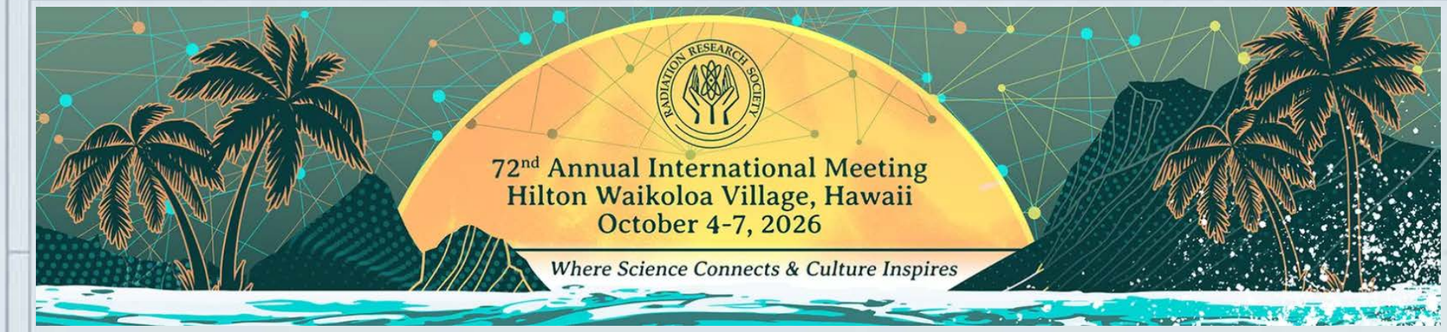


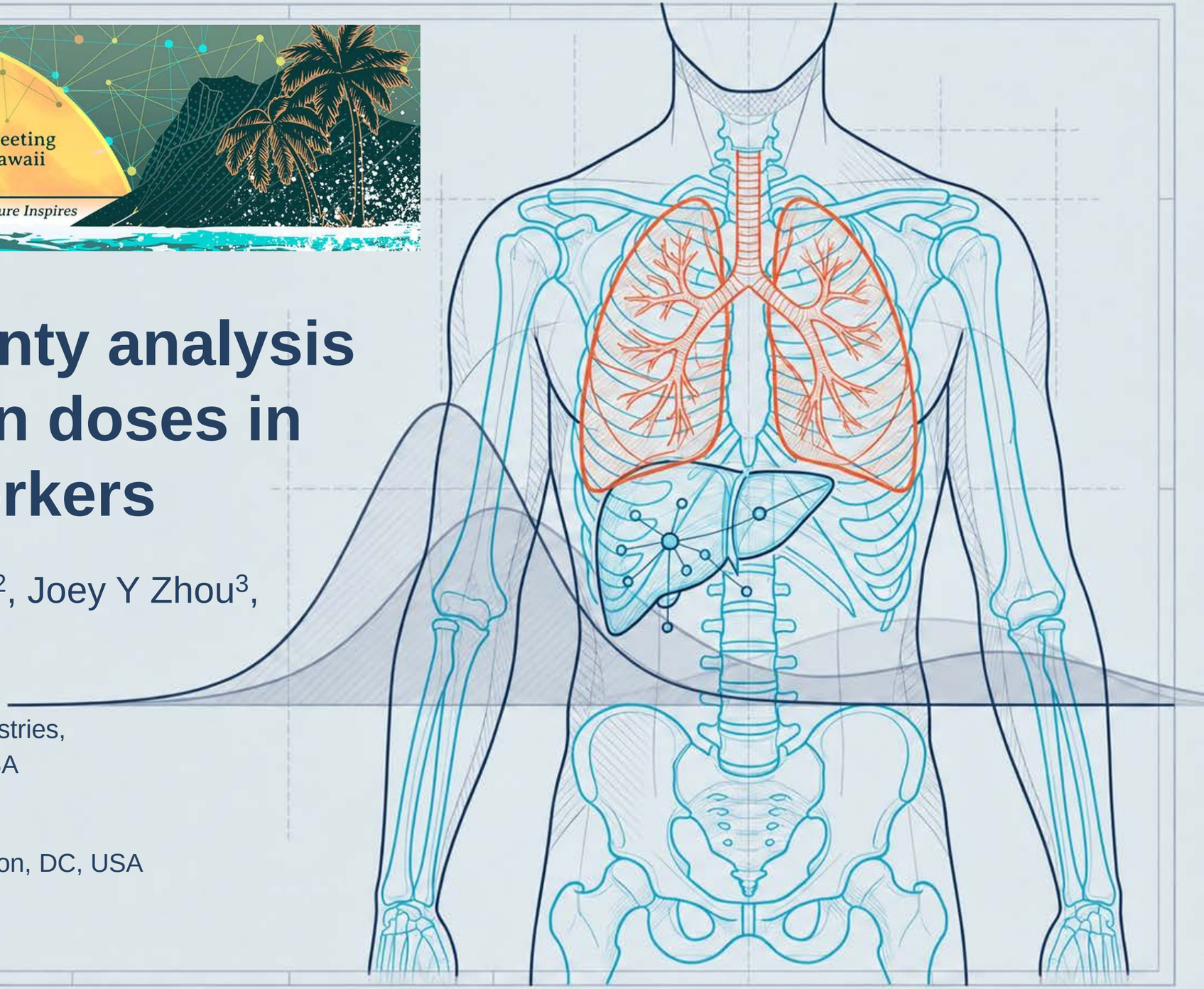
Bayesian uncertainty analysis of plutonium organ doses in former nuclear workers

