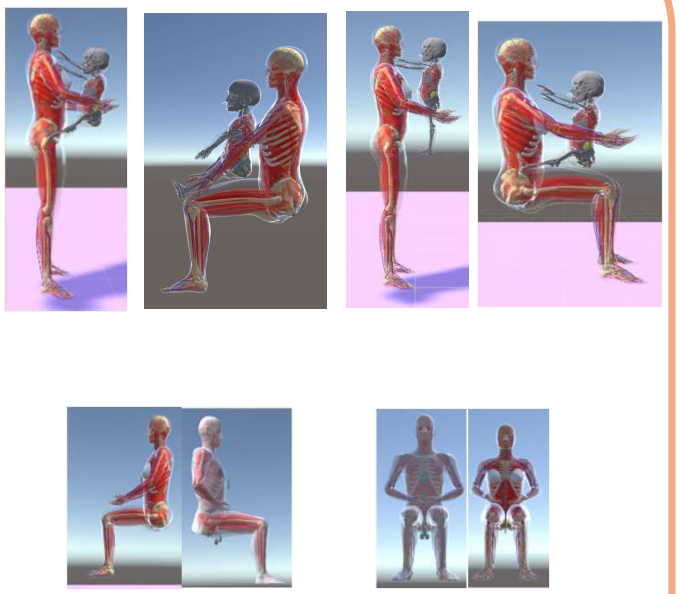
Choice of contact postures

Specific contact postures

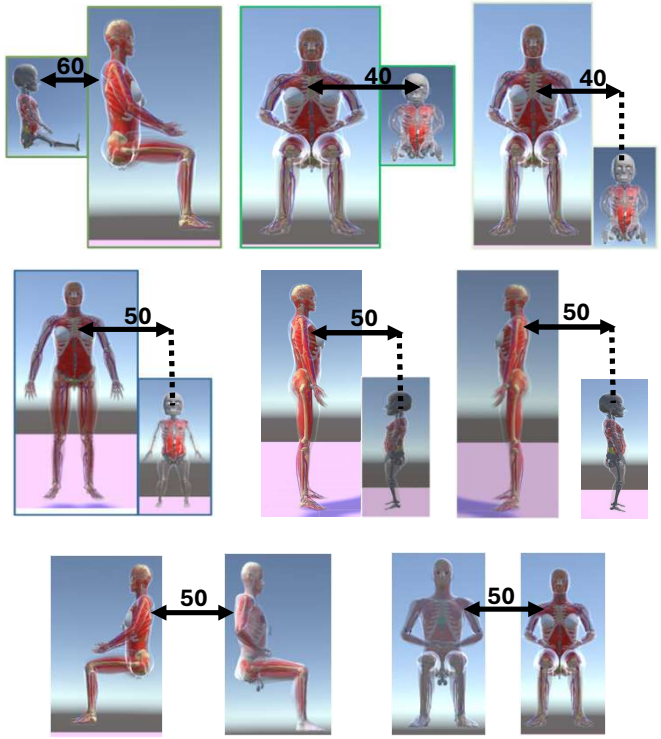
- Nature
  - Guided by situations that occur in everyday life
  - Guided by typical questions that may arise after NM procedures
- Variety exposure situations
  - Adult patient ↔ adult (female↔male)
  - Adult patient (female↔male) ↔ child (1 y old)
- Tens of simulations carried out
  - Calculated effective dose rate of the exposed individual as a function of time
  - Diagnostic/Therapeutic radiopharmaceuticals

Specific contact postures

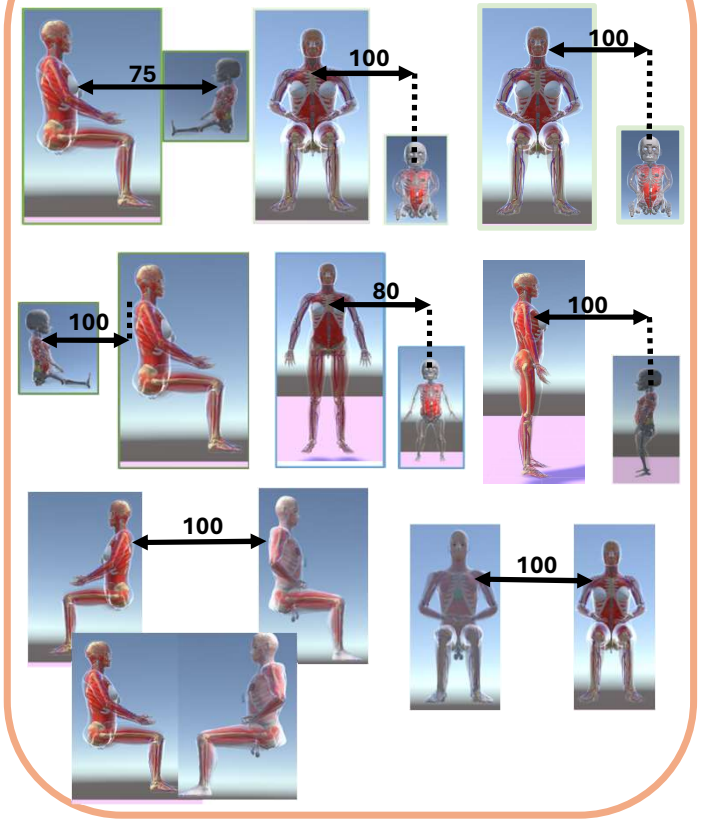
Close-contact <30 cm



30-50 cm



~ 100 cm



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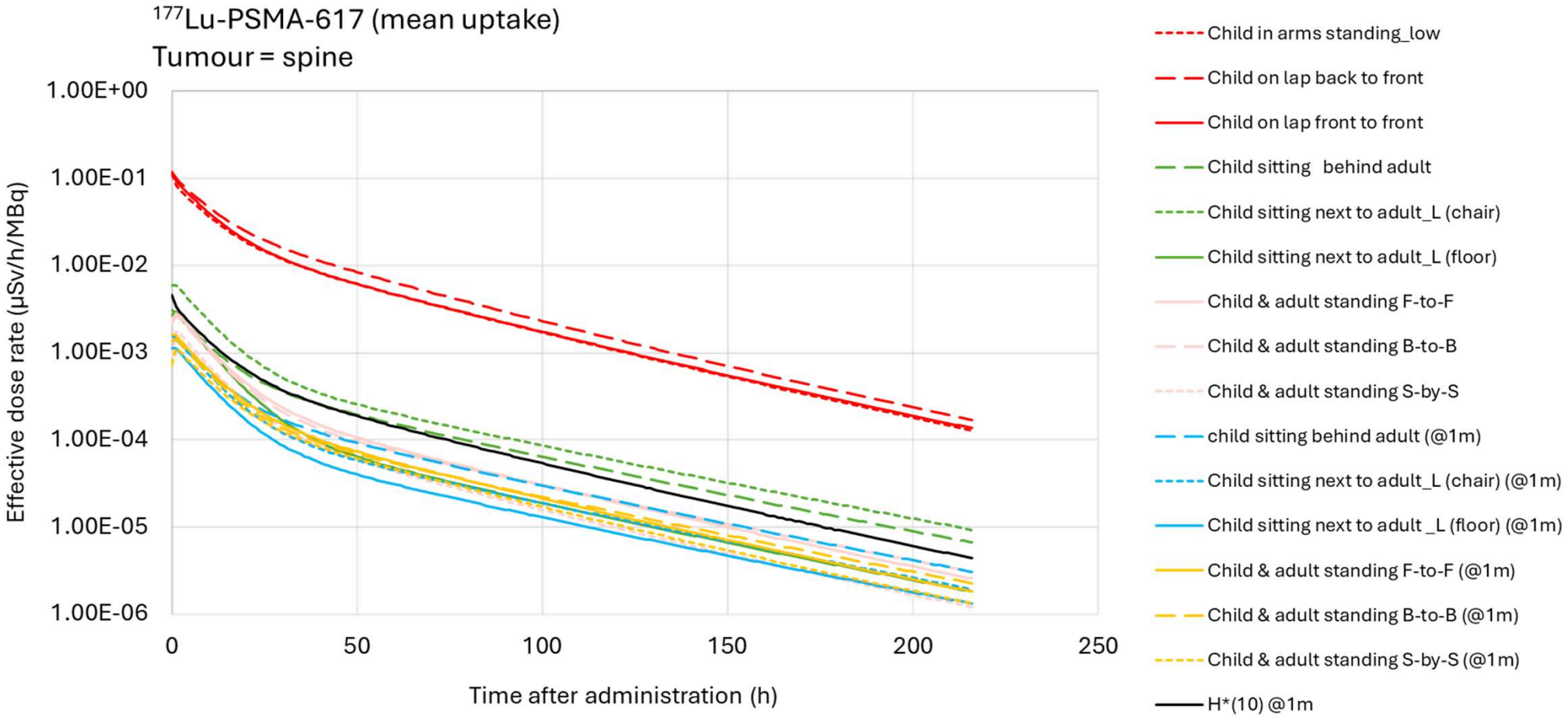
Case study: Adult (patient)→Child (exposed individual)

