Uncertainties in Radiation Dose Assessment for Internally Deposited Plutonium in Support of Radiation Epidemiology

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Motivation

- In radiation epidemiology, worksite records and bioassay measurements are used to estimate the radiation doses
- Bioassay data are typically collected by worksite and may not be available after the end of employment
- Post-mortem tissue/organ analyses can be used to evaluate the accuracy of the reference biokinetic and dosimetric models used for radiation epidemiology

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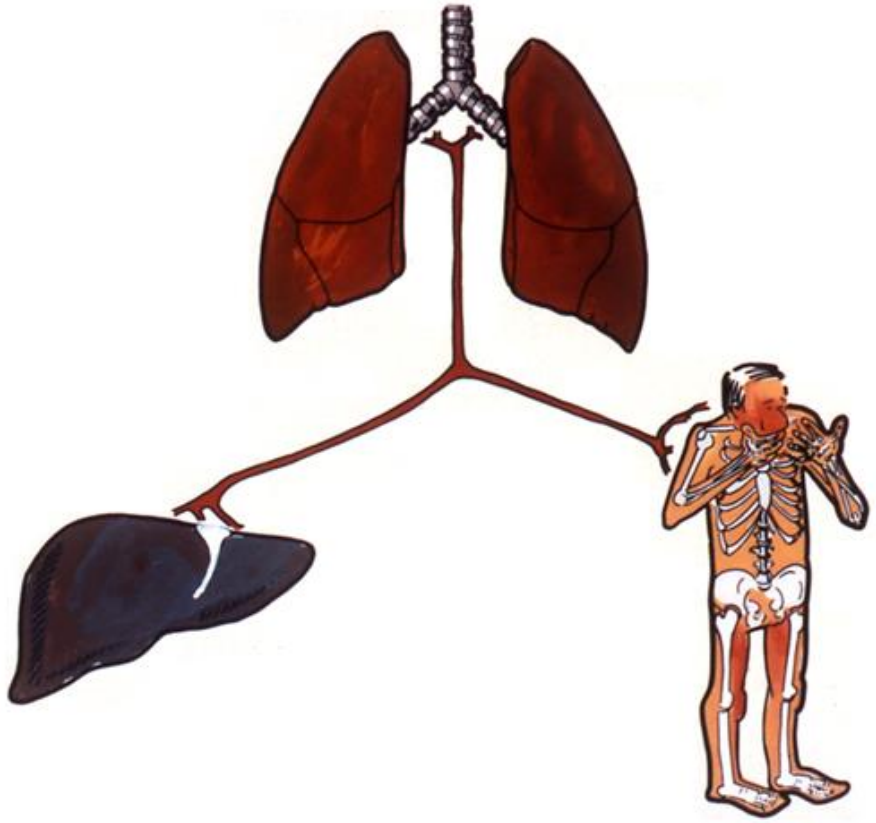
Objectives

- Comparison of plutonium activity in liver+skeleton predicted from urine bioassay collected during and/or after employment with post-mortem radiochemical analyses to evaluate biokinetic models
- Comparison of doses predicted using urine bioassay to those predicted using both urine bioassay and post-mortem tissue analysis results