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

[1]United States Transuranium and Uranium Registries, Washington State University, Richland, WA, USA

[2]AMEDIS, spol. s r.o., Prague, Czechia

[3]United States Department of Energy, Washington, DC, USA



USTUR-0743-26A

Dose Assessment for Radiation Epidemiology

URINE DATA





BAYESIAN INFERENCE ENGINE

ESTIMATED HISTORICAL ORGAN DOSE



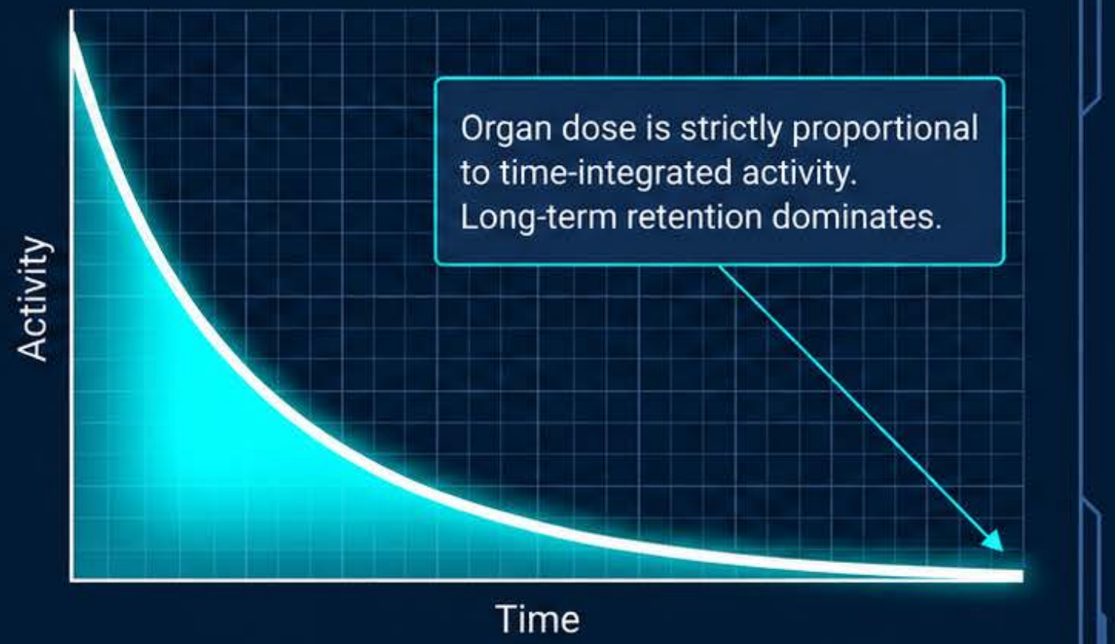
Radiation epidemiology increasingly relies on Bayesian internal dosimetry derived from **urine bioassays** to **estimate historical organ doses**.

But how accurate are these predictions when tested against real human data?