Simulations Male→Child ^{177}Lu-PSMA-617



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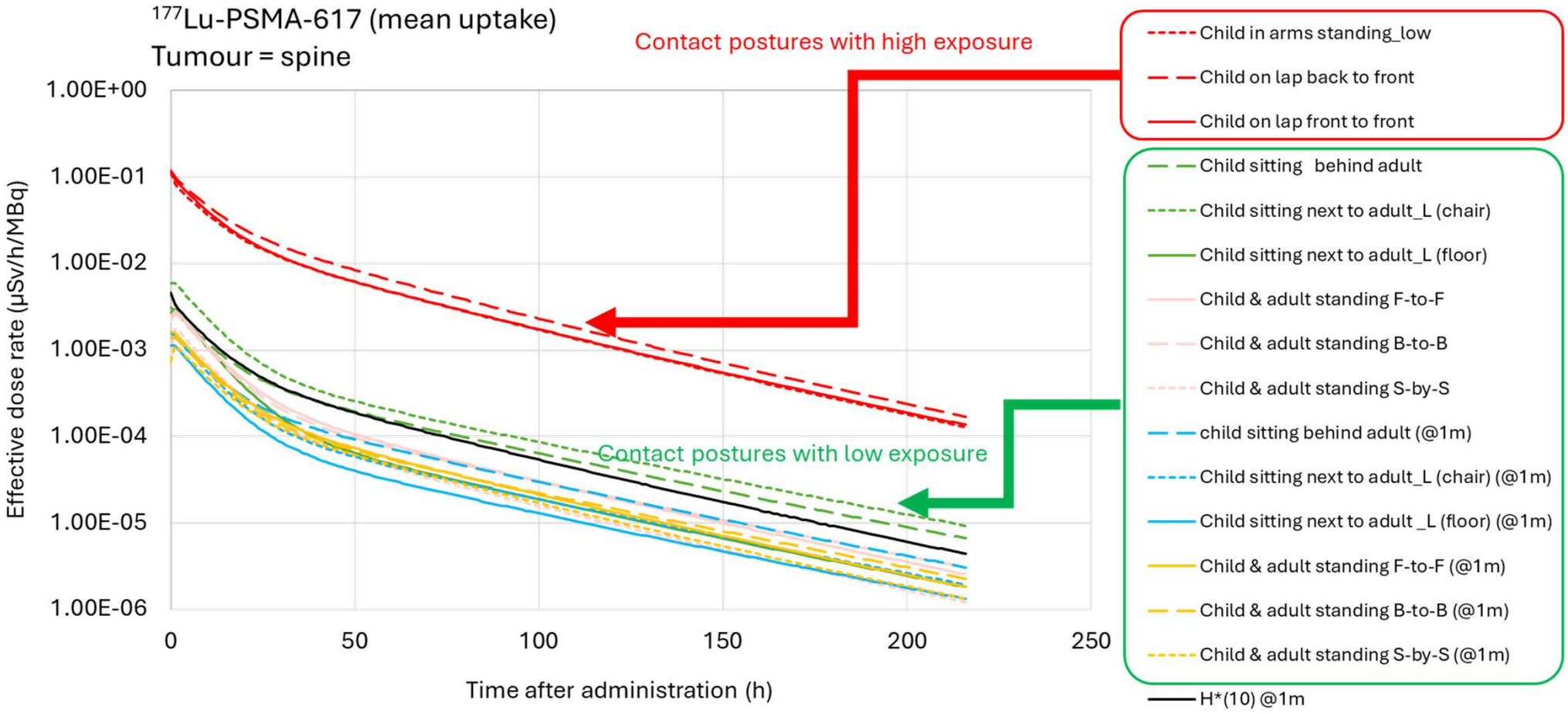
Simulations Male→Child ^{177}Lu-PSMA-617



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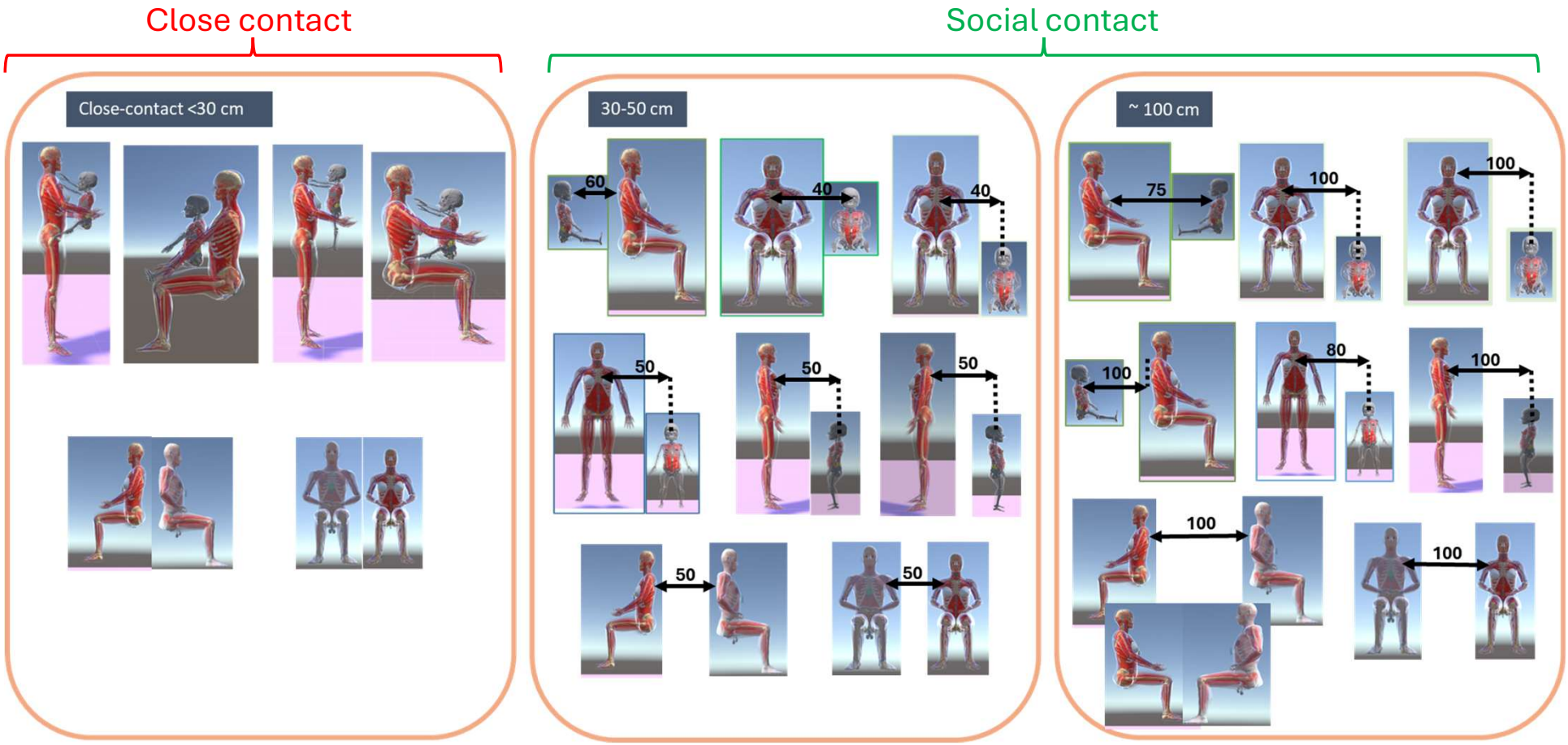
Main findings after simulations

- Classification
  - Typical postures associated with high exposure (close contact)
  - Postures associated with lower exposure (social contact)
- Future general risk assessment: classify postures into two groups
  → avoid too much complexity
- Specific postures can always be used to refine the risk assessment!
- “Distance” not always the determining factor associated with the exposure within the close contact group and the social contact group!