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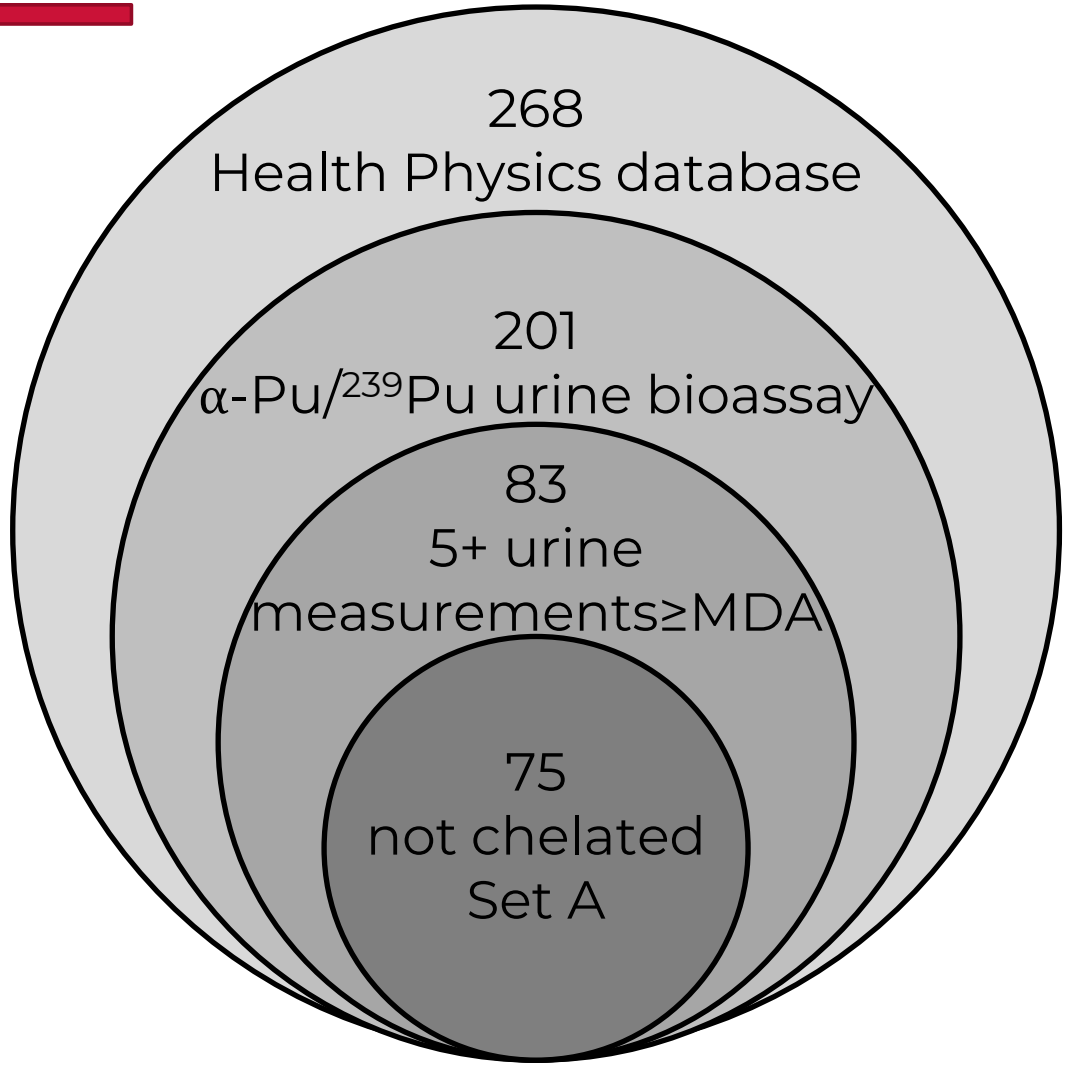
Unique Data Resource

12 353

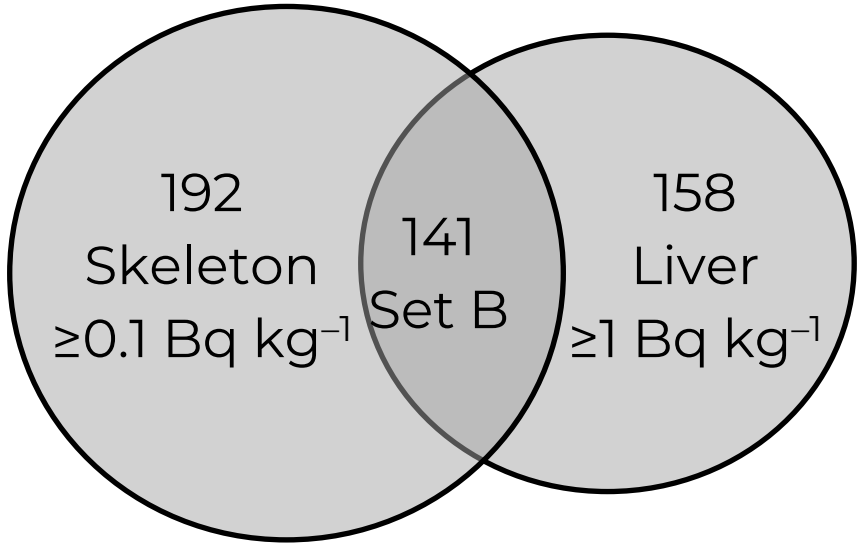
- Work history
- Medical records
- Smoking history†
- Chemical exposure records†
- Radiation exposure records
- Bioassay measurements
- Tissue analysis results (Pu, Am, U)

