

Spokane, August 13, 2021

53-year Follow-up of a Manhattan Project Worker

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United States Transuranium and Uranium Registries

The USTUR's mission is to:

- Follow up occupationally-exposed individuals (volunteer Registrants) by studying the biokinetics (deposition, translocation, retention, and excretion) and tissue dosimetry of uranium and transuranium elements, such as **plutonium**, americium, curium, and neptunium.
- Obtain, analyze, preserve, and make available for future research, materials from individuals who had documented intakes of uranium and transuranium elements.
- Apply USTUR data to refine dose assessment methods in support of reliable epidemiological studies, radiation risk assessment, and regulatory standards for radiological protection of workers and general public.

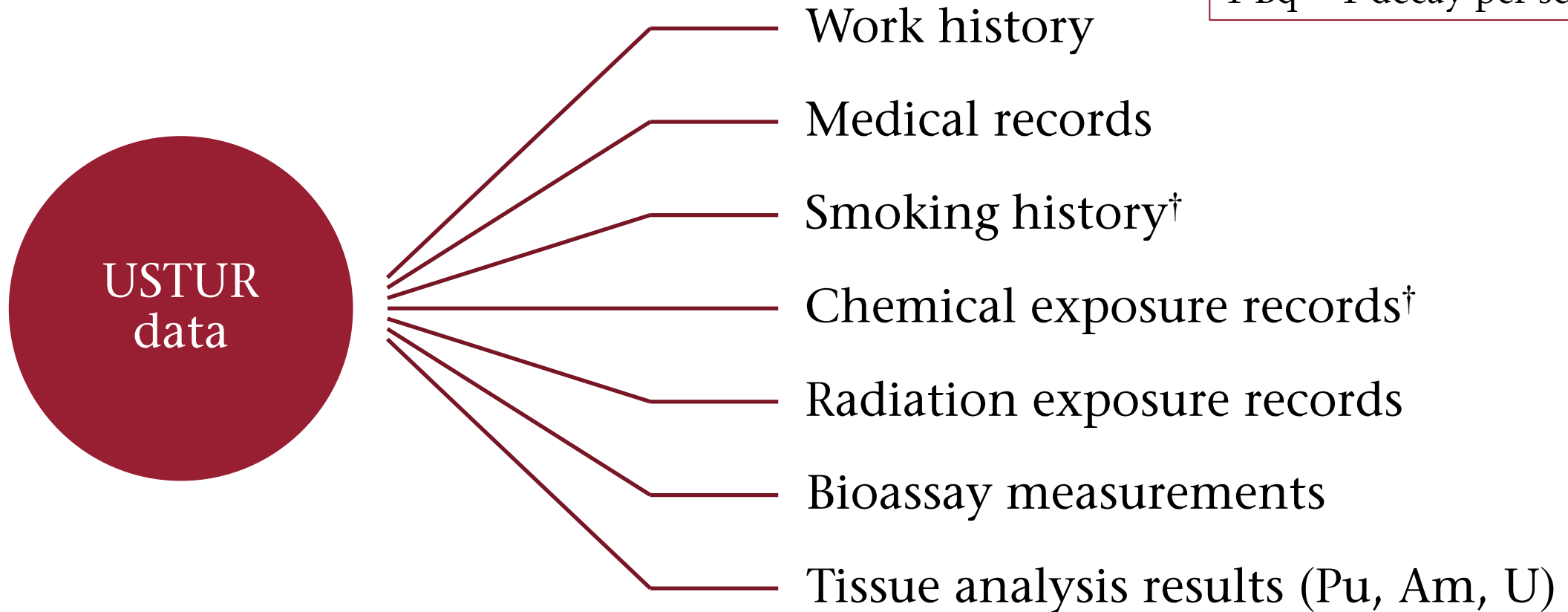




Unique Data Resource

- Registrant acceptance: ≥ 74 Bq systemic content

Becquerel (Bq) is a unit of radioactivity
1 Bq = 1 decay per second



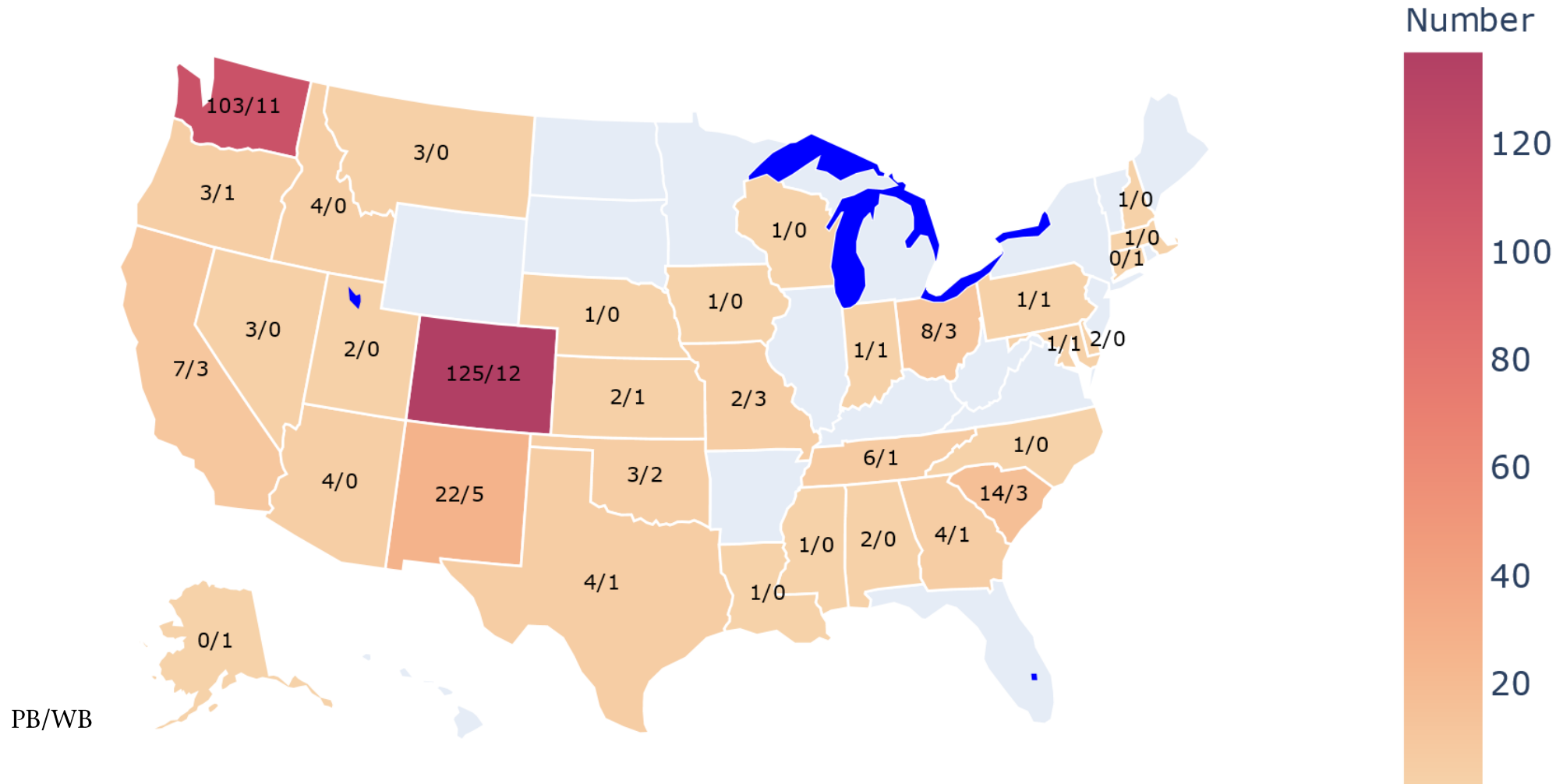
† - self-reported data





USTUR Registrants

- Partial-body: 334 (19 living)
- Whole-body: 52 (5 living)





Plutonium

- Plutonium is an artificial element discovered on December 14, 1940
- Isotopes range from ^{228}Pu to ^{247}Pu
- Registrants were exposed to ^{239}Pu (half-life 24,100 y), and ^{238}Pu (half-life 87.74 y)
- ^{239}Pu :
 - fissile, can sustain nuclear fission – nuclear weapons
 - produced in a nuclear reactor
 - Manhattan Project – first weapon