Simplification of the postures into two groups



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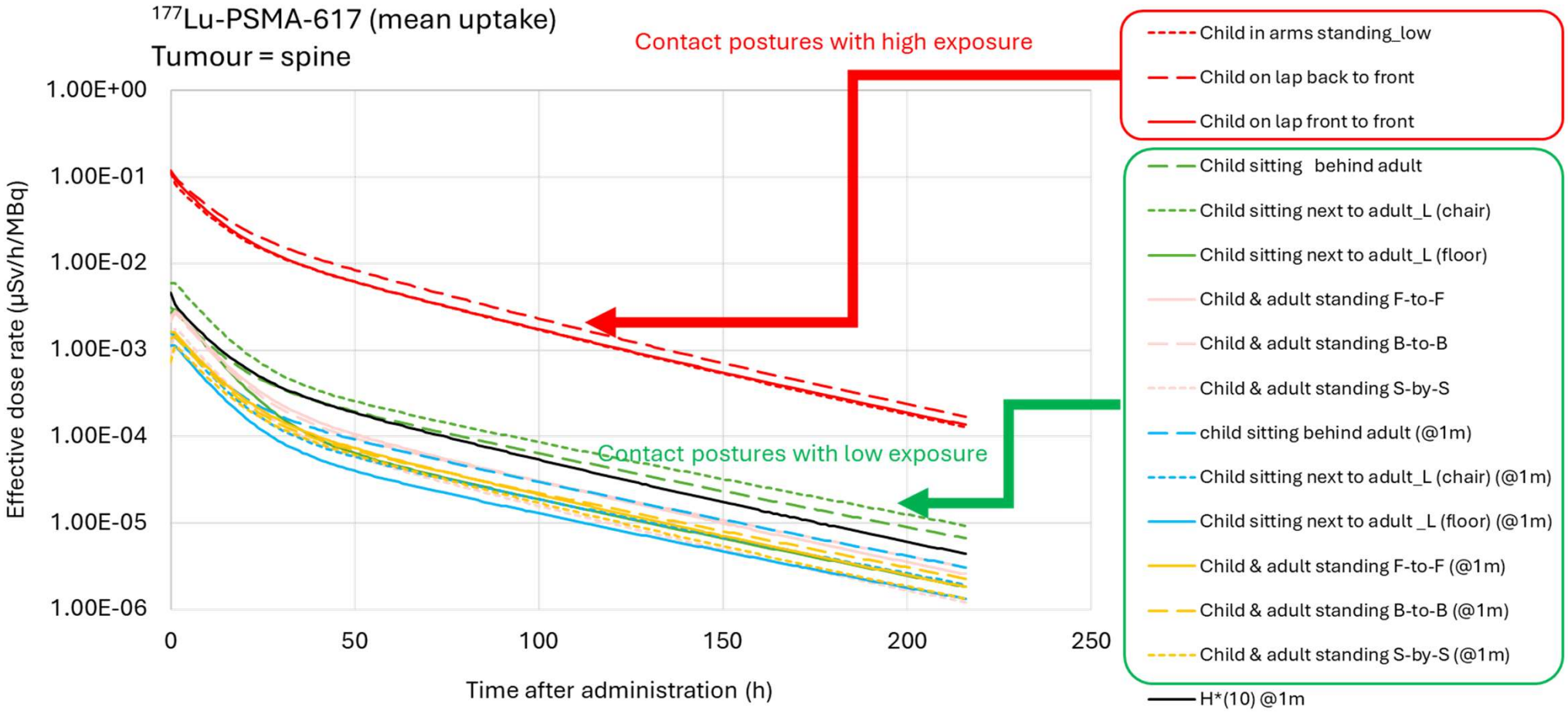
Simulations Male→Child ^{177}Lu-PSMA-617



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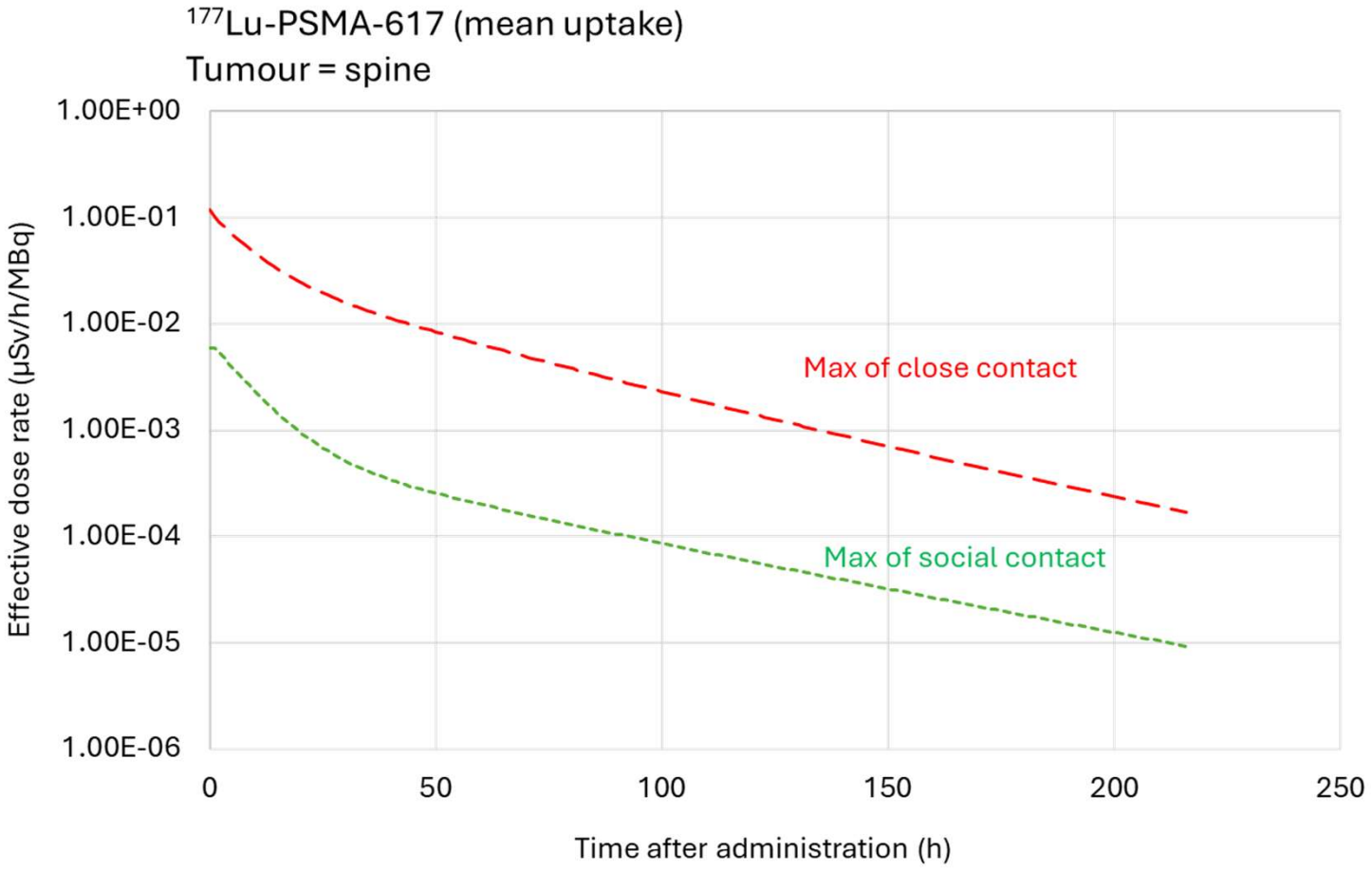
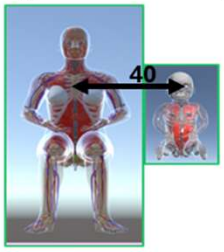
Male-Child exposure ^{177}Lu-PSMA-617: worst cases



Child on lap back to front

Child sitting next to adult_L (chair)



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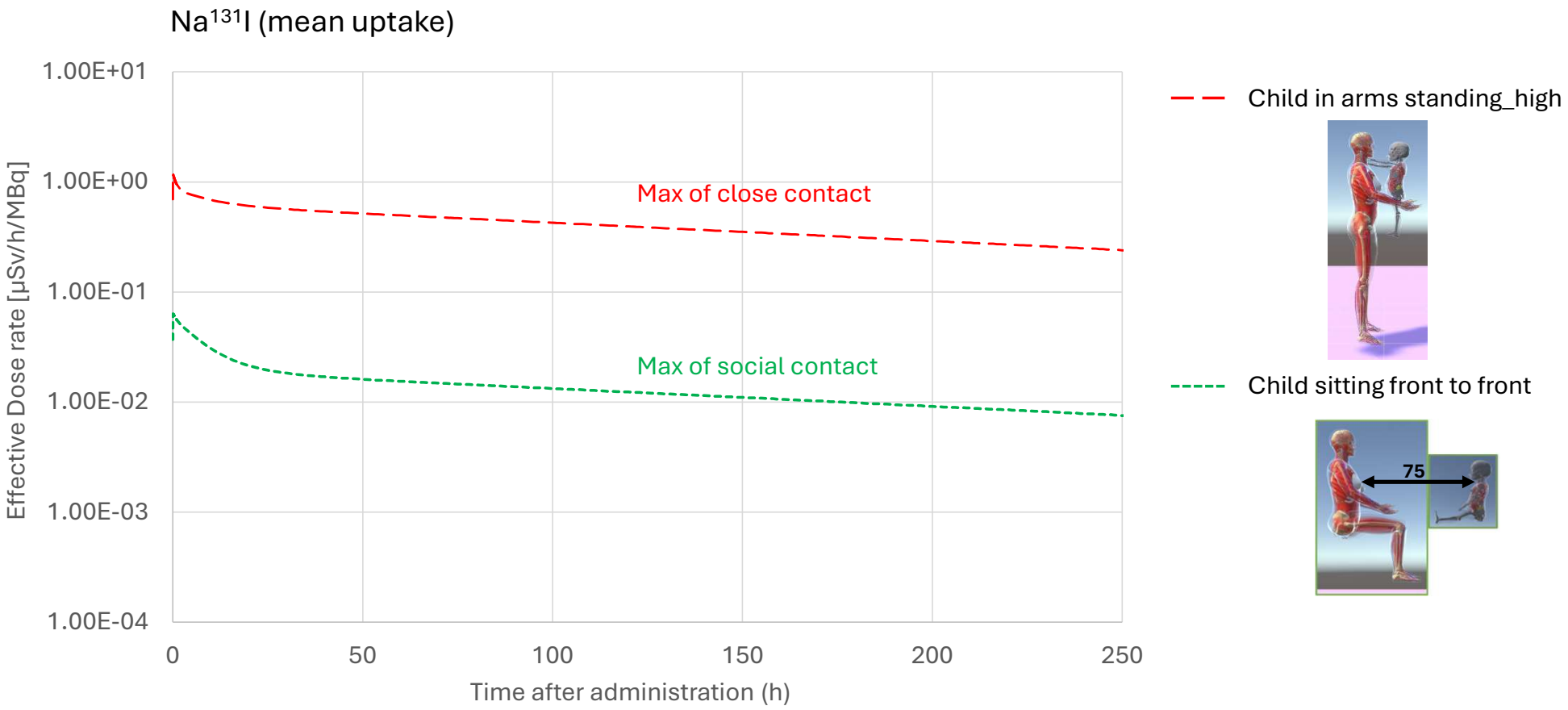
Female-Child exposure $Na^{131}I$ (Hyperthyroidism): worst cases