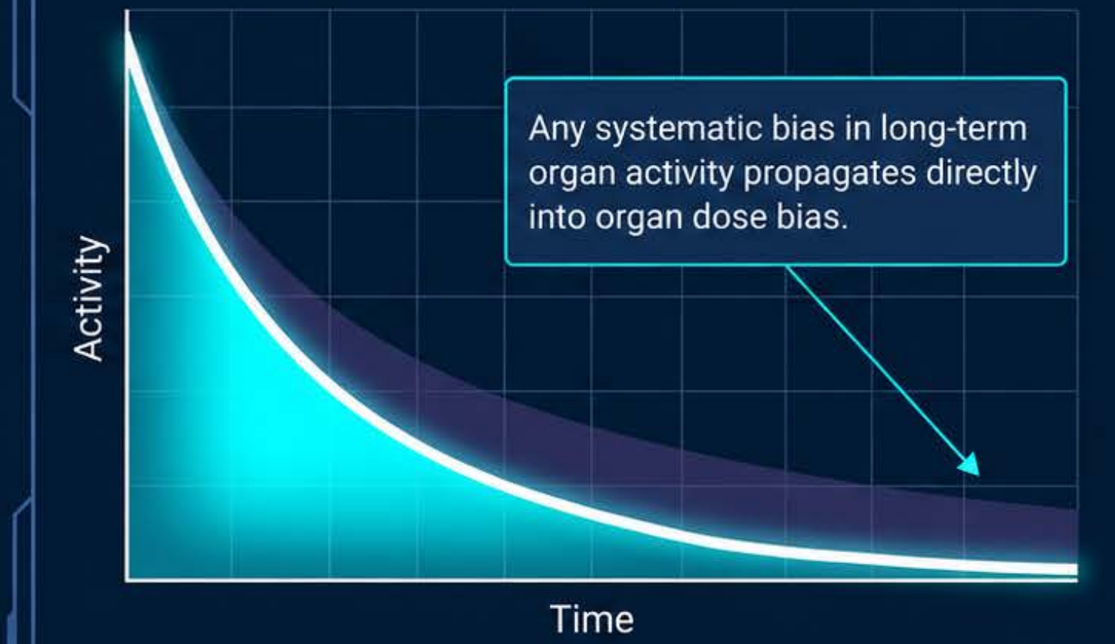
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Uncertainties in Dose Assessment

A THE CURVE



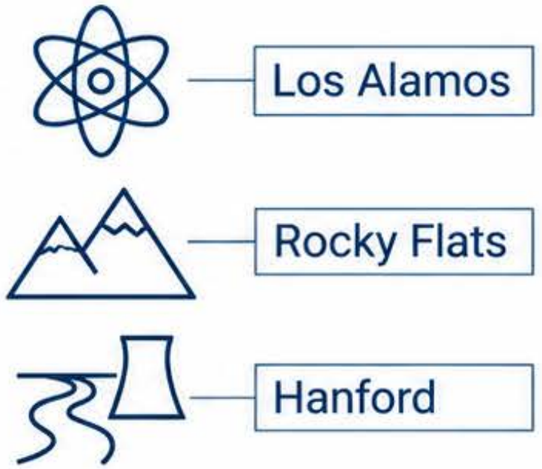
B THE UNCERTAINTY BAND



Uncertainties in biokinetic model predictions of organ activities function as direct surrogates for uncertainties in dose.

USTUR Provides Real Human Data for Validation

THE SOURCE



Former nuclear workers with complex exposure scenarios involving both chronic and acute intakes.

35

Voluntary posthumous tissue donors with known internal ^{239}Pu deposition.

