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Validation of Bayesian modeling approach of uncertainty in organ doses using post-mortem measurements

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Motivation:

ICRP biokinetic and dosimetric models do not account for dosimetric uncertainties

Bayesian analysis provides a distribution of dose estimates, not just a point estimate

- It is believed that the 'true' dose is part of the Bayesian posterior distribution

Objective:

This study aimed to validate Bayesian approach using post-mortem organ measurements

- Precision in organ activity prediction serves as a 'surrogate' for dose uncertainties

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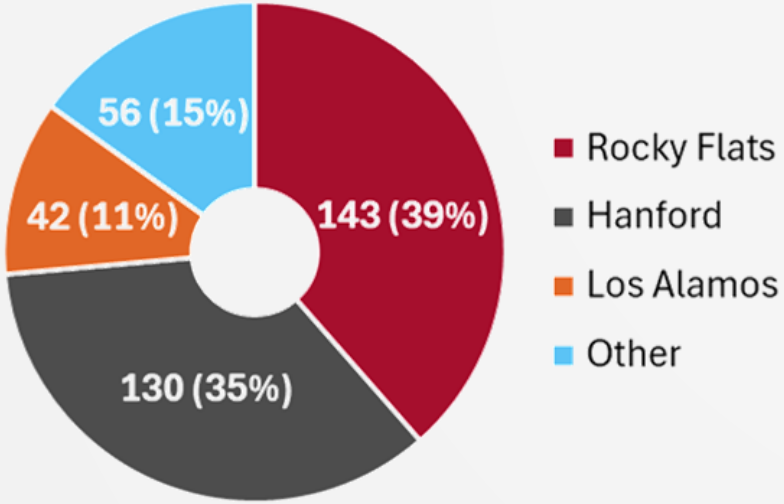
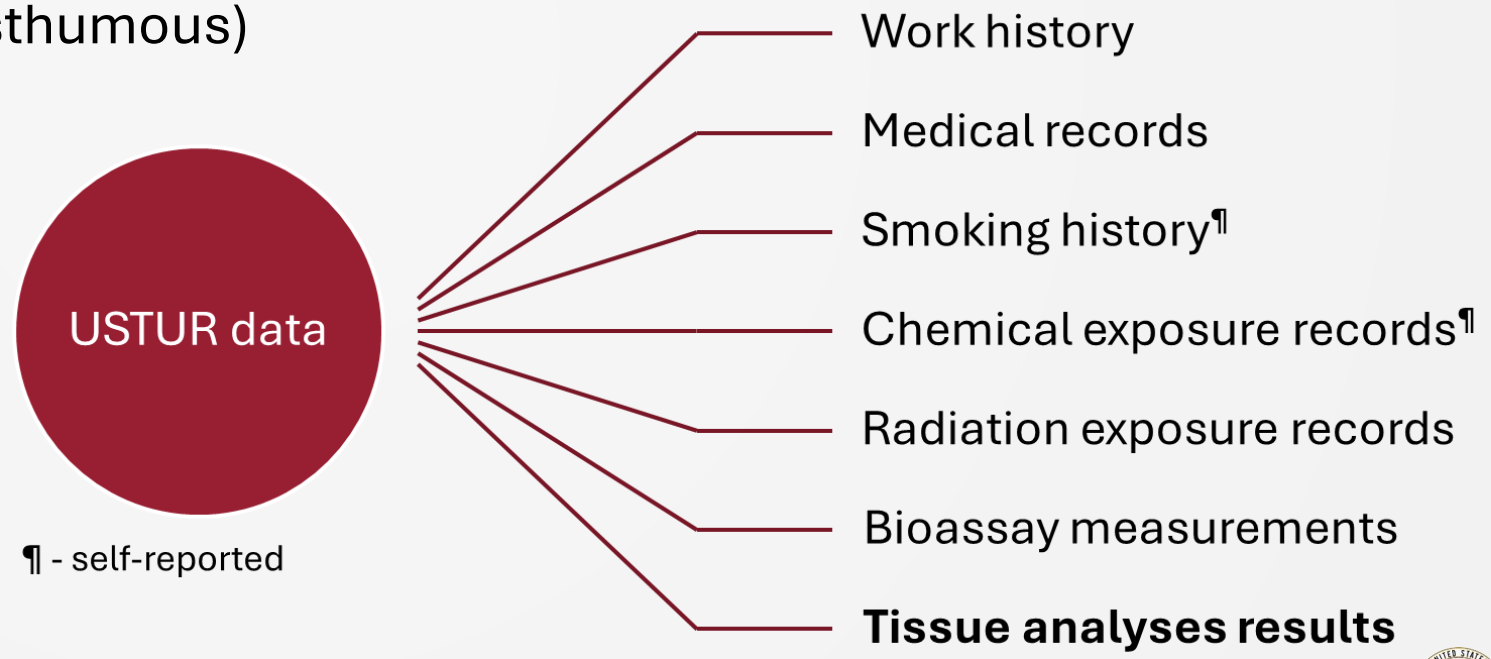
United States Transuranium and Uranium Registries