Case study: Adult (patient)→Child (exposed individual)

Influence of uncertainties in biokinetics

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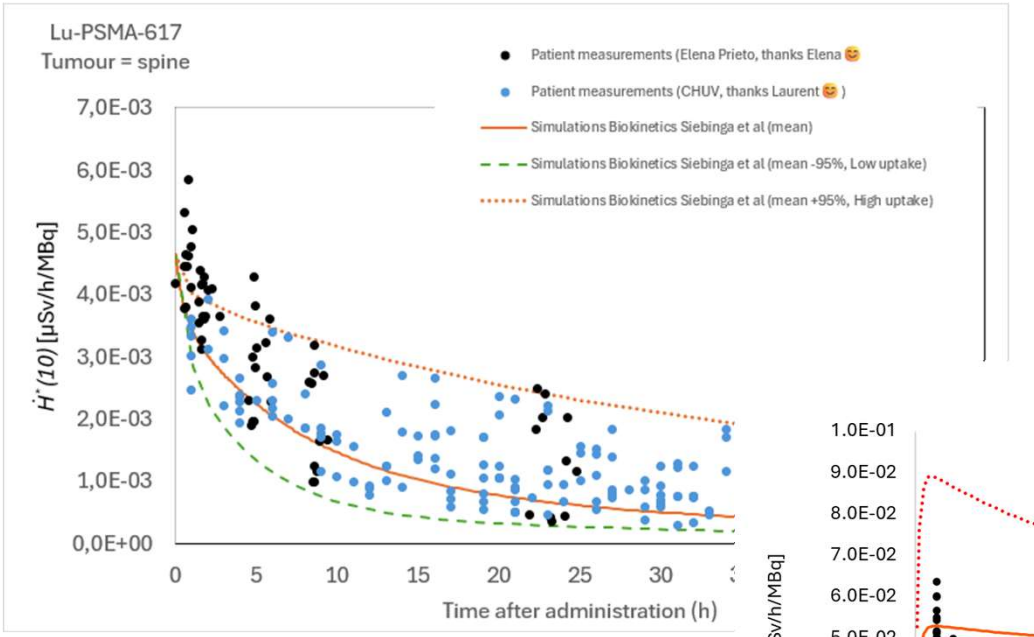
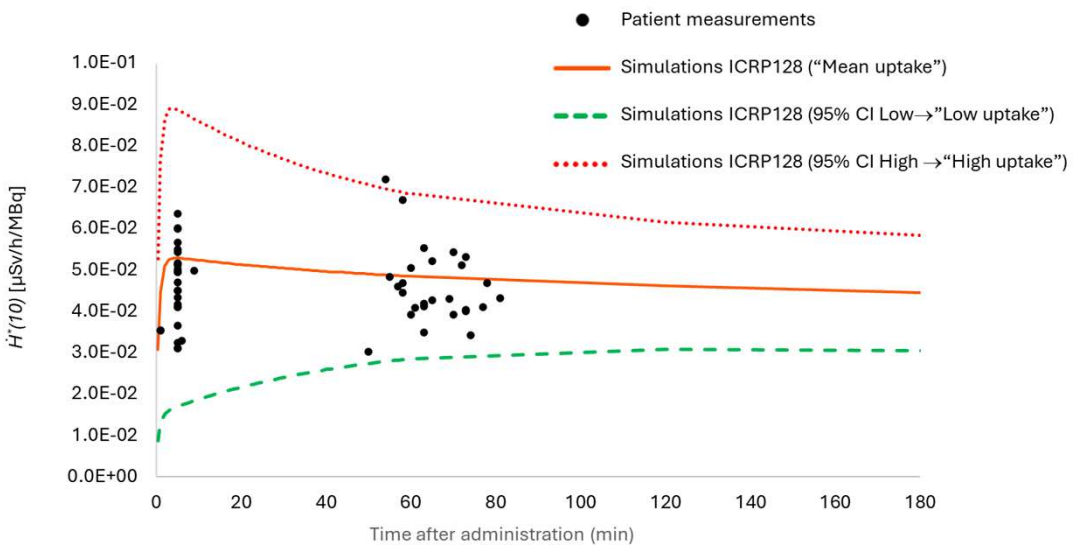
Variation in patient biokinetics





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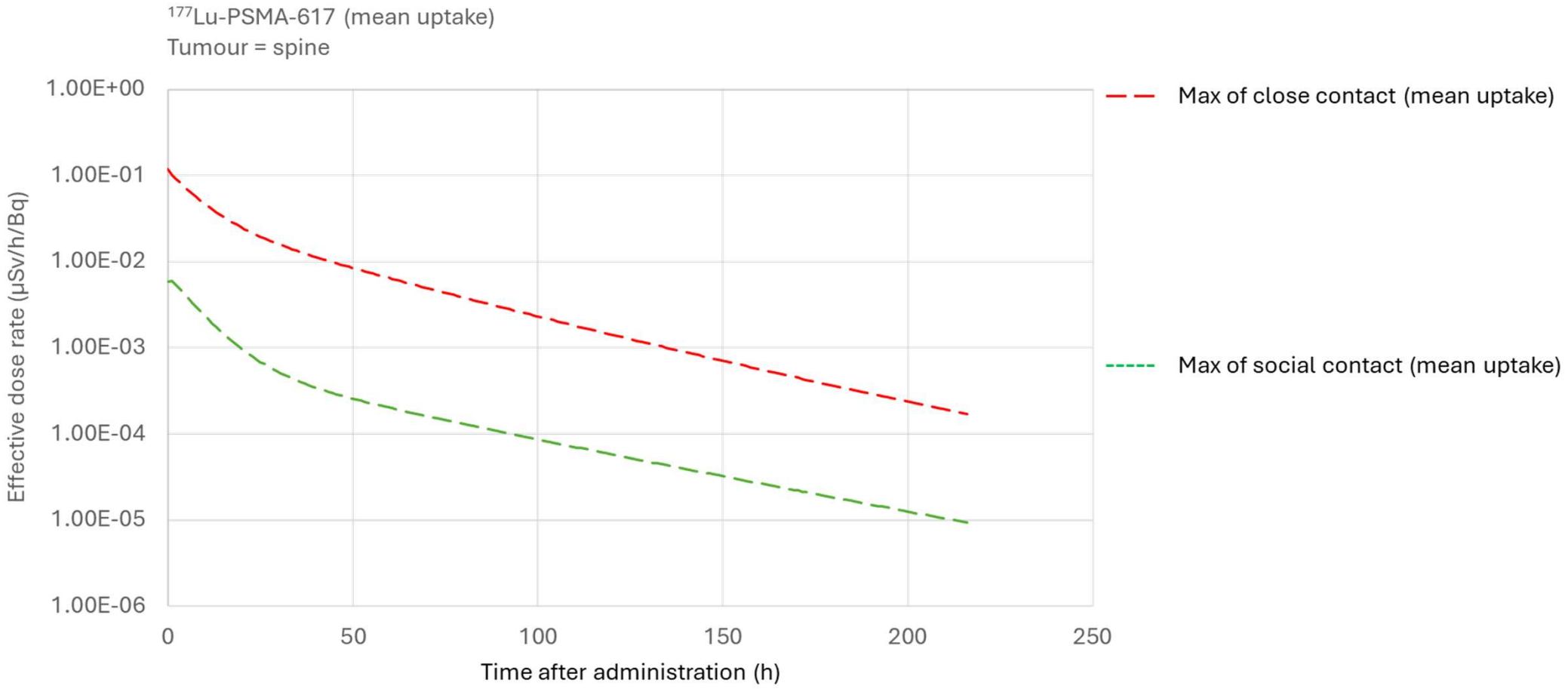
Male-Child exposure ^{177}Lu-PSMA-617: patient biokinetics