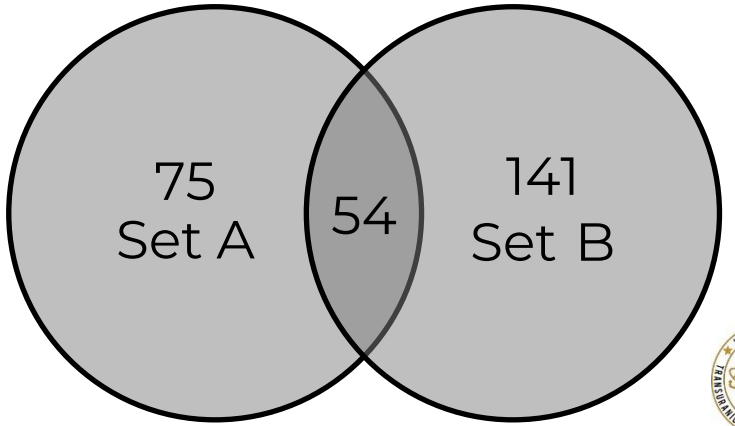
† - self-reported data

Study Case Selection Criteria



Radiochemical analysis





Studied group “You Pee Pu” (UPPU)

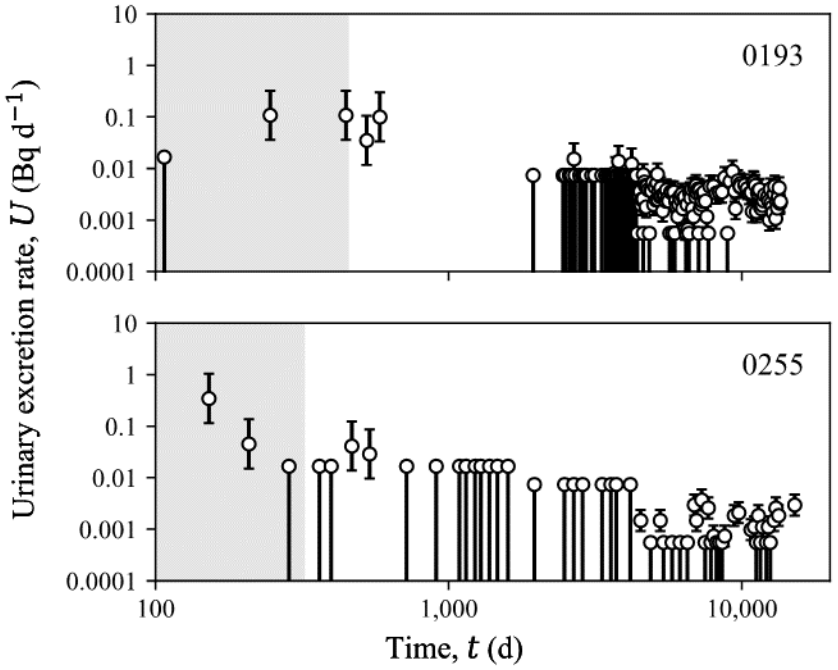
- Total of 26 individuals, 14 are USTUR Registrants
- Worksite: Los Alamos Scientific Laboratory
- Exposure period: 1944–1948 (Manhattan Project)
- Post-exposure follow-up: 1953–1997
- Studied cases: 11 (7 whole-body, 4 partial-body)
- Route of intake: chronic inhalation, 0.3 µm AMAD
- Material: 78% $Pu(NO_3)_4$, 22% refractory PuO_2†
- Post-mortem organ activity:
  - ✓ Liver: 27.8–927 Bq
  - ✓ Skeleton: 48.6–897 Bq