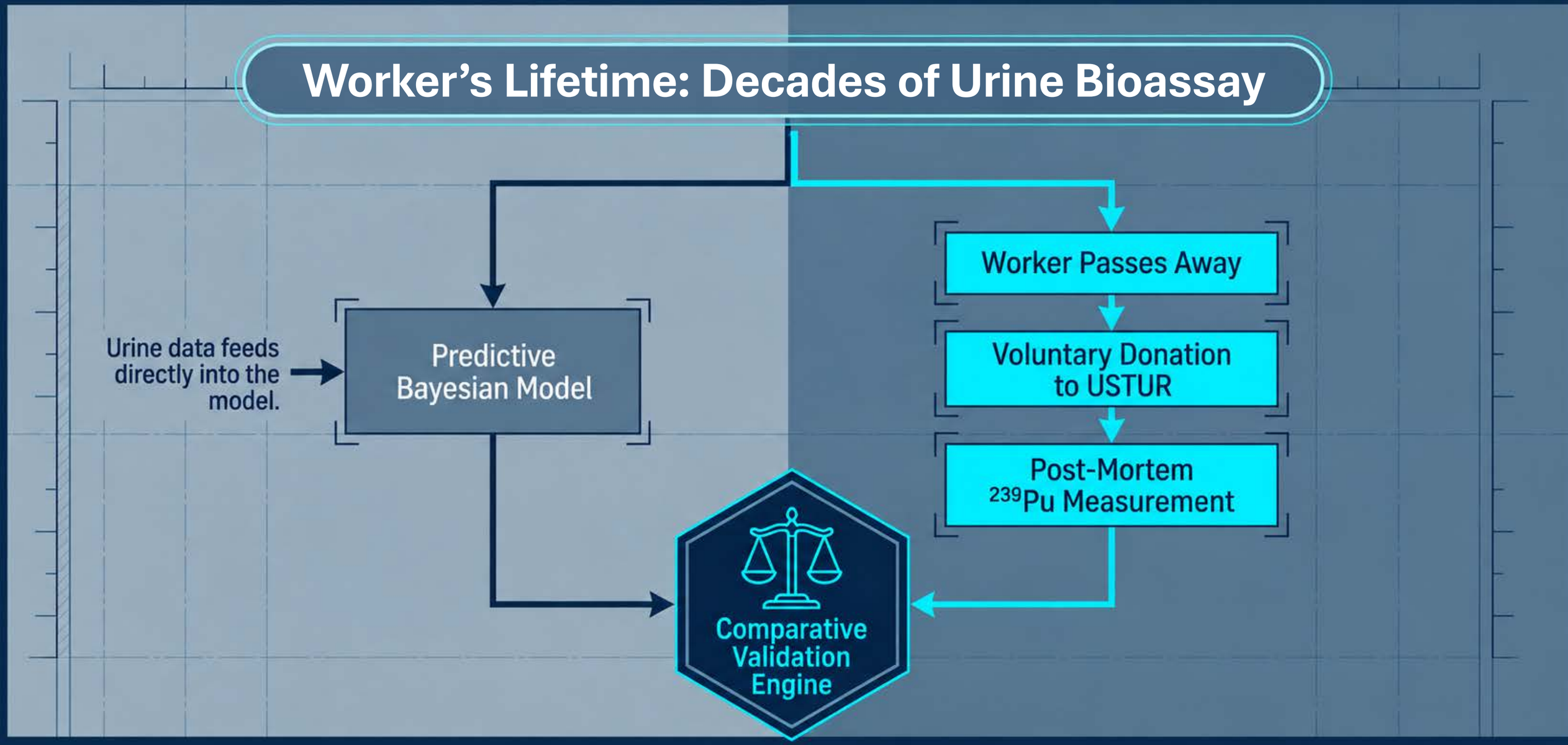
THE TARGET SCALE

Organ	Measured Activity Range (Bq)
Liver	3.5–920
Skeleton	3.3–774
Respiratory Tract	0.2–6550

Measured organ activities span 4 orders of magnitude

Post-mortem physical measurements provide the rare **empirical evidence** required to **bypass bioassay-driven modeling** assumptions.

Worker's Lifetime: Decades of Urine Bioassay



By entirely withholding post-mortem data from the predictive model, the study creates a realistic test of epidemiological assumptions.

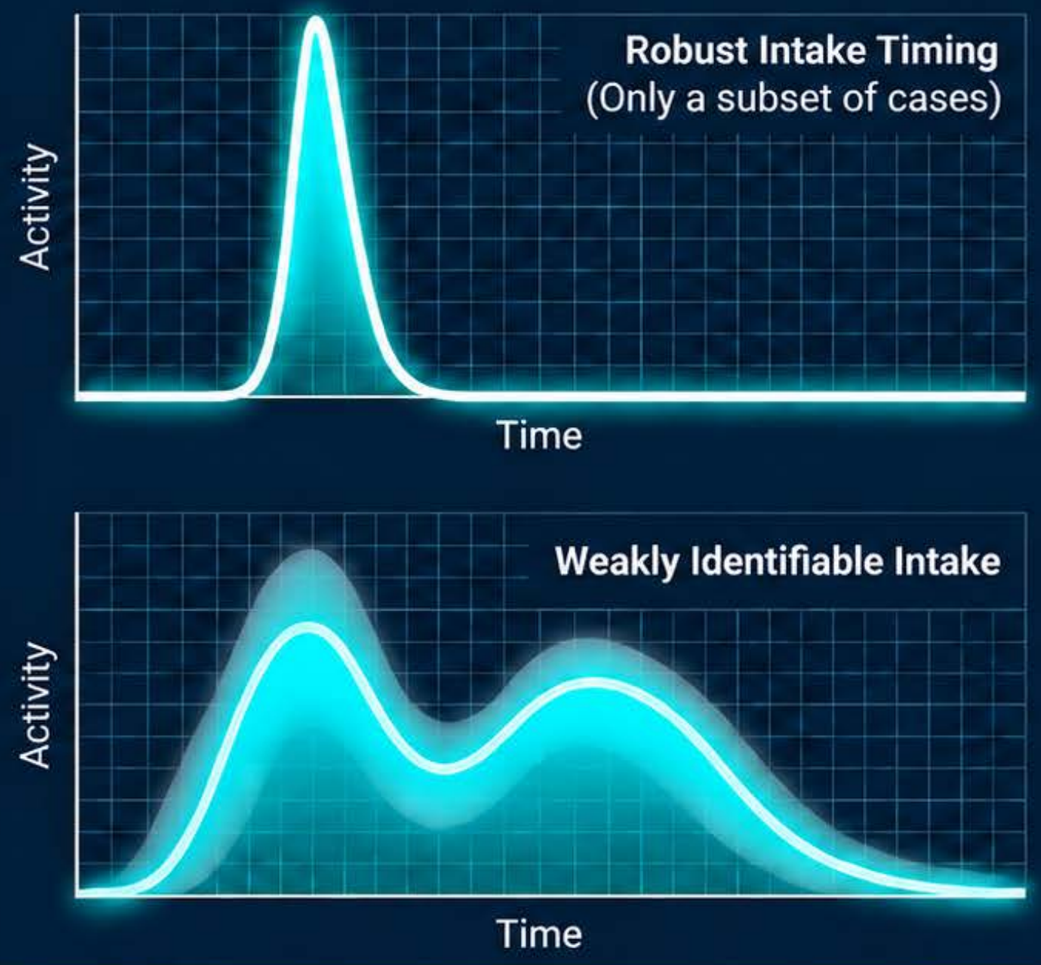
Two Paths of Inference: Looking Forward vs. Looking Back