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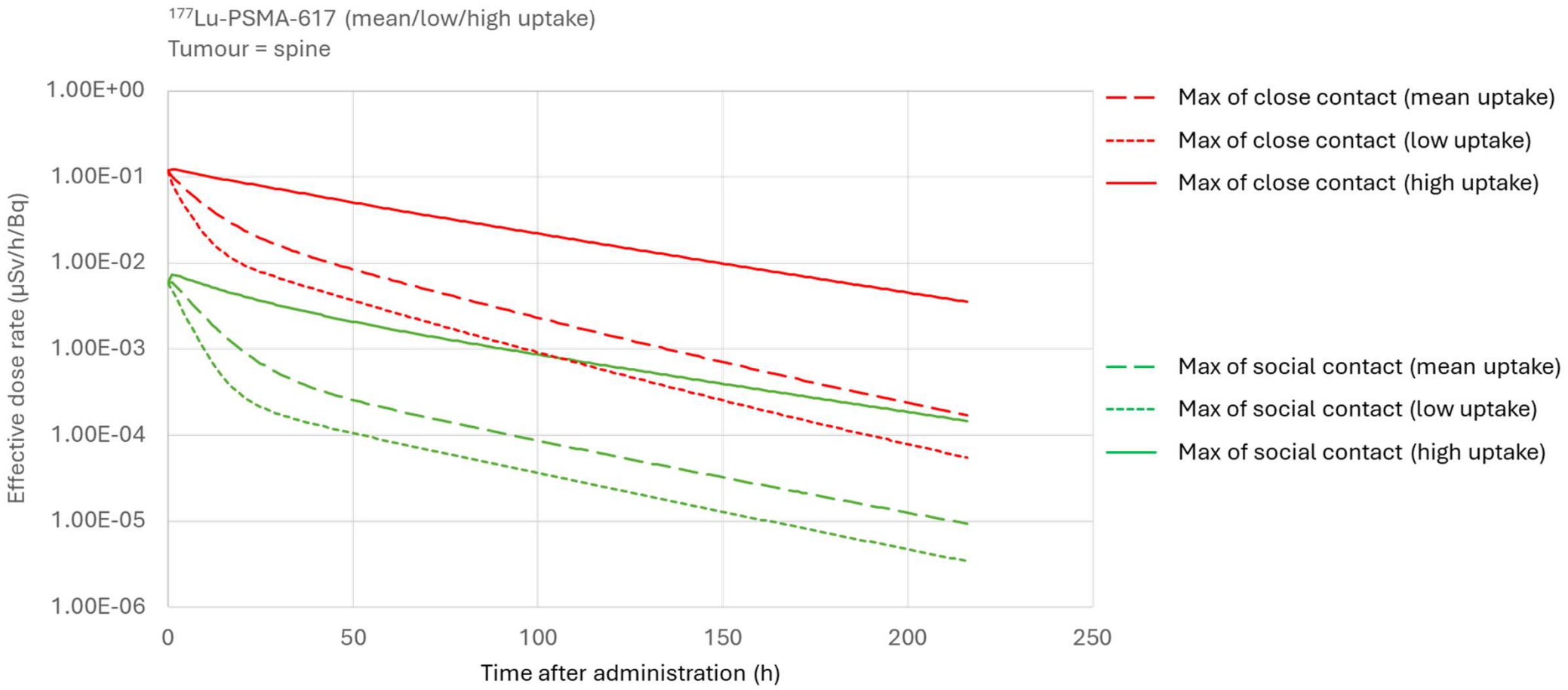
Male-Child exposure ^{177}Lu-PSMA-617: patient biokinetics



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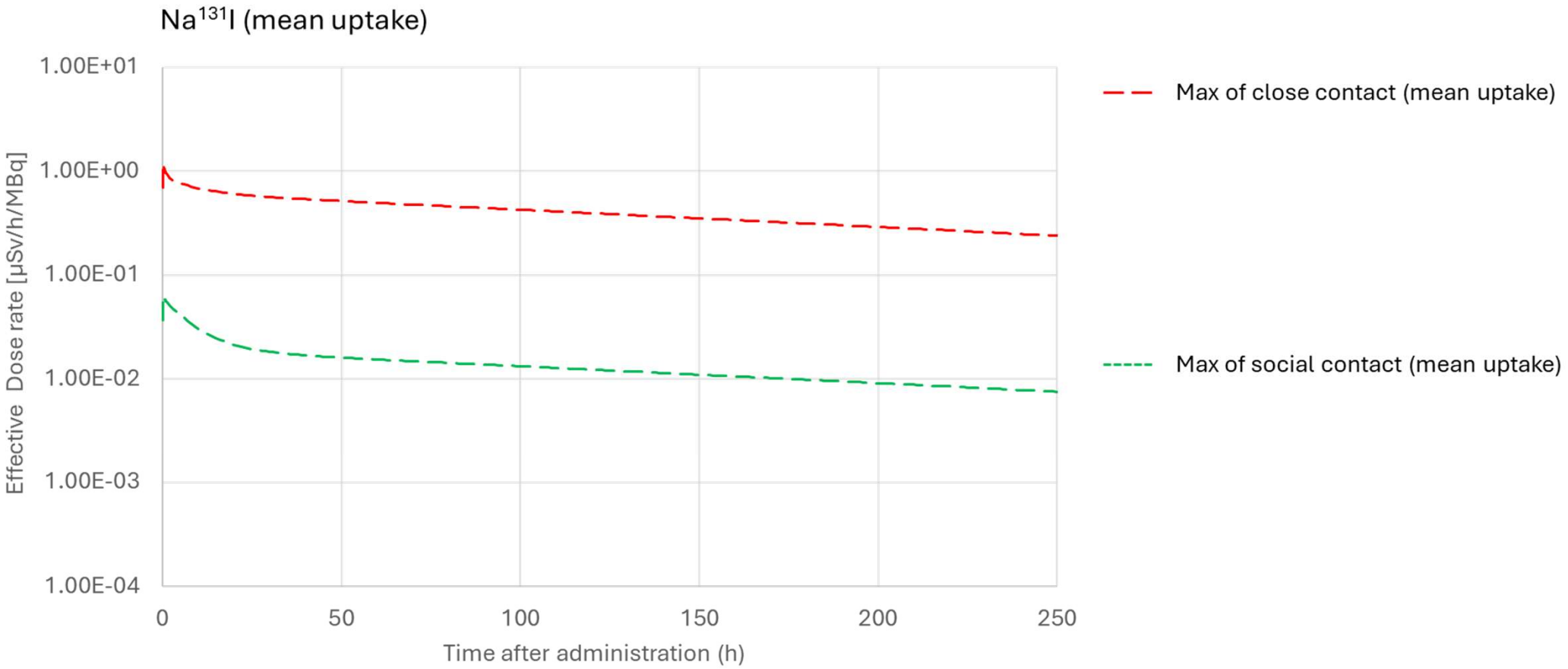
Female-Child exposure $Na^{131}I$: patient biokinetics