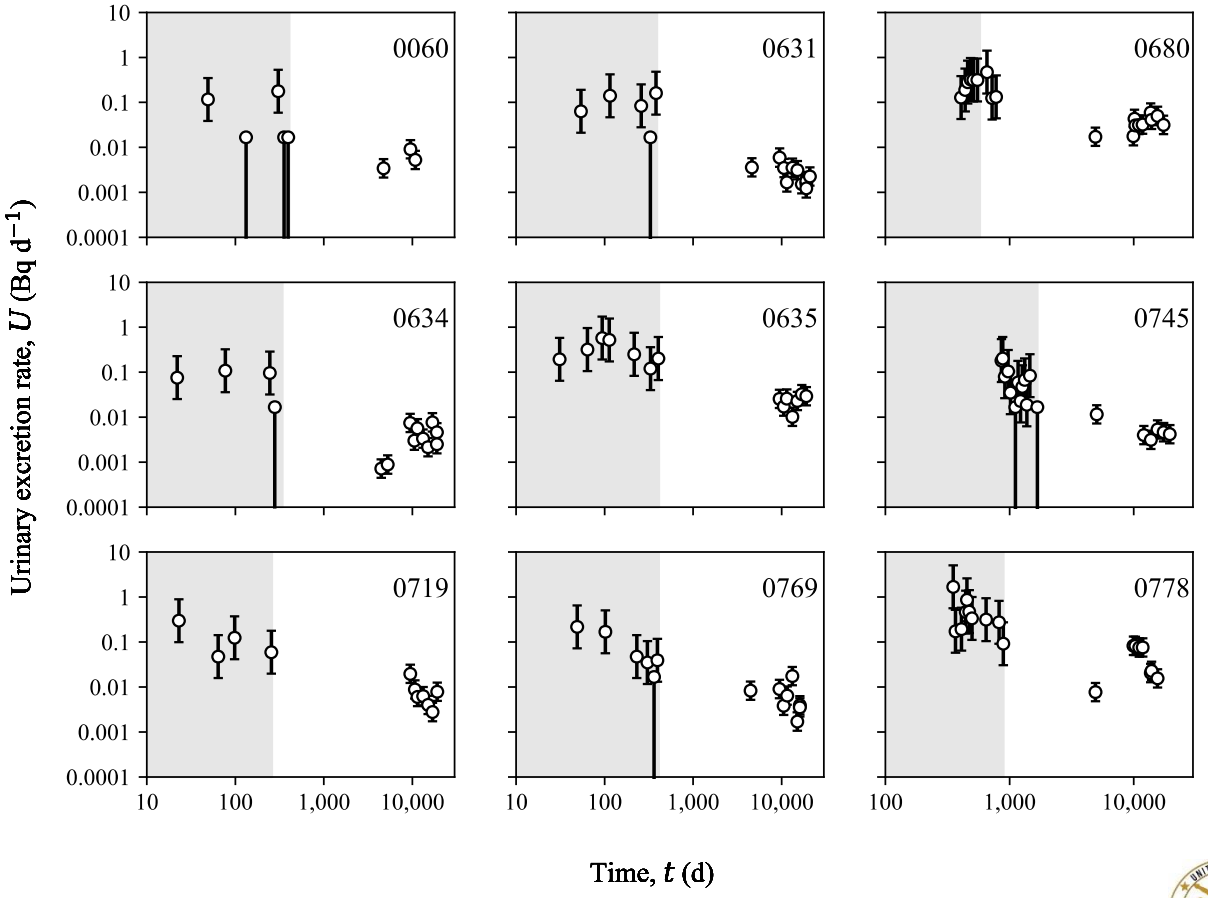
Open hood in D-Building-1944

Los Alamos Science, Vol 23, 1995

† - Šefl M et al. *Inhalation of Soluble Plutonium: 53-year Follow-up of Manhattan Project Worker*. Health Phys. 120(6): 661–670; 2021.

Data: Urine Bioassay for Study Cases





Data: Post-mortem Organ Activities

- Organ activity (Bq) = Concentration (Bq/kg) × Weight (kg)
- Liver: concentration and weight measured
- Skeleton: concentration and weight estimated

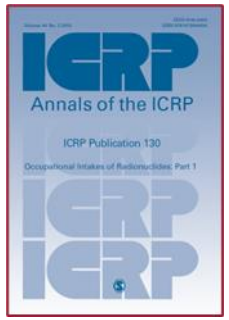
Skeleton	Activity concentration based on analysis of	Weight
Whole body	70–90 bone samples (right side of the skeleton)	Measured
Partial body	4–8 bone samples	Estimated†

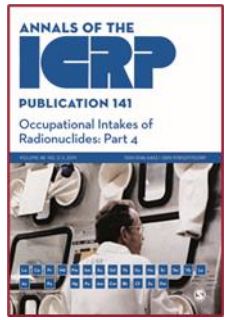
† - Avtandilashvili M, Tolmachev SY. *Modeling the Skeleton Weight of an Adult Caucasian Man.* Health Phys. 117(2):149–155; 2019.