Follows up occupationally exposed workers by studying the biokinetics and tissue dosimetry of the actinides

- Primary exposure: ^{239}Pu, ^{238}Pu, ^{241}Am, U_{nat}, HEU, DU, ^{244}Cm, ^{237}Np
- Criteria: 4 nCi (148 Bq) internal deposition or 10 rem (100 mSv) external exposure
- Mainly former nuclear workers from U.S. DOE sites
- 371 voluntary tissue donors (posthumous)





¶ - self-reported

Results

Study Group:

- 10 individuals from Los Alamos: **soluble** ^{239}Pu-nitrate
- 10 individuals from Rocky Flats: **insoluble** $^{239}PuO_2$

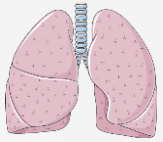
Model Prediction Accuracy:

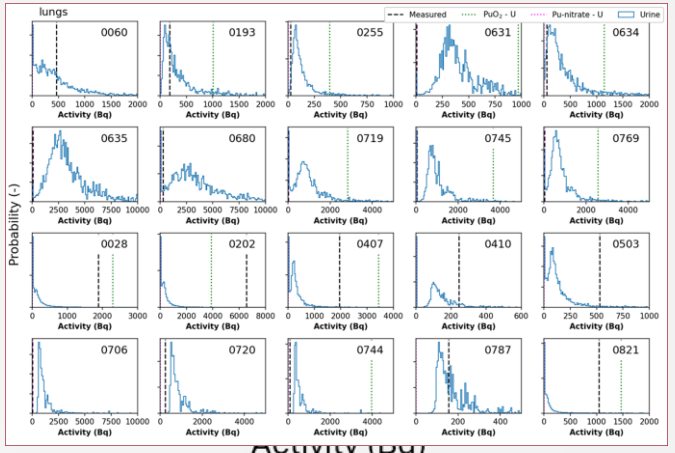
- Respiratory tract: **highly inaccurate**
- Systemic organs (liver, skeleton):
  - ✓Posterior distributions relatively **narrow**
  - ✓Median values **within 60%** of measured activities
  - ✓Often **do not** cover measured values

Other Findings:

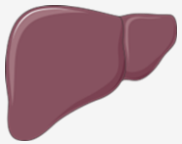
- Urine bioassay **inconclusive** for solubility parameters
- Some predictions **not conservative:** radiation protection concern