	URINE-ONLY ANALYSIS	ALL-DATA ANALYSIS
Inputs	Decades of urine bioassays.	Urine bioassays + Post-mortem organ measurements.
Autopsy Data	**WITHHELD** for validation.	**INCLUDED.**
Nature of Analysis	Independent predictive validation. (Represents what epidemiologists actually have).	Retrospective reconciliation. (Represents the theoretical best-fit).

Urine-only analysis reflects typical epidemiological practice.

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Intake timing: a nuisance parameter



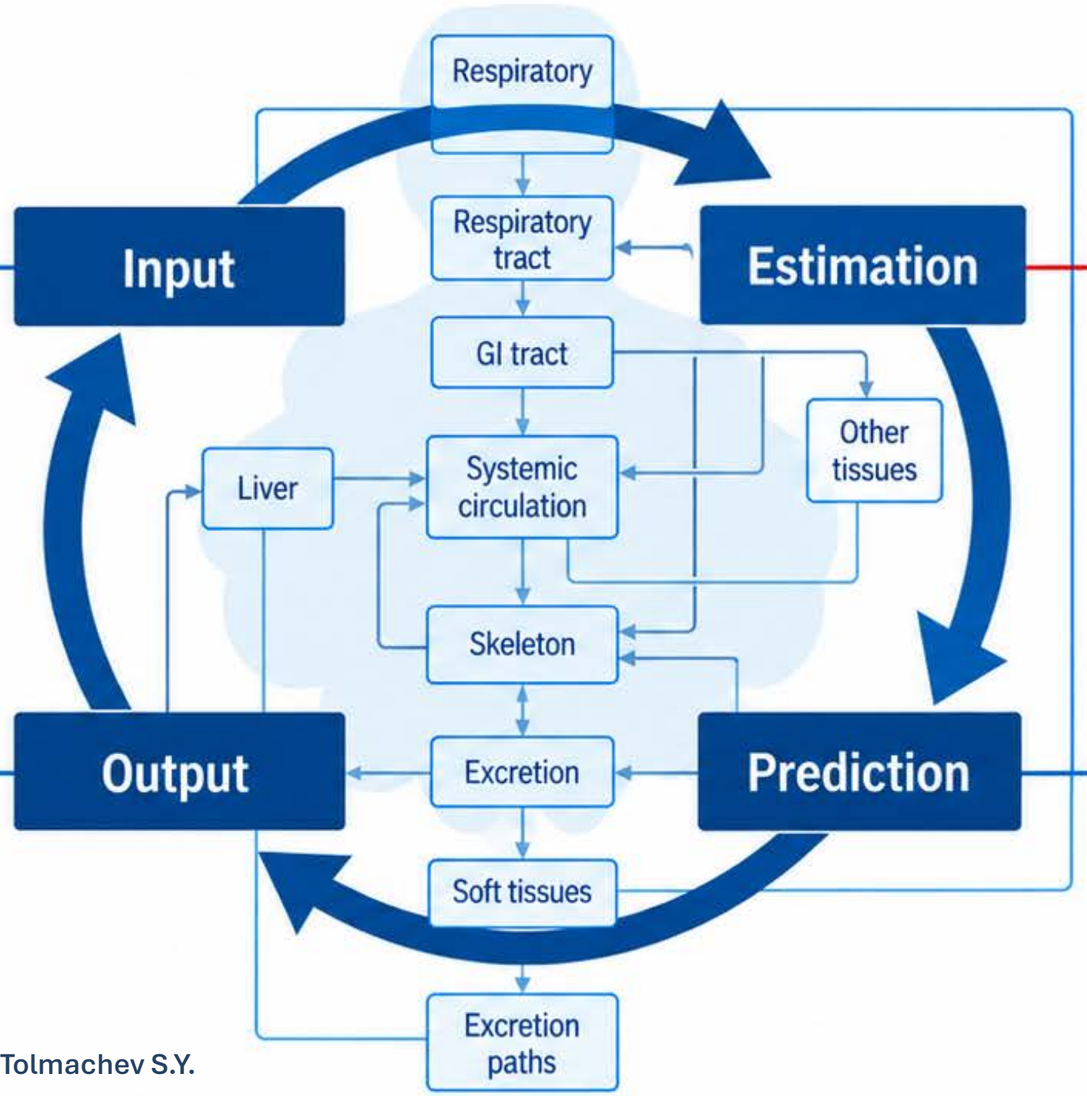
- In many cases, precise acute intake timing is weakly identifiable.
- Consequently, intake timing functions mathematically as a '**nuisance parameter**'.
- **Chronic inhalation intake** over the working lifetime is typically assumed in radiation epidemiology studies.