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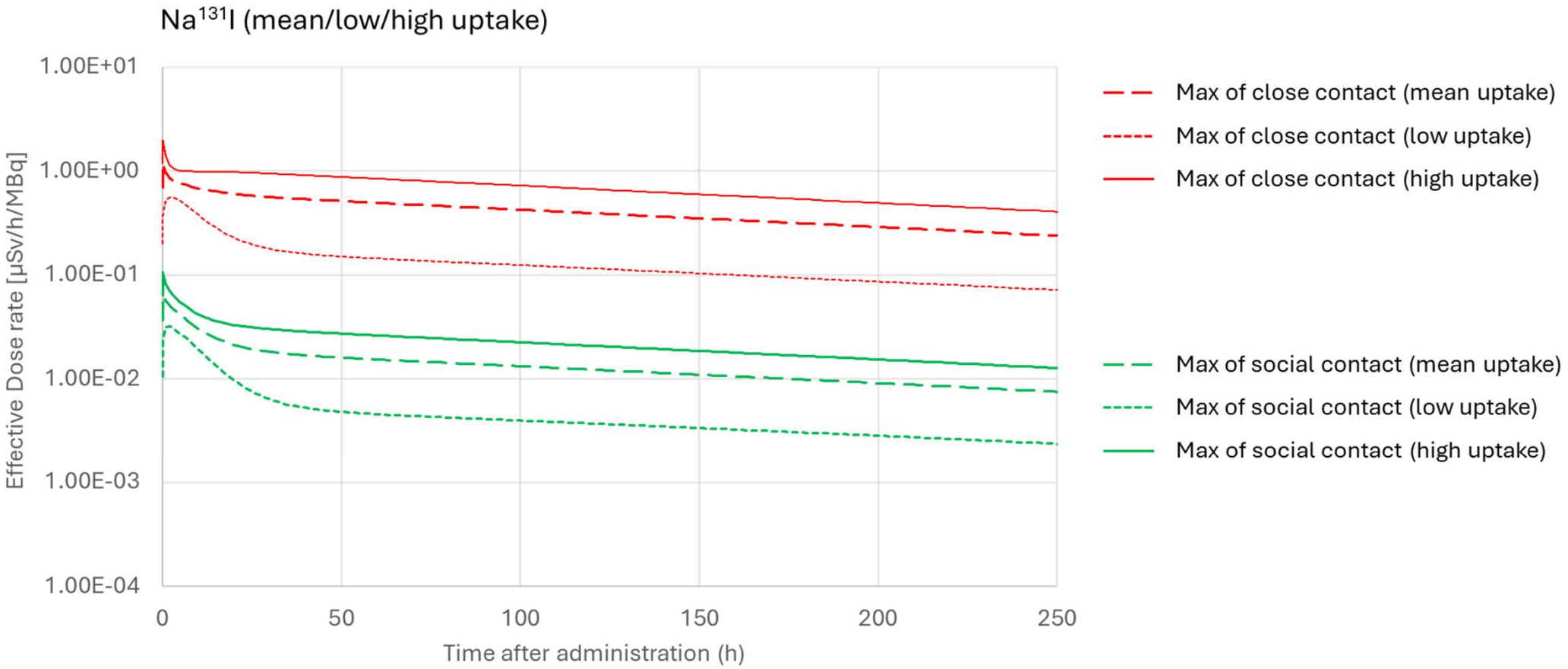
Female-Child exposure $Na^{131}I$: patient biokinetics



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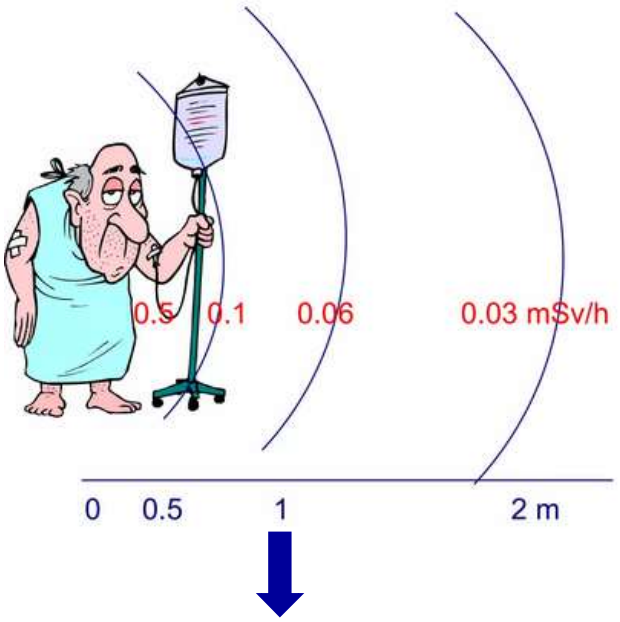
Case study: Adult (patient)→Child (exposed individual)

Comparison with existing extrapolation methods

Existing extrapolation methods



H*(10) measurement

Use of scaling factors for risk assessment at short distance

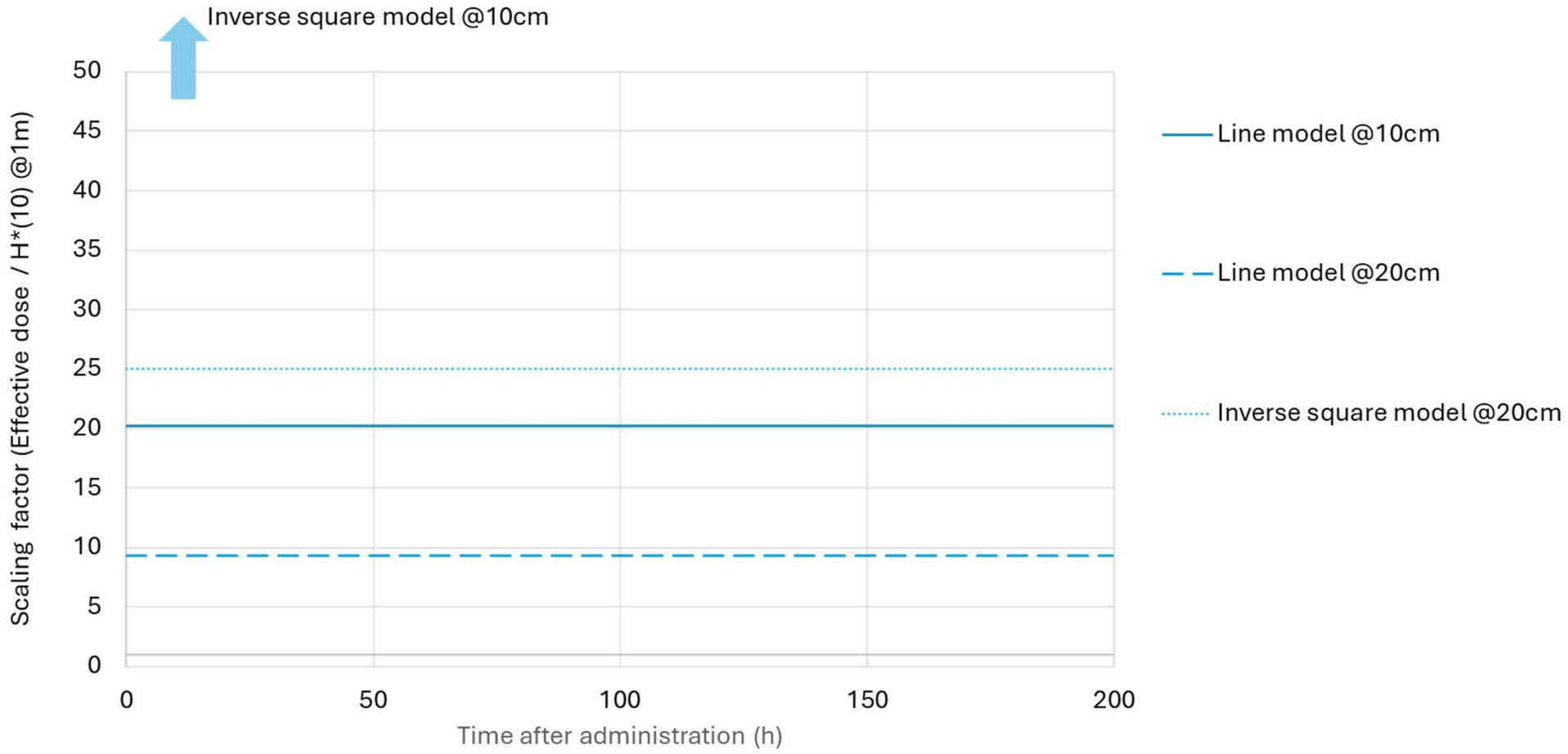
- Point-to-point inverse square law model
  - 100 cm → 10 cm: 100
  - 100 cm → 20 cm: 25

  } Fixed value over T
- Point-line source model (Broggio, 2022), patient= 178 cm tall
  - 100 cm → 10 cm: 20.2
  - 100 cm → 20 cm: 9.3

  } Fixed value over T
- This computational approach with realistic geometries?