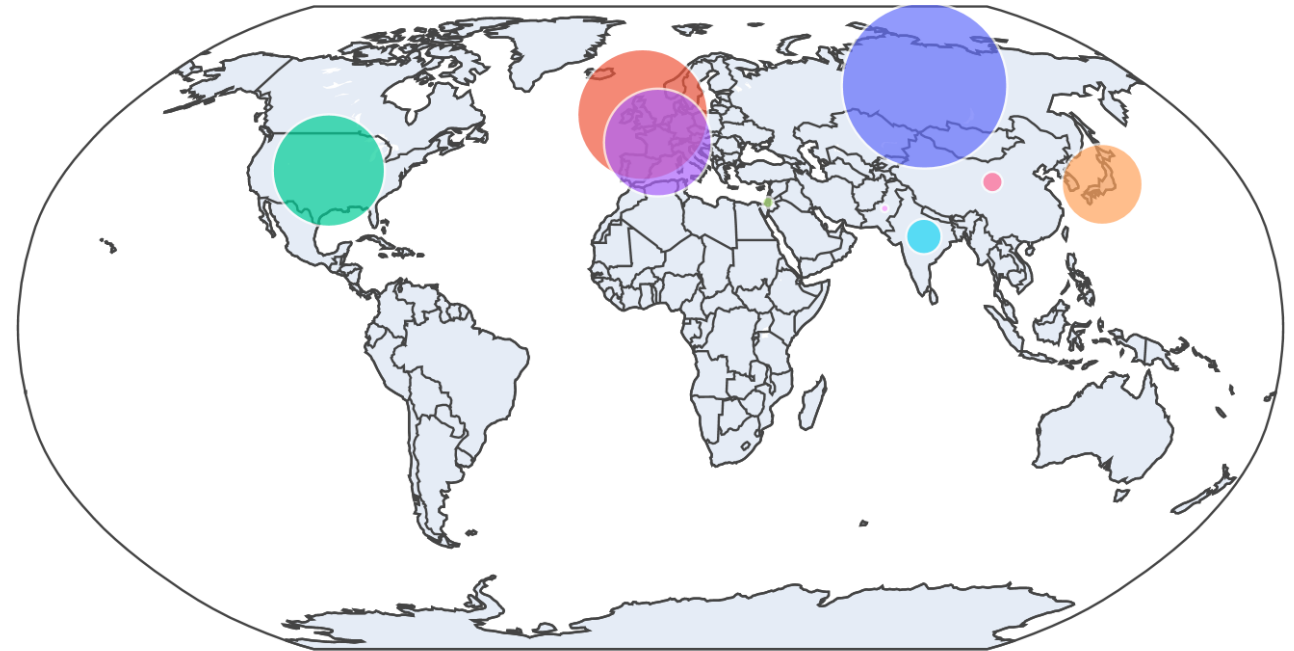
en.wikipedia.org/wiki/Nuclear_weapon#/media/File:Trinity_Detonation_T&B.jpg





Plutonium in the World

- As of beginning of 2020 global stockpile of separated plutonium was about 540 tons (metric)
- 316 tons considered civilian plutonium
- France, Russia, UK, Japan, India, China operate reprocessing facilities separating plutonium from spent power reactor fuel