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Computational workflow

Latin Hypercube Sampling (LHS).

- Focusing strictly on two absorption parameters.
- Rapid dissolving fraction (f_r, Uniform 0.0–0.2) and
- Slow dissolution rate (s_s, Lognormal median 1×10^{-4} d^{-1}, GSD 6).



Crucial Assumption:
Intake scenario: Chronic inhalation over employment.

10,000 realizations per case building the posterior dose distribution.

Predict specific ^{239}Pu organ activity at exact time of death.

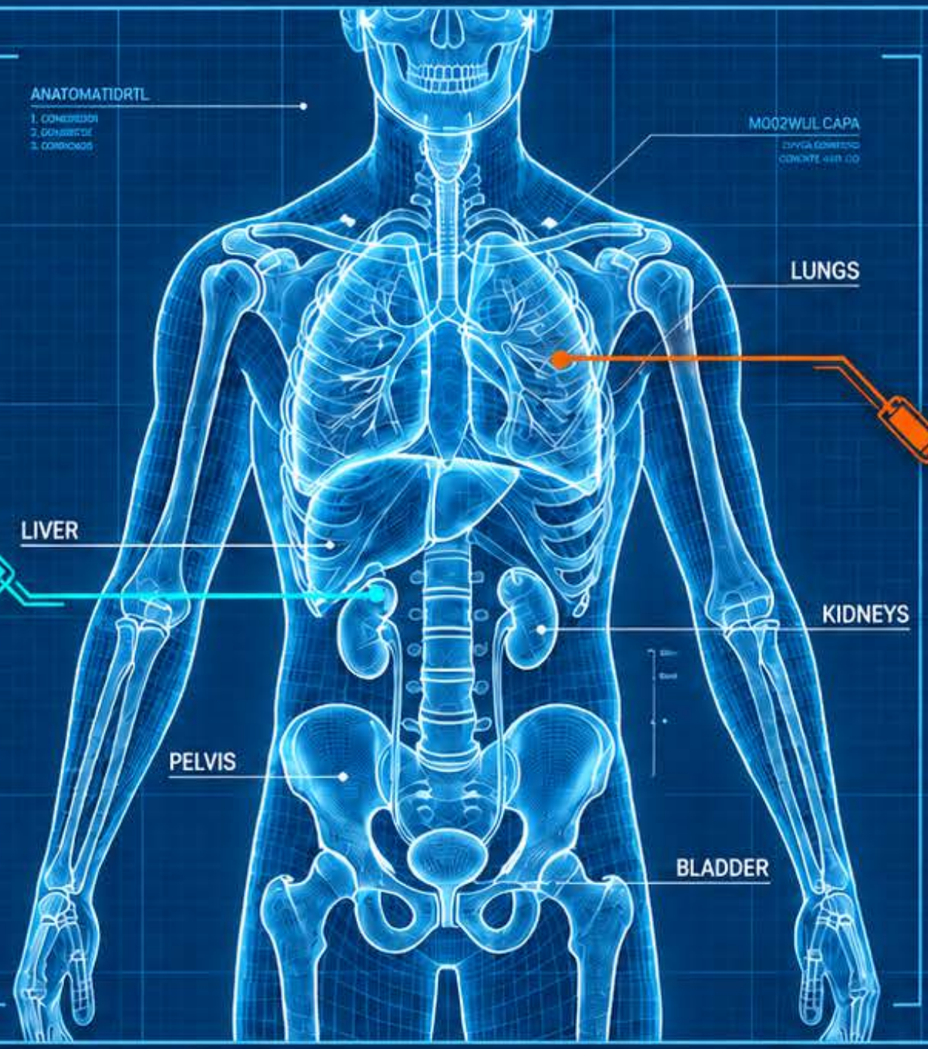
Software Architecture:
Adaptable Python 3.9 engine processing current ICRP OIR models.

Avtandilashvili, M., Šefl, M., Zhou, J.Y., Tolmachev S.Y.
Scientific Reports 15:20476; 2025
https://doi.org/10.1038/s41598-025-04799-3

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Do urine bioassay accurately predict organ retention?