$$\frac{\dot{E}_{posture,\,sim,\,T}}{\dot{H}^{*}(10)_{sim,\,T}}$$

Comparison with existing extrapolation methods



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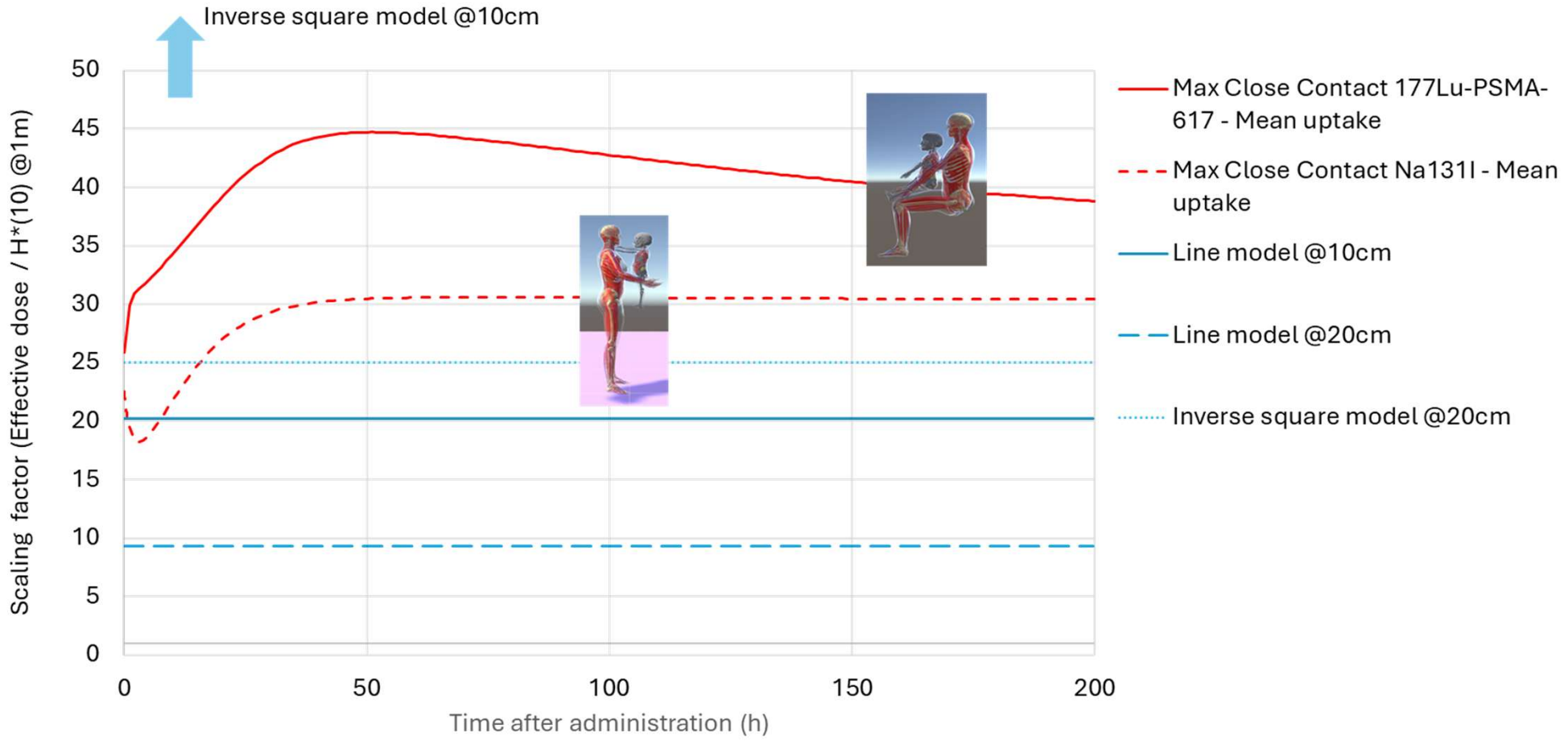

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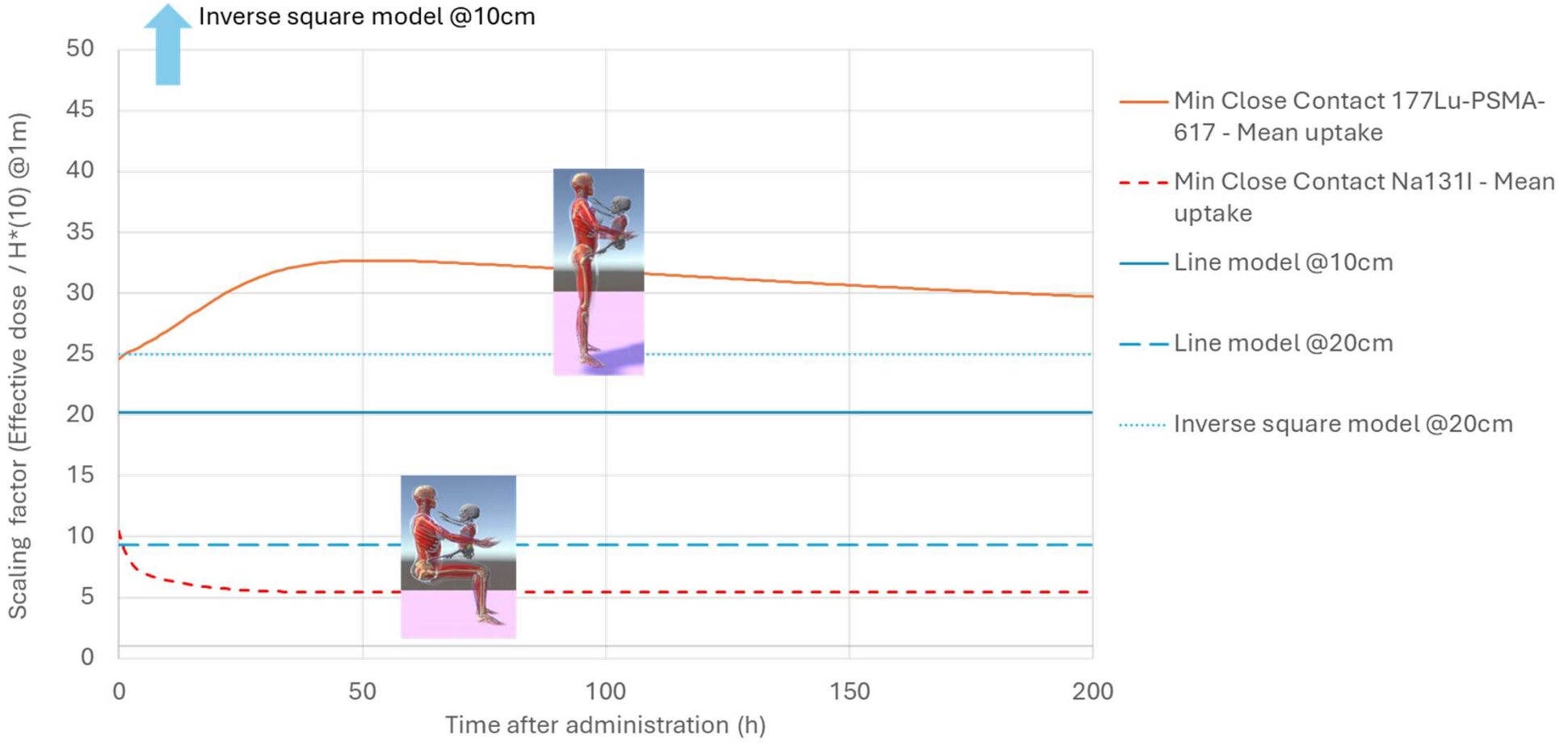

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Case study: Adult (patient)→Child (exposed individual)

Impact on cumulated dose using specific exposure scenarios

Exposure scenarios

- Difficult to predict a specific pattern for contact between adult and child
- The pattern can be corrected by following specific patient instructions after discharge
- Not many guidance documents are available
- Data from Dutch report

Typical daily contact Adult-Child without specific patient instructions:

Close contact: ~ 1 h/day

Social contact: ~ 6 h/day

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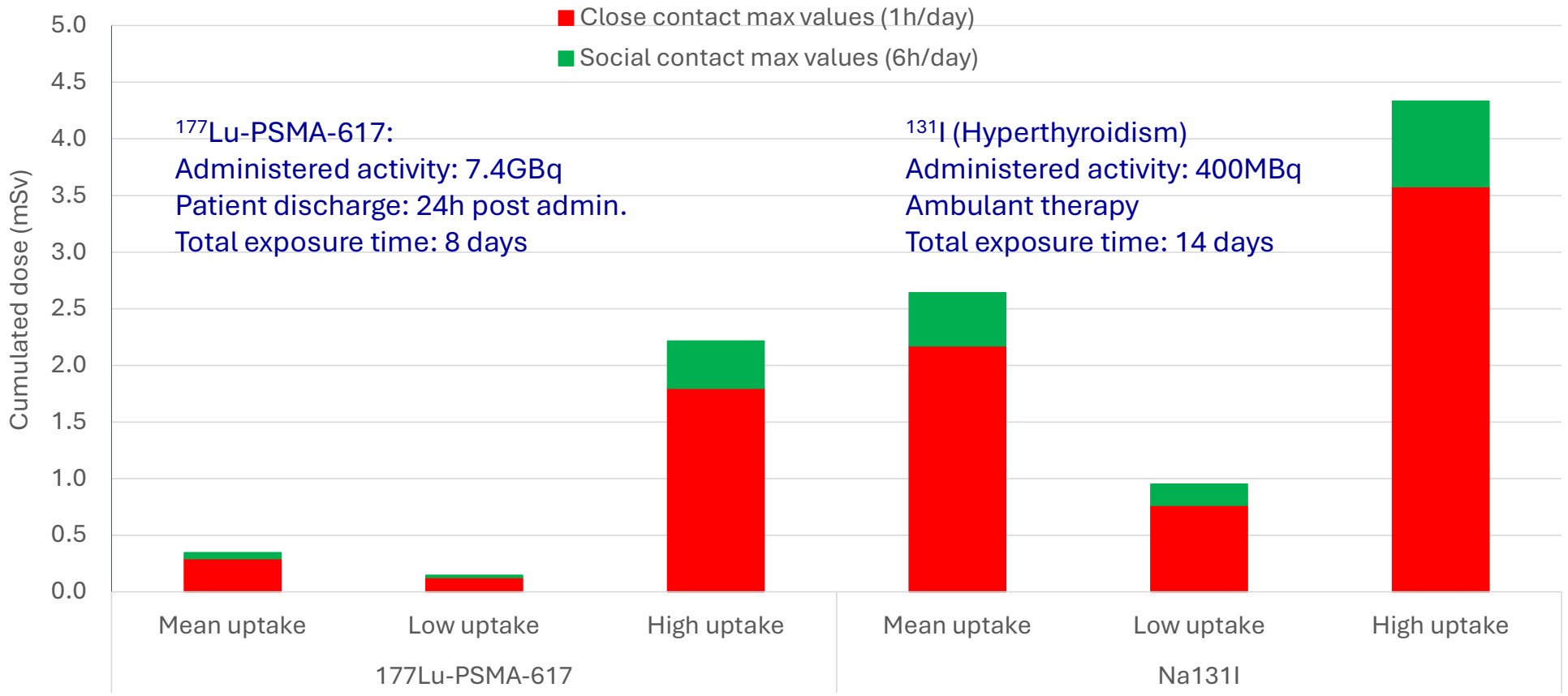
Risk assessment using exposure scenarios