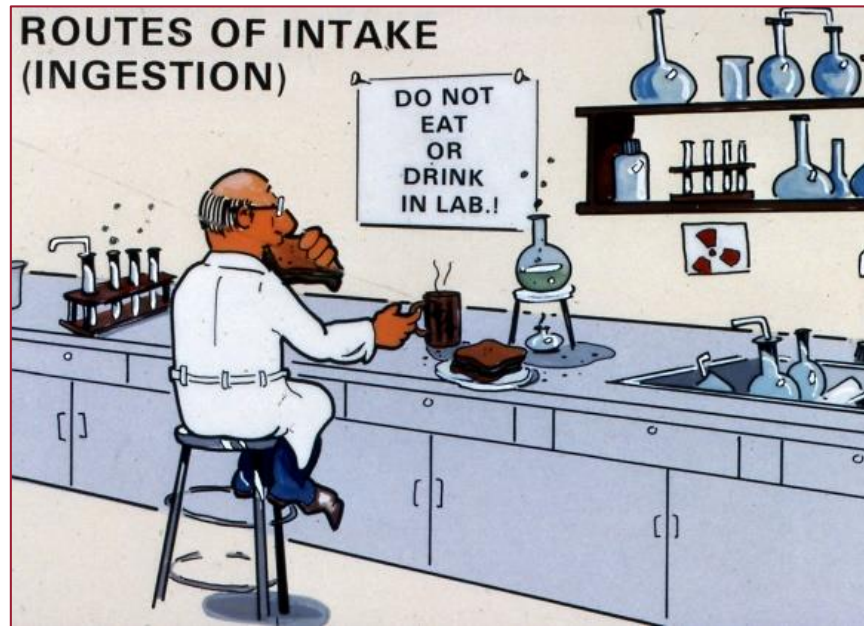
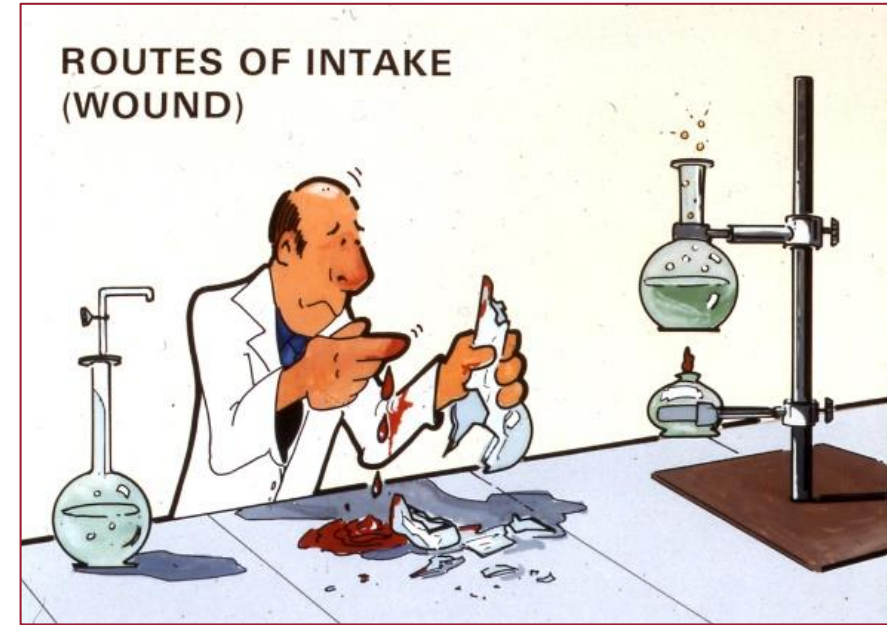
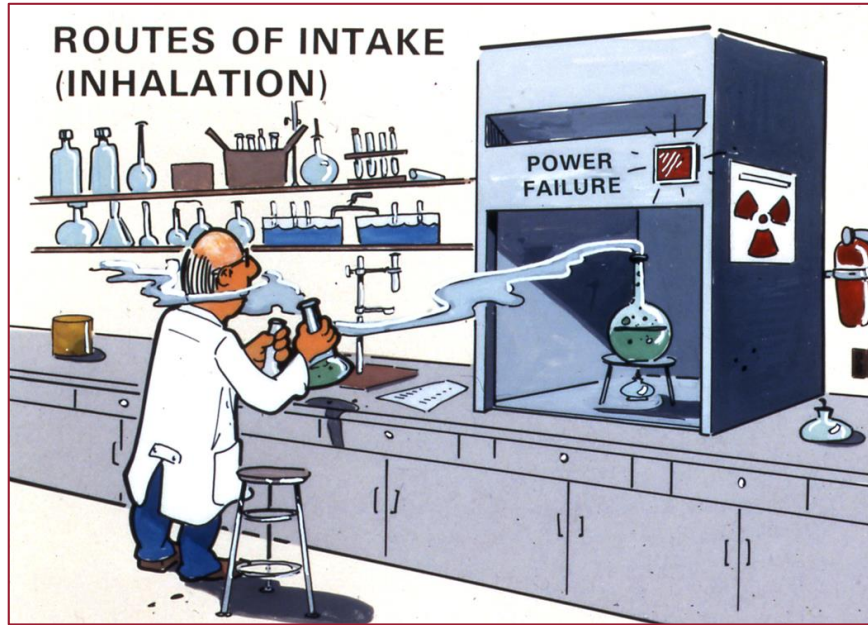