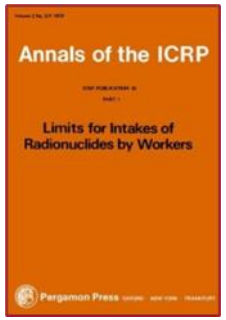
Skeleton-to-Liver Activity Ratio

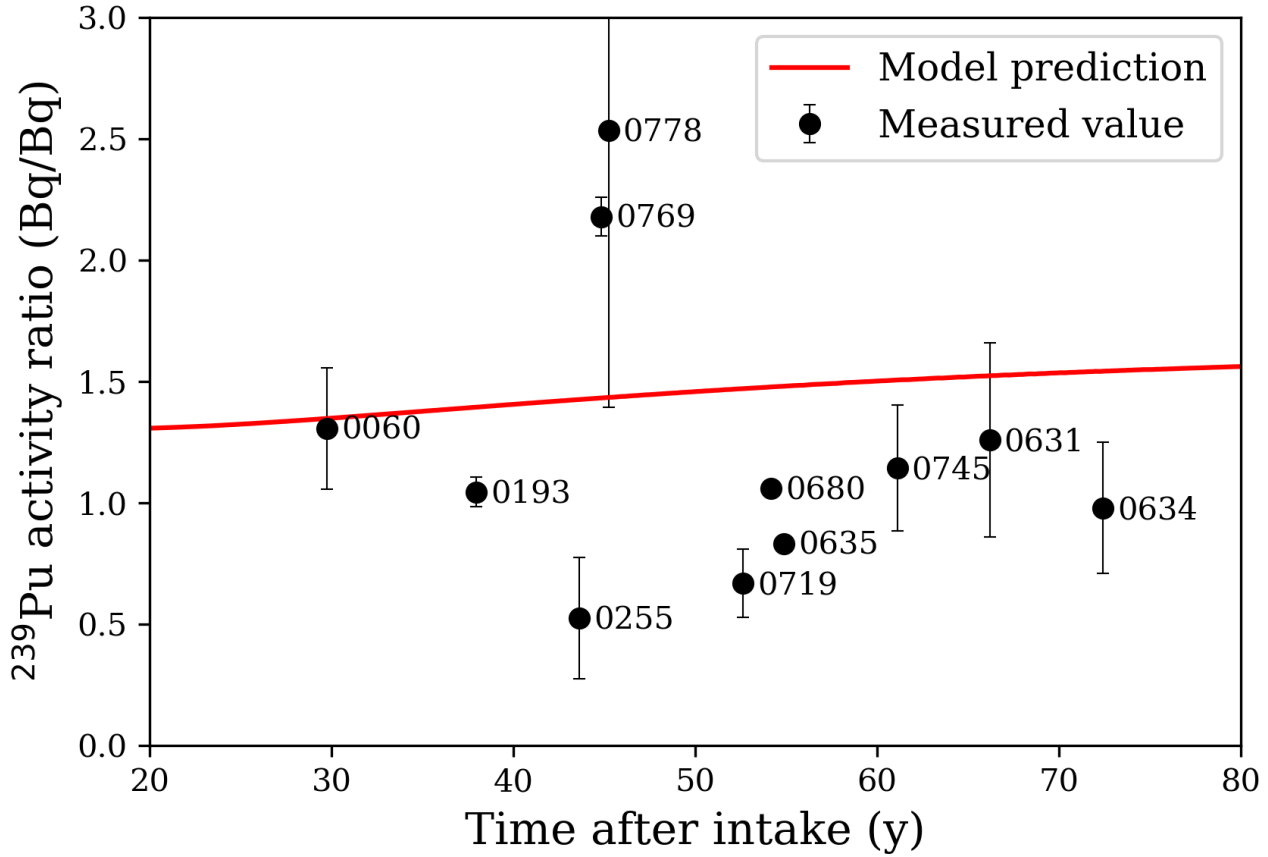
IMBA Professional Plus®

- ICRP 130 Human Respiratory Tract Model
- ICRP 141 Plutonium Systemic Model
- ICRP 30 Gastrointestinal Tract Model