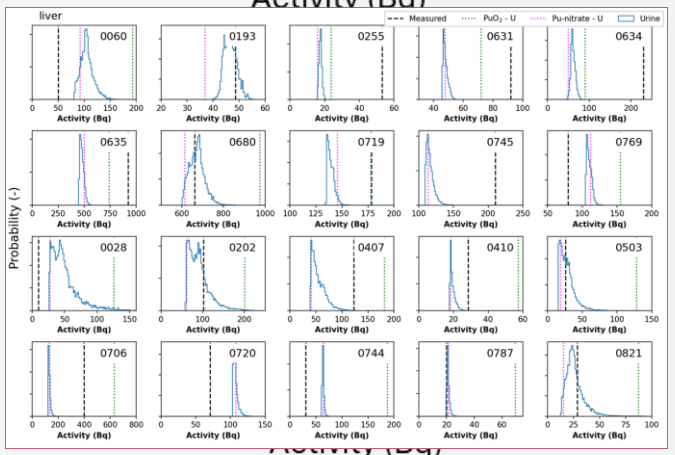
Respiratory tract



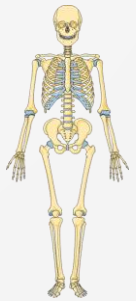


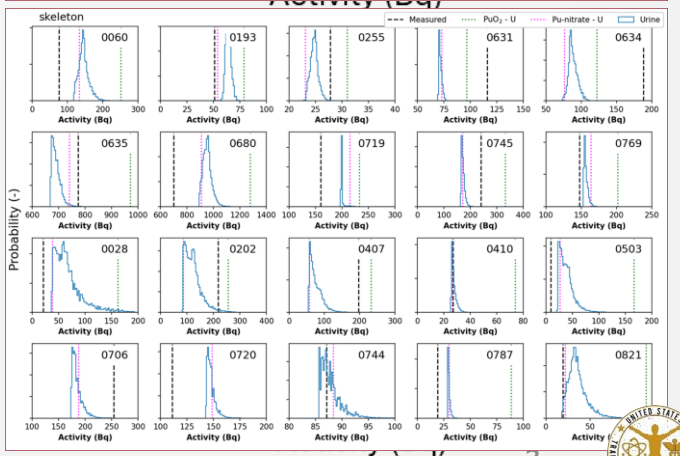
Liver





Skeleton





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Summary

Key Takeaways:

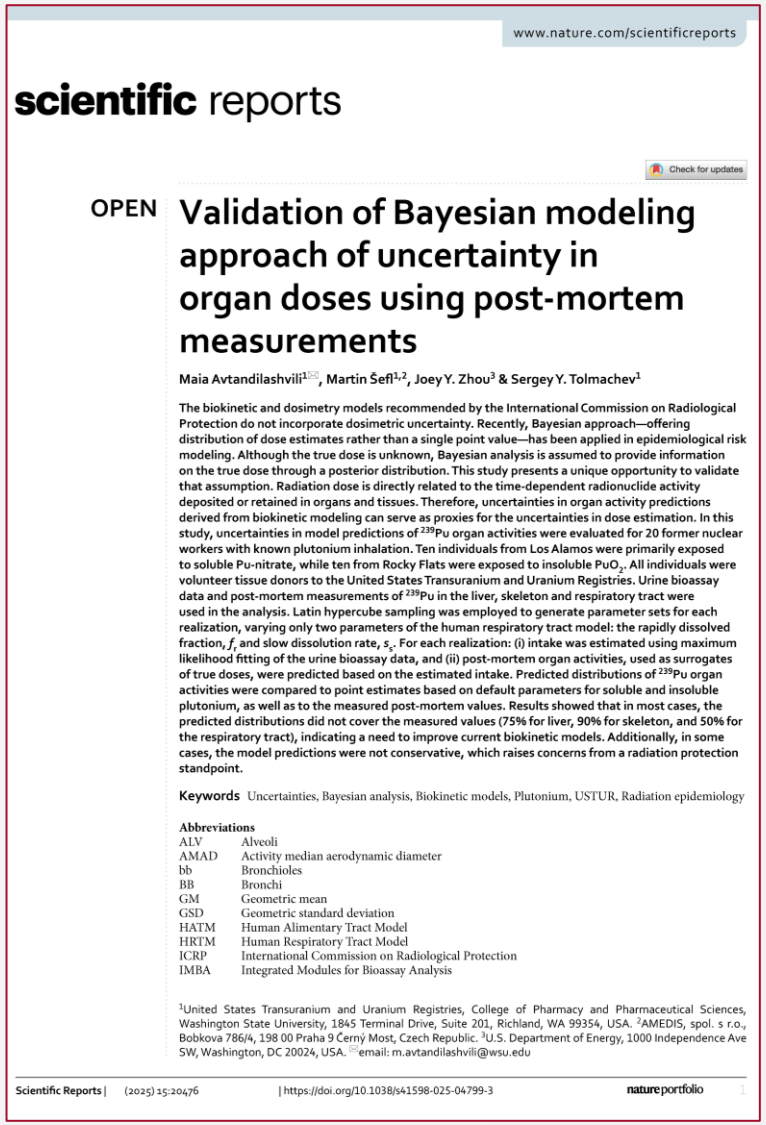
- Bayesian modeling provides valuable uncertainty estimates
- Current models need refinement to improve accuracy
- Non-conservative predictions highlight potential safety risks