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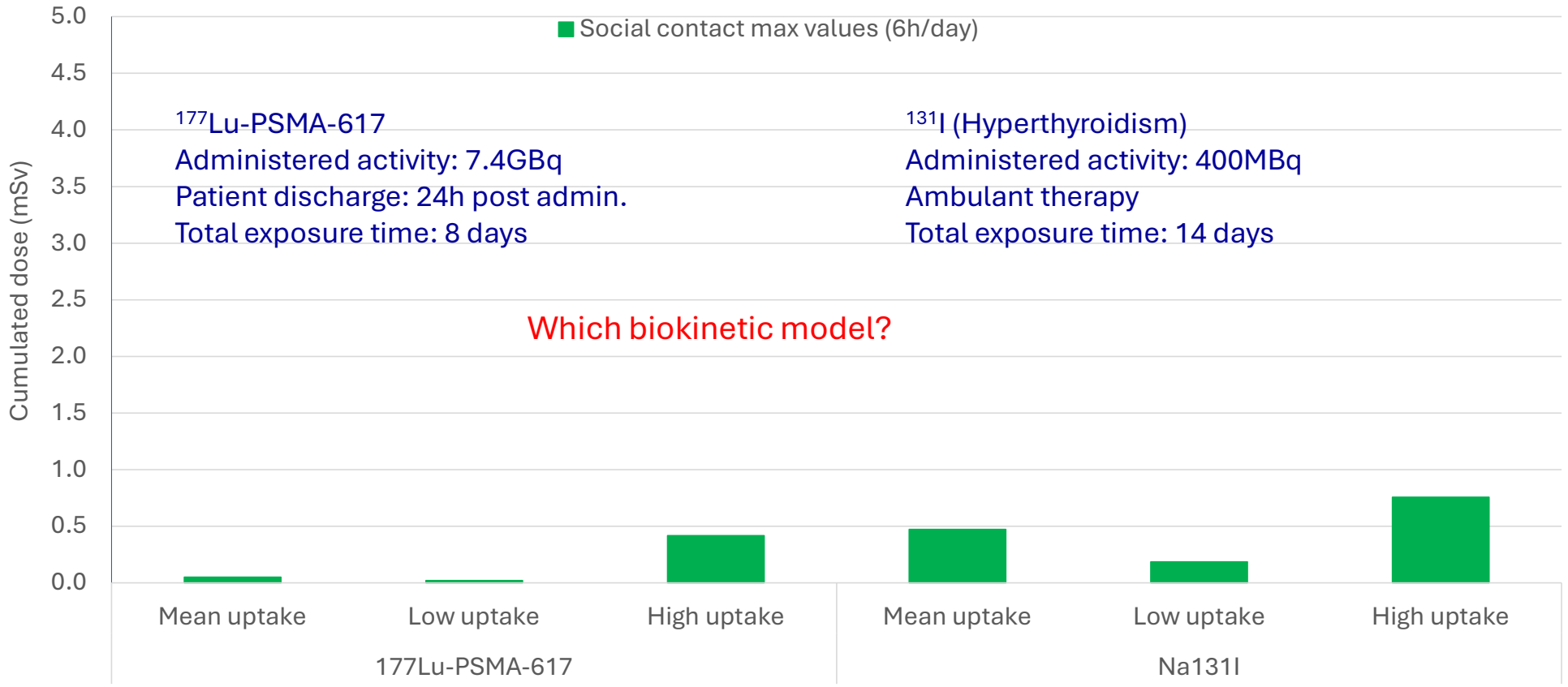
Risk assessment using exposure scenarios with restrictions



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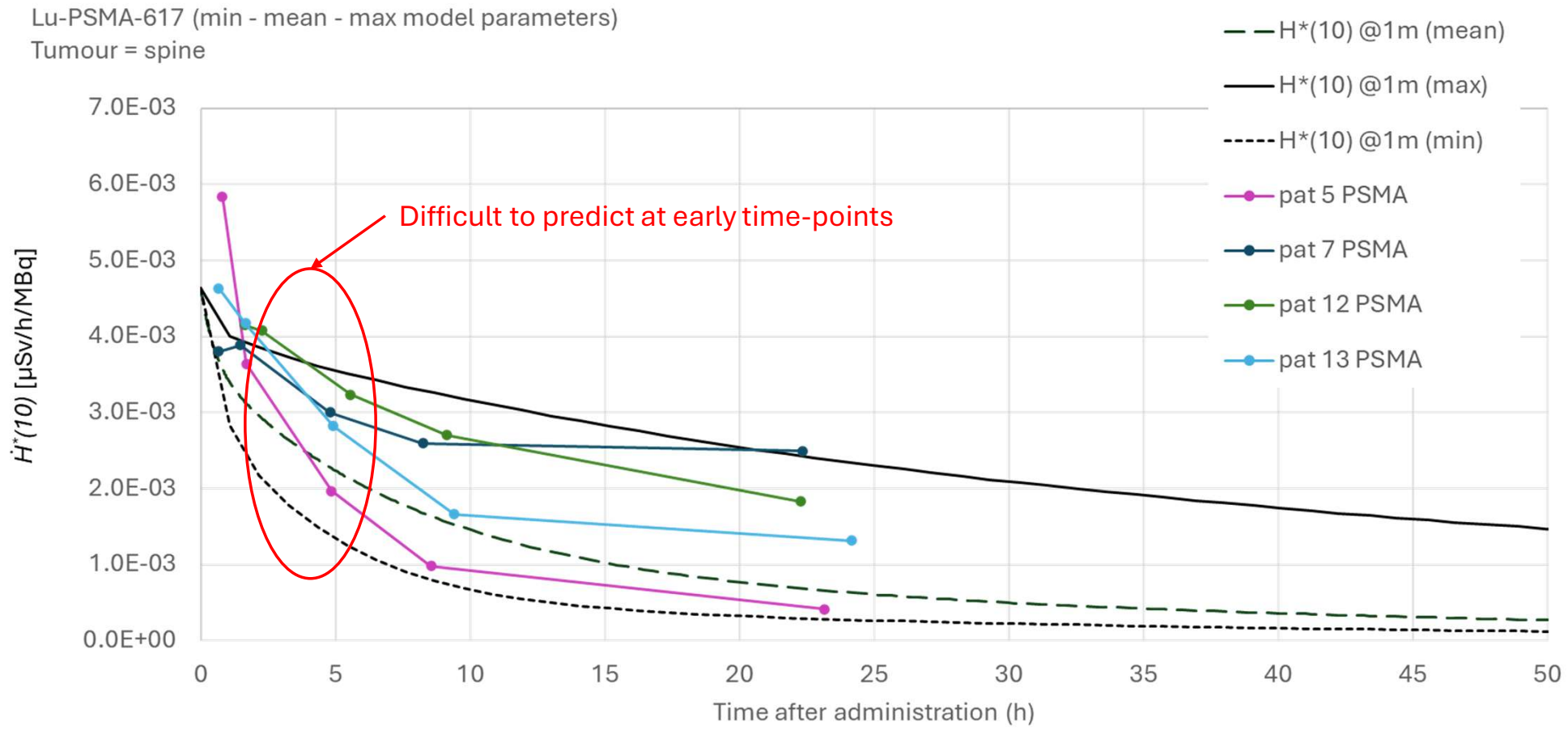
Patient tailored?



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To conclude…

- This is a computational framework!
  - To refine risk assessment studies in specific situations
  - It is flexible and can be adapted to various situations for diagnostic and therapeutic procedures
  - Optimisation of a component in the bigger process of setting patient release criteria
- First results
  - Large influence of the nature of the close contact posture
  - Large influence of variations in biokinetics
- Next…
  - Focus on other radiopharmaceuticals
  - Development of a tool for user-friendly calculations

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Thank you!

Happy to be the spokesman here for multi-centre work…

sck cen
Exploring a better tomorrow

Bundesamt für Strahlenschutz

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