Data source <http://fissilematerials.org/>





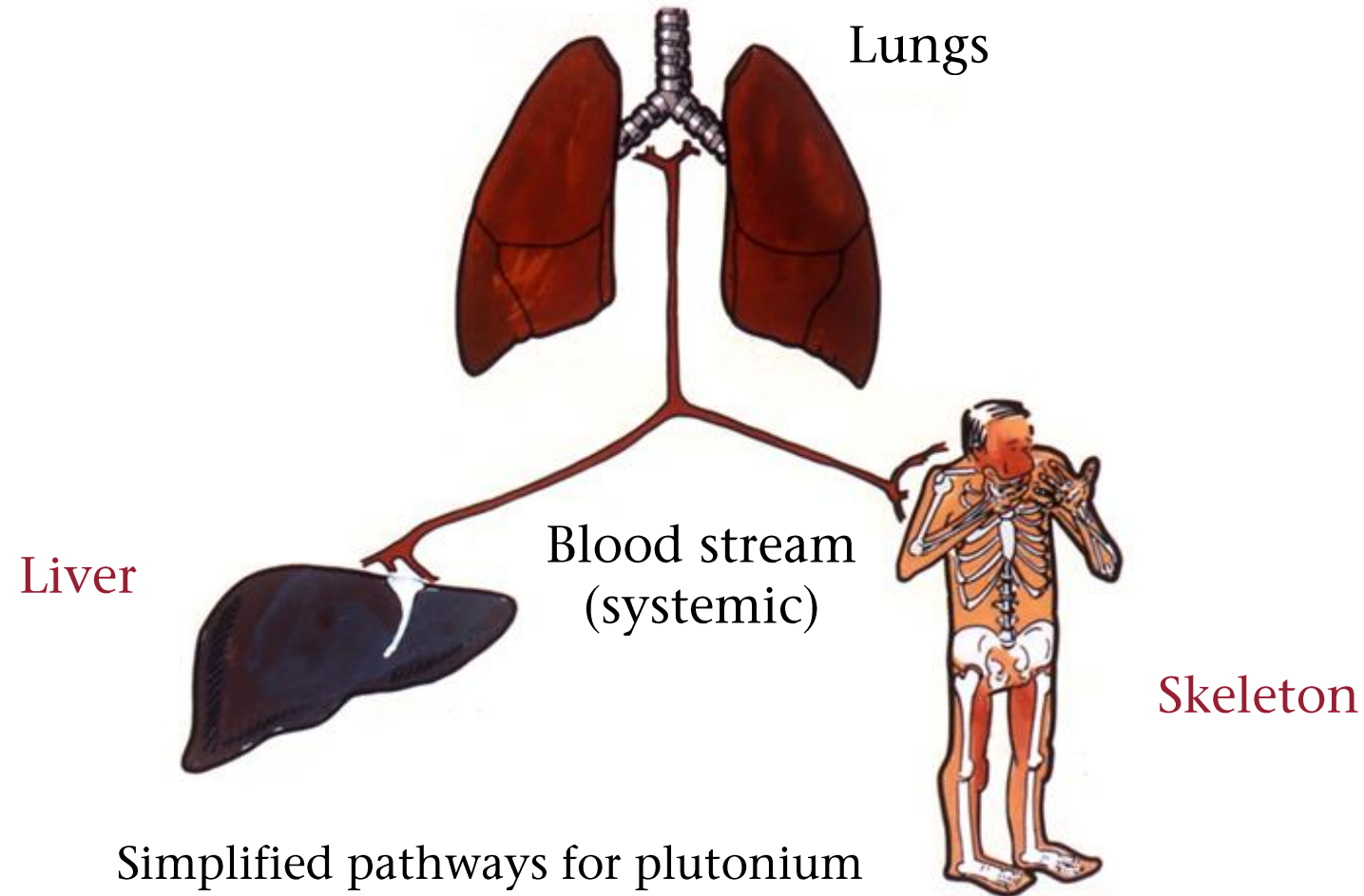
Routes of intake





Plutonium in Human Body

- Plutonium is a *bone and liver seeker*





USTUR Case 0680

- One of 26 Manhattan Project plutonium workers selected for medical follow-up “*on the basis of the amount of plutonium excreted in the urine assayed by methods available before 1950.*”
- Worked as a chemist on plutonium recovery for 18 months in 1940s
- Died 53 years after exposure at age 90+
- Whole-body tissue donor to the USTUR