Hypothesis:
Urine bioassay
accurately predict
systemic retention.



Hypothesis:
Urine bioassay
accurately predict
respiratory retention.

The results differ substantially across anatomical regions, challenging the assumption of consistent predictive accuracy throughout the whole body.

Urine-only inference successfully recovers systemic retention





41%
Liver median deviation

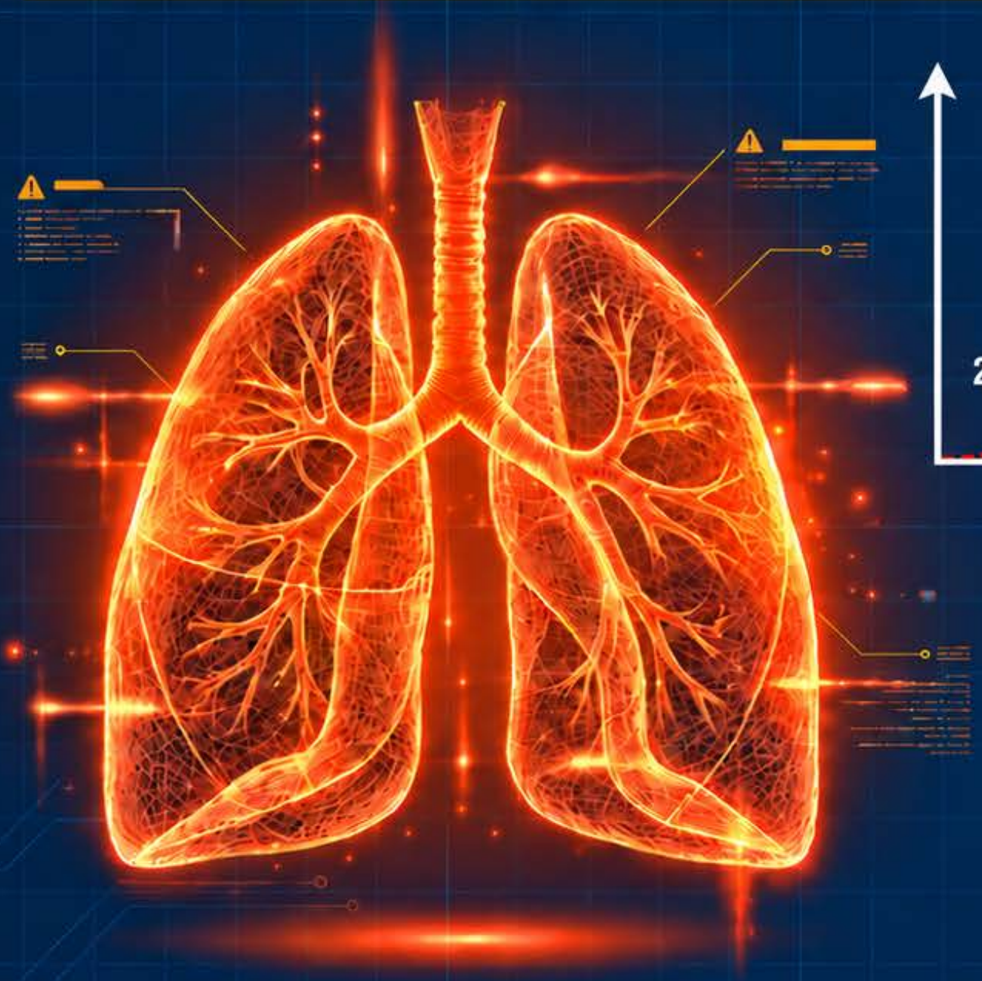
29%
Skeleton median deviation

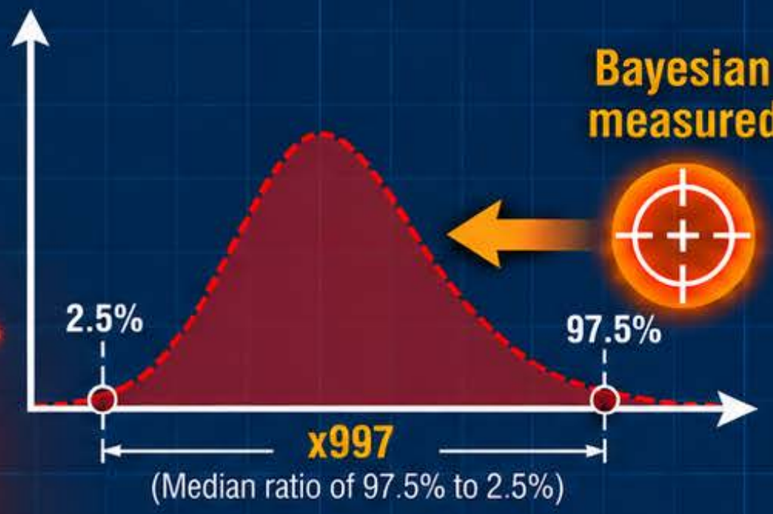
- Urine-only inference produced stable and reproducible estimates of systemic plutonium retention.
- Narrow posterior distributions indicated relatively low uncertainty in estimates, even in the absence of autopsy data.