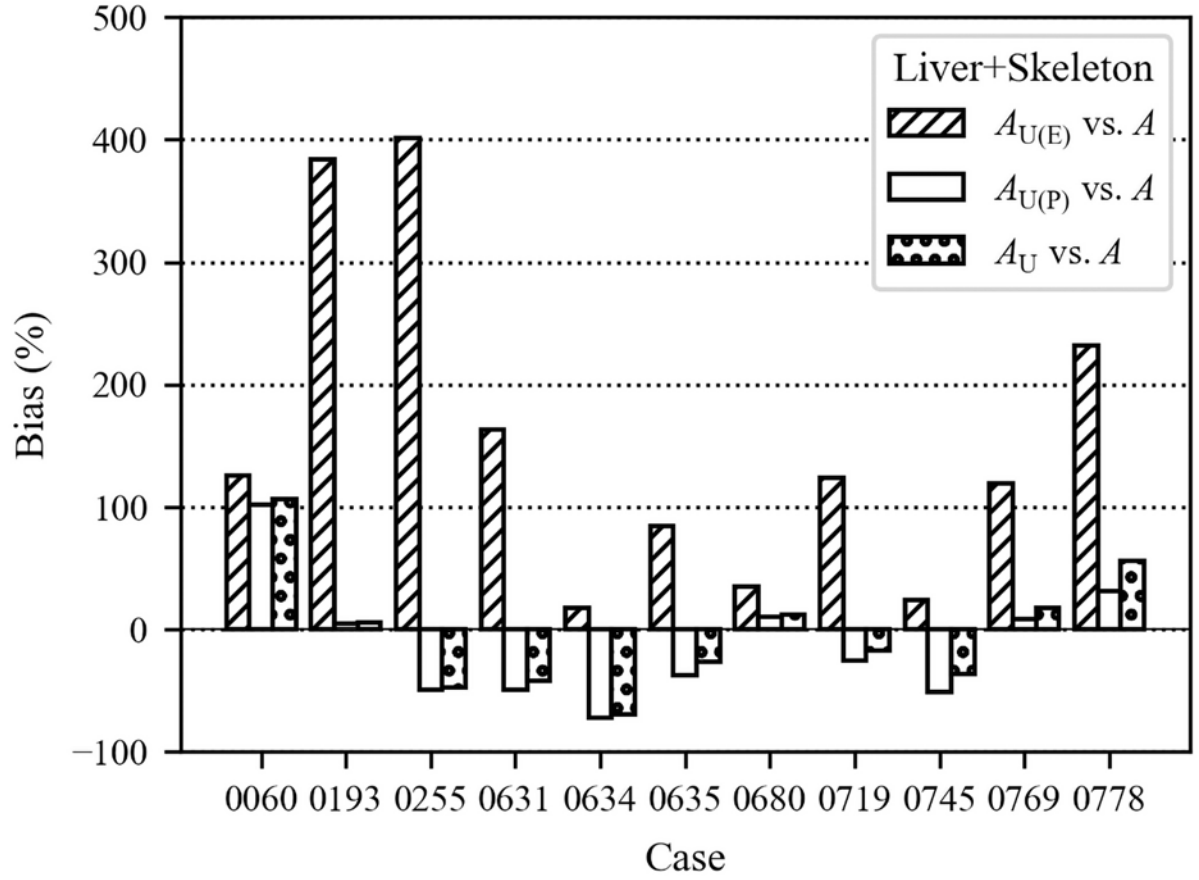




Bias in Organ Activity

- IMBA Professional Plus fit of urine bioassay to estimate intake
- Predict plutonium activities $A_{U(E)/U(P)/U}$ (Bq) in liver+skeleton (to eliminate intersubject liver and skeleton variability) at the time of death
- Compare to measured post-mortem liver+skeleton activity A with predicted value based on:
  - ✓ urine data collected during exposure period, $A_{U(E)}$
  - ✓ using urine data collected post-exposure, $A_{U(P)}$
  - ✓ using all available urine data, A_U

Bias in Liver+Skeleton Activity



Mean absolute bias (%)	
$A_{U(E)}$ vs. A	156±133
$A_{U(P)}$ vs. A	40±29
A_U vs. A	40±30