Future Directions:

- Enhance biokinetic models for better dose prediction
- Incorporate more robust validation using empirical data

Further Reading:

- Avtandilashvili et al. *Scientific Reports* **15**:20476; **2025**
  https://doi.org/10.1038/s41598-025-04799-3



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Validation of Bayesian modeling approach of uncertainty in organ doses using post-mortem measurements

Maia Avtandilashvili[1✉], Martin Šefl[1,2], Joey Y. Zhou[3] & Sergey Y. Tolmachev[1]

The biokinetic and dosimetry models recommended by the International Commission on Radiological Protection do not incorporate dosimetric uncertainty. Recently, Bayesian approach—offering distribution of dose estimates rather than a single point value—has been applied in epidemiological risk modeling. Although the true dose is unknown, Bayesian analysis is assumed to provide information on the true dose through a posterior distribution. This study presents a unique opportunity to validate that assumption. Radiation dose is directly related to the time-dependent radionuclide activity deposited or retained in organs and tissues. Therefore, uncertainties in organ activity predictions derived from biokinetic modeling can serve as proxies for the uncertainties in dose estimation. In this study, uncertainties in model predictions of ^{239}Pu organ activities were evaluated for 20 former nuclear workers with known plutonium inhalation. Ten individuals from Los Alamos were primarily exposed to soluble Pu-nitrate, while ten from Rocky Flats were exposed to insoluble PuO_2. All individuals were volunteer tissue donors to the United States Transuranium and Uranium Registries. Urine bioassay data and post-mortem measurements of ^{239}Pu in the liver, skeleton and respiratory tract were used in the analysis. Latin hypercube sampling was employed to generate parameter sets for each realization, varying only two parameters of the human respiratory tract model: the rapidly dissolved fraction, f_r and slow dissolution rate, s_s. For each realization: (i) intake was estimated using maximum likelihood fitting of the urine bioassay data, and (ii) post-mortem organ activities, used as surrogates of true doses, were predicted based on the estimated intake. Predicted distributions of ^{239}Pu organ activities were compared to point estimates based on default parameters for soluble and insoluble plutonium, as well as to the measured post-mortem values. Results showed that in most cases, the predicted distributions did not cover the measured values (75% for liver, 90% for skeleton, and 50% for the respiratory tract), indicating a need to improve current biokinetic models. Additionally, in some cases, the model predictions were not conservative, which raises concerns from a radiation protection standpoint.

Keywords Uncertainties, Bayesian analysis, Biokinetic models, Plutonium, USTUR, Radiation epidemiology

Abbreviations

ALV	Alveoli
AMAD	Activity median aerodynamic diameter
bb	Bronchioles
BB	Bronchi
GM	Geometric mean
GSD	Geometric standard deviation
HATM	Human Alimentary Tract Model
HRTM	Human Respiratory Tract Model
ICRP	International Commission on Radiological Protection
IMBA	Integrated Modules for Bioassay Analysis

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