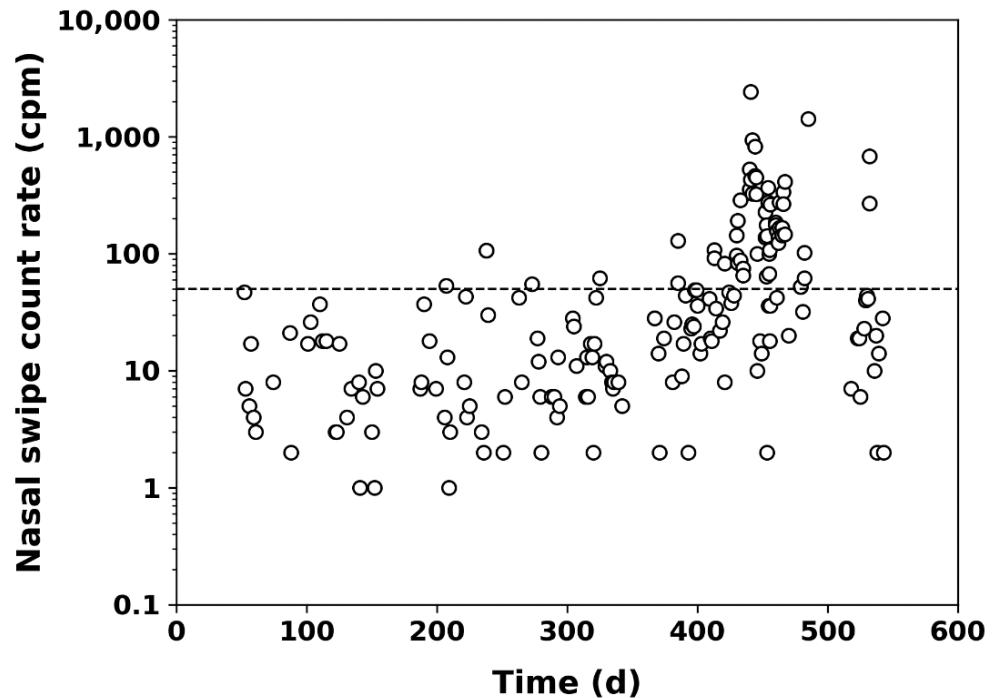
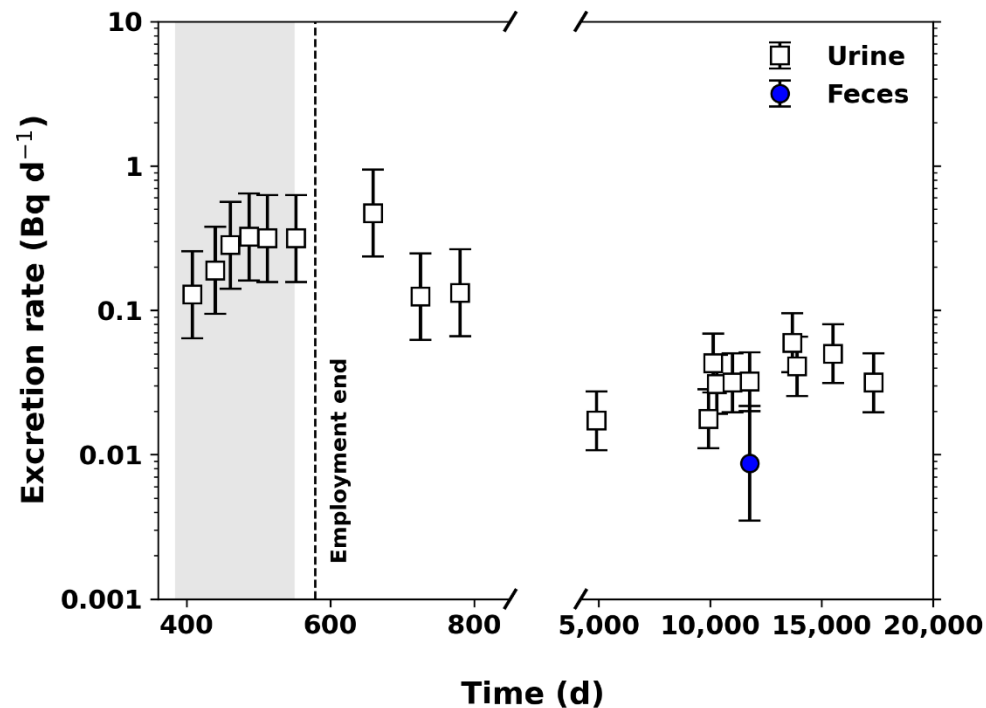
Voelz GL, Hempelmann LH, Lawrence JNP, Moss WD. A 32-year medical follow-up Manhattan Project plutonium workers. *Health Phys* 37(4): 445–485; 1979.





Data: Bioassay Measurements

- 19 urine samples
- 1 fecal sample
- 1 blood sample
- 212 nasal swipes
- 14 chest counts < MDA