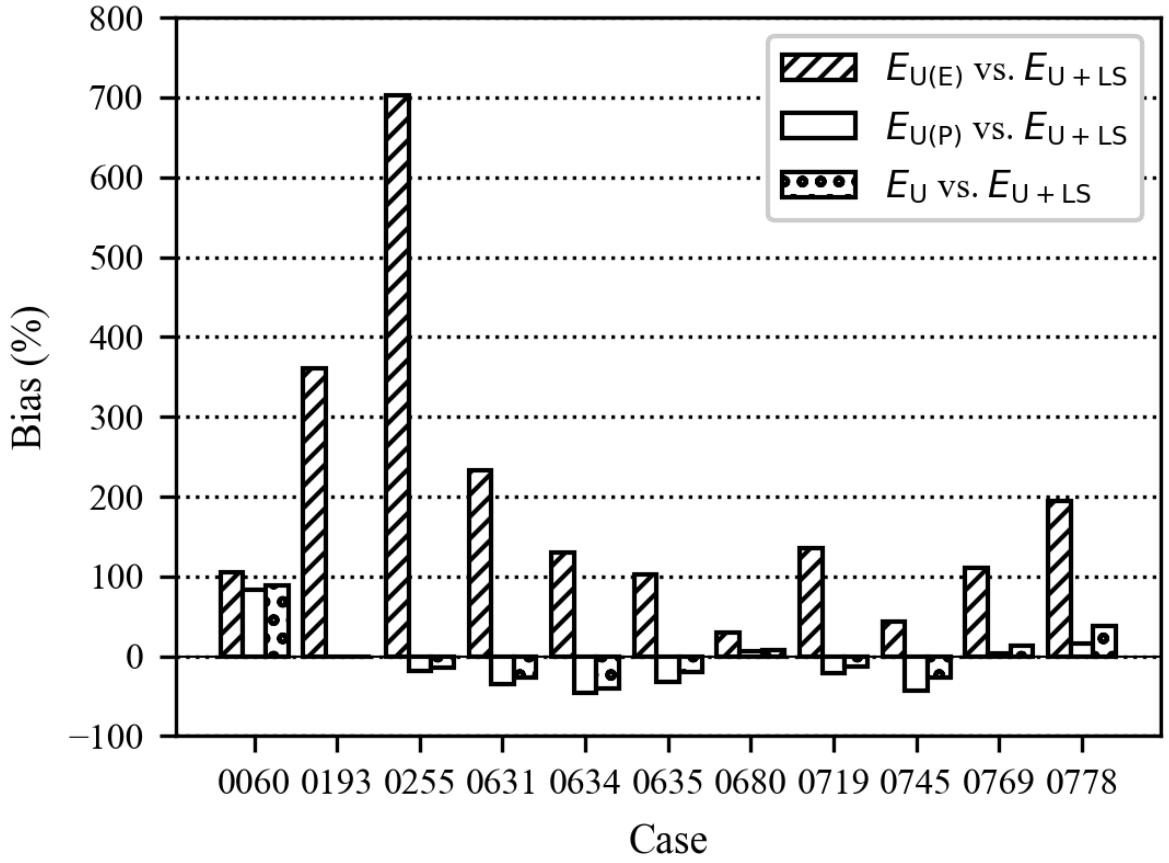
Šefl *et al* . *Plutonium in Manhattan Project workers: Using autopsy data to evaluate organ content and dose estimates based on urine bioassay with implications for radiation epidemiology* . PLOS One 16(10): e0259057; 2019.

Bias in Committed Effective Dose

- Reference “best estimate” using all available data, urine bioassay and post-mortem liver+skeleton activity – E_{U+LS}
- $E_{U(E)}$ – using urine data collected during exposure period
- $E_{U(P)}$ – using urine data collected post-exposure
- E_U – using all available urine data