Current Bayesian internal dosimetry methods are **suitable** for systemic organ dose reconstruction.

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Respiratory tract posteriors are wide and still miss the measurement





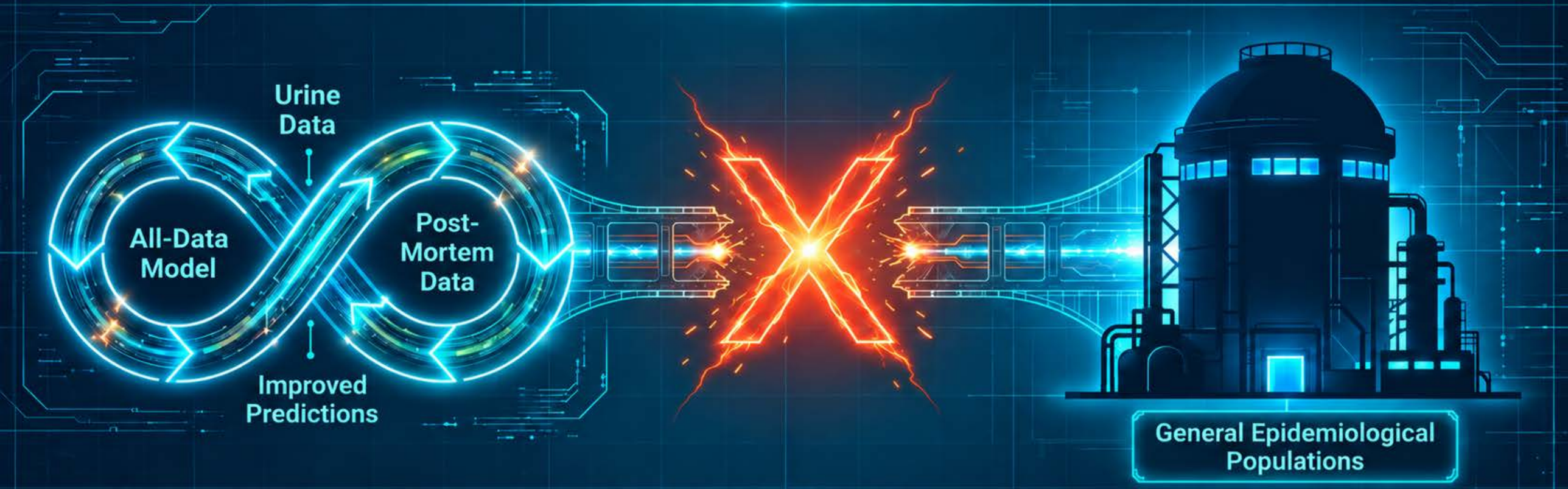


- Urine-based respiratory tract estimates were highly unreliable.
- Models produced extremely wide posterior distributions, representing **large** uncertainty.
- Despite this **large** uncertainty, the models frequently **failed** to capture the actual measured organ activities.

Urine bioassays fail to predict time-integrated plutonium activity in the respiratory tract. Breadth of the distribution did not translate into coverage of the truth.

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Retrospective reconciliation is not predictive validation



Adding **post-mortem measurements** successfully forced the model to agree across the entire body, including **lungs.**

However, this is **mathematical reconciliation.** It does not validate the model's independent predictive power.

Epidemiologists studying **general nuclear worker** populations only have **bioassays**. Postmortem measurements are usually unavailable.

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Organ-specific performance matrix

	Predictive Accuracy	Precision	Verdict for Epidemiological Risk Models
Systemic Organs	**High**	Reasonable	Supports dose reconstruction
Respiratory Tract	**Low / Failing**	**Highly Unreliable**	**Less suited for standalone dose estimation**

Urine-only analyses may not be sufficient for accurate whole-body dosimetry; organ-specific validation is recommended.

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Take-away message



Systemic Clearance: Continue utilizing urine-only based Bayesian internal dosimetry for systemic organ dose reconstruction.

Organ-Specific Evaluation: Cease applying uniform, cohort-level uncertainty metrics across the whole body; dose uncertainty must be evaluated on a strict organ-by-organ basis.

The Respiratory Warning: Proceed with extreme caution against the uncritical use of urine-only lung dose estimates. Without accounting for these large uncertainties, lung cancer risk models may result in significant inaccuracies.

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Thank you for your attention!
Questions?

m.avtandilashvili@wsu.edu