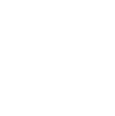




Data: Post-mortem Tissue Analyses

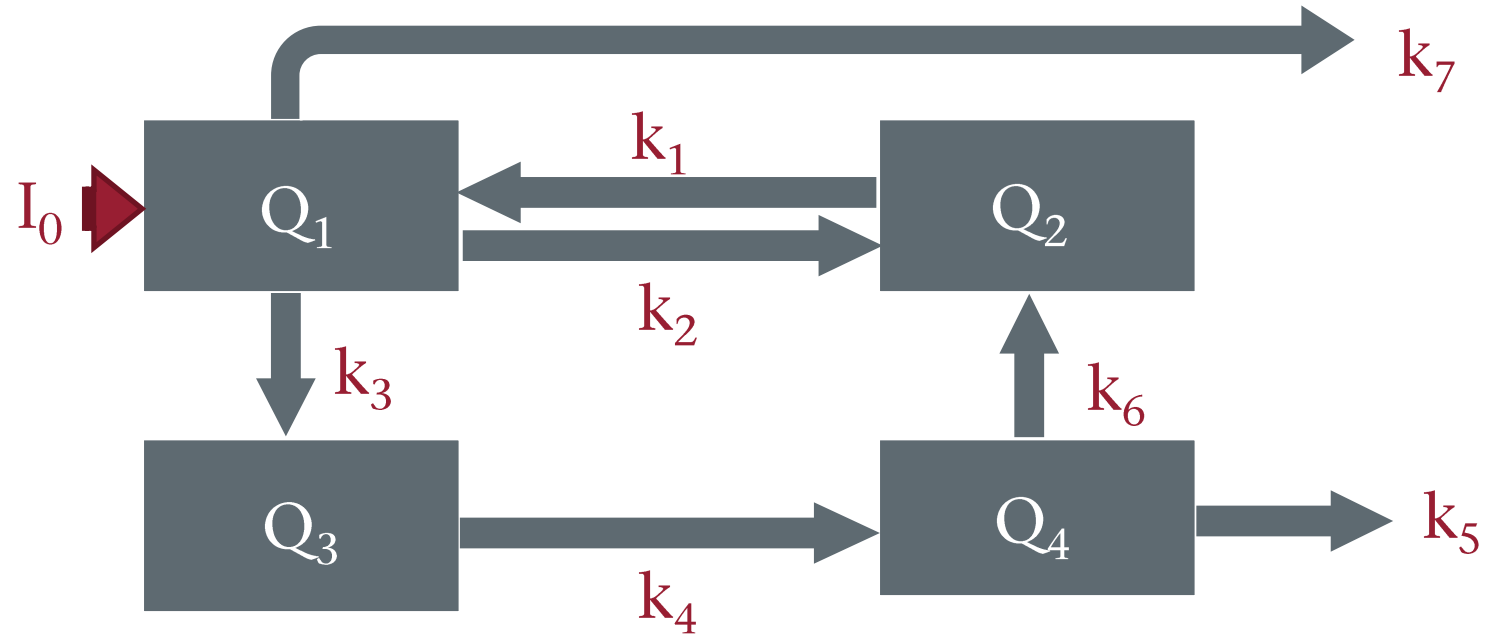
- Tissues analyzed: 82 bone samples and 13 soft tissues
- Total body: $1,765 \pm 12$ Bq

Systemic		Respiratory
		Lungs: 181 ± 3 Bq
	Liver: 661 ± 11 Bq	
	Other Soft Tissues: 120 ± 4 Bq	LNTN: 101 ± 1 Bq
Skeleton: 700 ± 3 Bq		



Biokinetic Modeling: Compartmental Model

- Used for modeling distribution of Pu in human body
- Set of ordinary differential equations with constant coefficients
- Solvable analytically or numerically