$$\text{Bias}(\%) = \frac{E_U - E_{U+LS}}{E_{U+LS}} \times 100$$

Bias in Committed Effective Dose

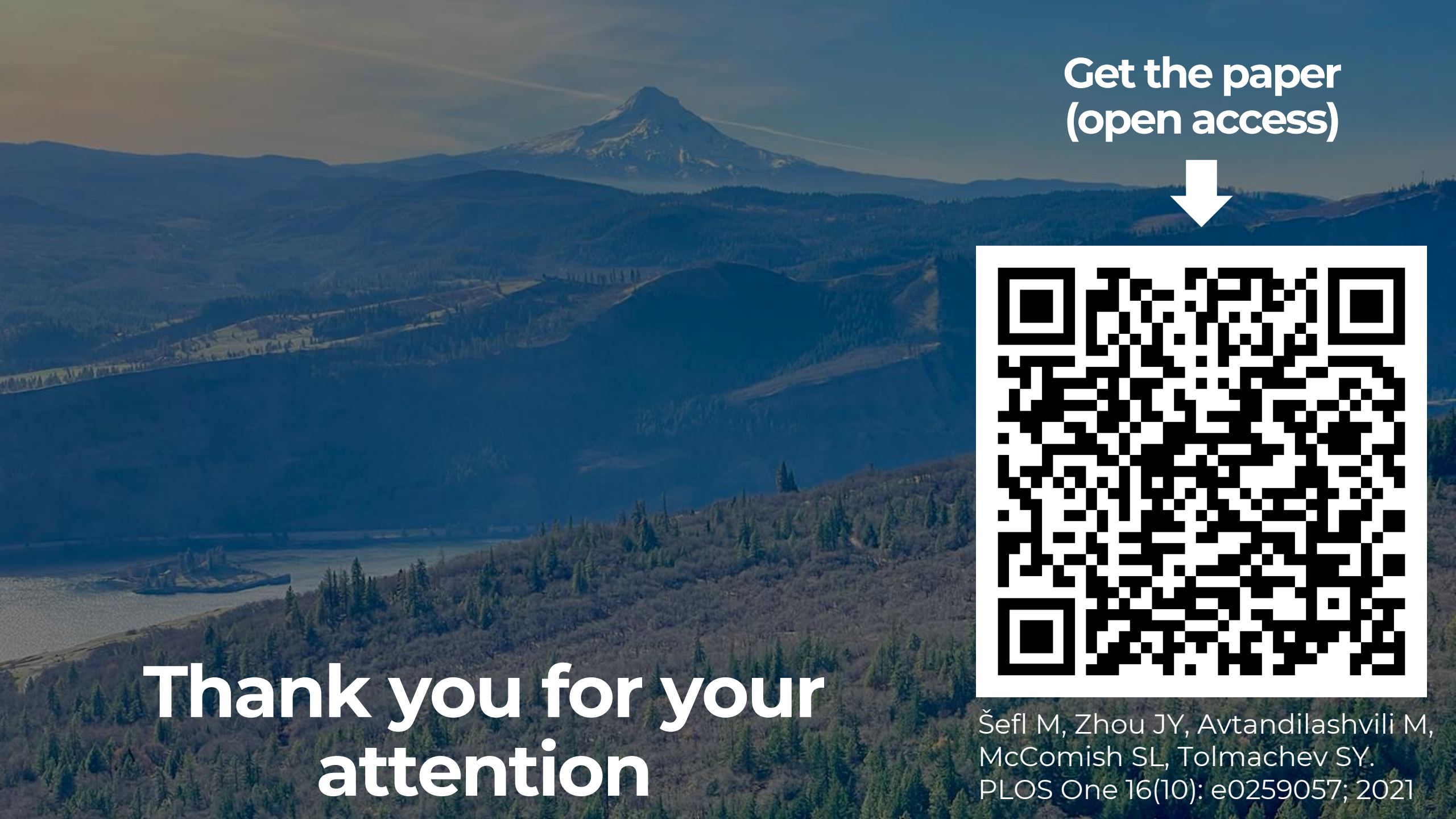


Mean absolute bias (%)	
$E_{U(E)}$ vs. A	196±192
$E_{U(P)}$ vs. A	28±24
E_U vs. A	26±24

Šefl *et al* . *Plutonium in Manhattan Project workers: Using autopsy data to evaluate organ content and dose estimates based on urine bioassay with implications for radiation epidemiology* . PLOS One 16(10): e0259057; 2019.

Conclusions

- On average, current biokinetic model predictions for the liver+skeleton retention appear to be in good agreement with the measured organ activities (–4±51%); however, the individual variability is high
- Use of urine bioassay data collected during the exposure period in the 1940s overestimated the liver+skeleton activity on average by a factor of 2.5
- Using post-exposure urinalyses significantly improved the estimates of organ activities and doses – importance of a long-term collection of bioassays as a part of follow-up



Thank you for your attention

Šefl M, Zhou JY, Avtandilashvili M, McComish SL, Tolmachev SY. PLOS One 16(10): e0259057; 2021