$$dQ_1/dt = I_0 - (k_2+k_3+k_7)Q_1 + k_1Q_2$$

$$dQ_2/dt = k_2Q_1 - k_1Q_2 + k_6Q_4$$

$$dQ_3/dt = k_3Q_1 - k_4Q_3$$

$$dQ_4/dt = k_4Q_3 - (k_5+k_6)Q_4$$



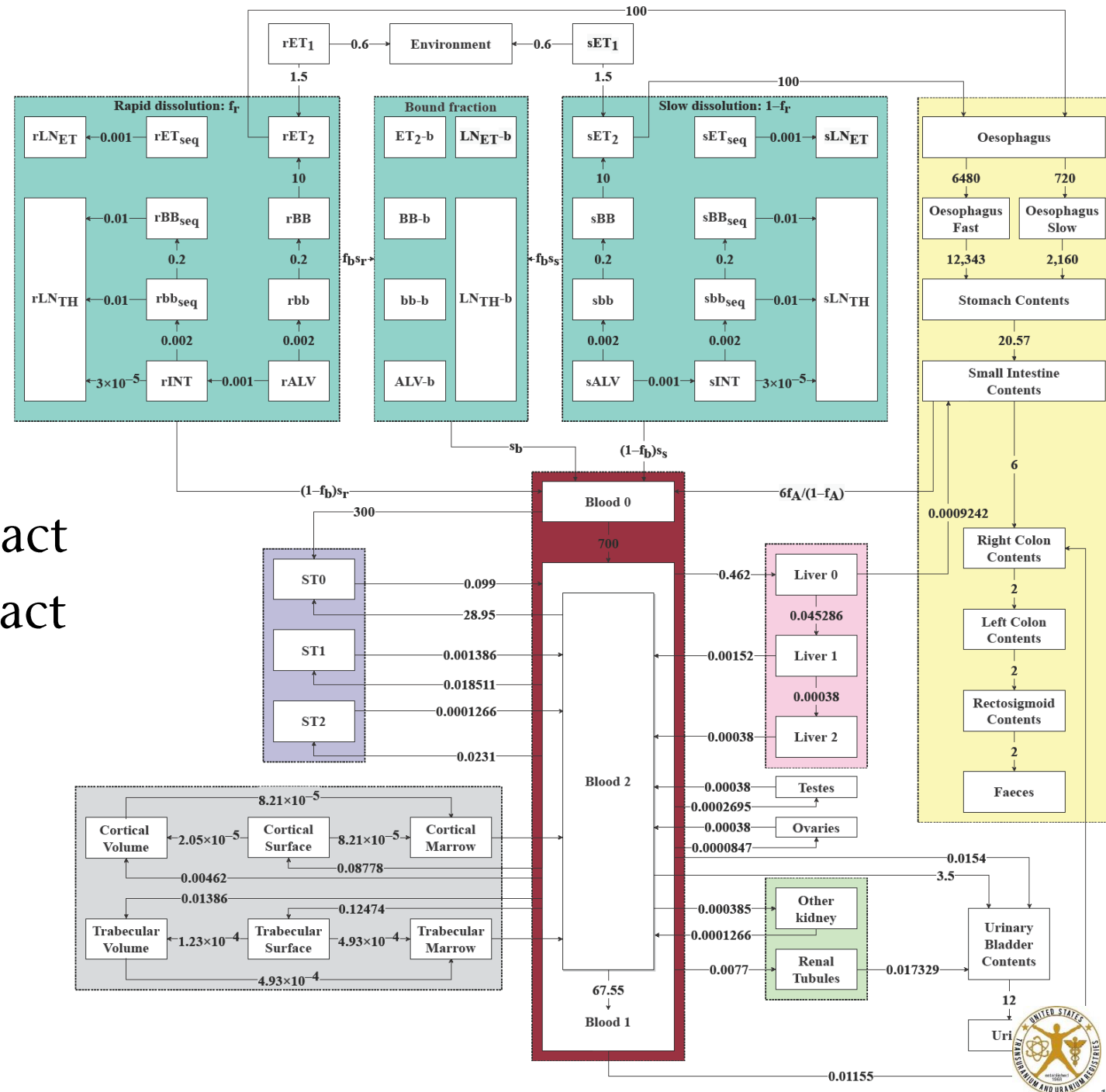
Intake Scenario

Chronic inhalation

- Pu-nitrate
- PuO₂

ICRP models

- 130 Human Respiratory Tract
- 100 Human Alimentary Tract
- 141 Plutonium Systemic





Taurus Internal Dosimetry Software

Taurus

File Preferences User guide Notebook Refresh screen About

Input

Reference
0680

Nuclide
Pu-239 2.411E+4y

Deposition parameters
 ICRP OIR series defaults
Light work
0.3 microns AMAD (for aerosols only)

Absorption parameters
 ICRP OIR series defaults
 User-defined form **Add**

Systemic biokinetics
 ICRP OIR series defaults

Alimentary tract
 ICRP OIR series defaults

Respiratory tract
 ICRP OIR series defaults

Intake regimes
Number of intake regimes (max. 20) **Retrieve forms** **Help: Forms** **Help**

	Form	Route	Mode	Start	End	Intake	fA	fr	sr	ss	fb	sb
1	PUN034	INH	Chronic	385	548	1.5247E+02	1.00E-04	0.2000	0.4000	2.0000E-03	2.0000E-03	0.000
2	PU02	INH	Chronic	385	548	4.2107E+01	2.00E-06	4.0000E-03	0.4000	1.0000E-05	2.0000E-03	0.000

Bioassay quantities

Whole body	<input type="checkbox"/>	Blood	<input checked="" type="checkbox"/>	Kidneys	<input type="checkbox"/>
Urine	<input checked="" type="checkbox"/>	Faeces	<input checked="" type="checkbox"/>	Liver	<input checked="" type="checkbox"/>
Lungs	<input checked="" type="checkbox"/>	Thyroid	<input type="checkbox"/>	Skeleton	<input checked="" type="checkbox"/>

Calculations **Help**

Quick dose and bioassay
 Prospective calculation
 Retrospective calculation (data fitting)

Start calculations

Progress

Results

Total effective dose, Sv

View doses

Goodness of fit

Plot bioassay

Report

short long

Save report

View report

Licence information
This copy of Taurus is registered to USTUR-W/SU for 5 users. It will expire on 07/10/2021.

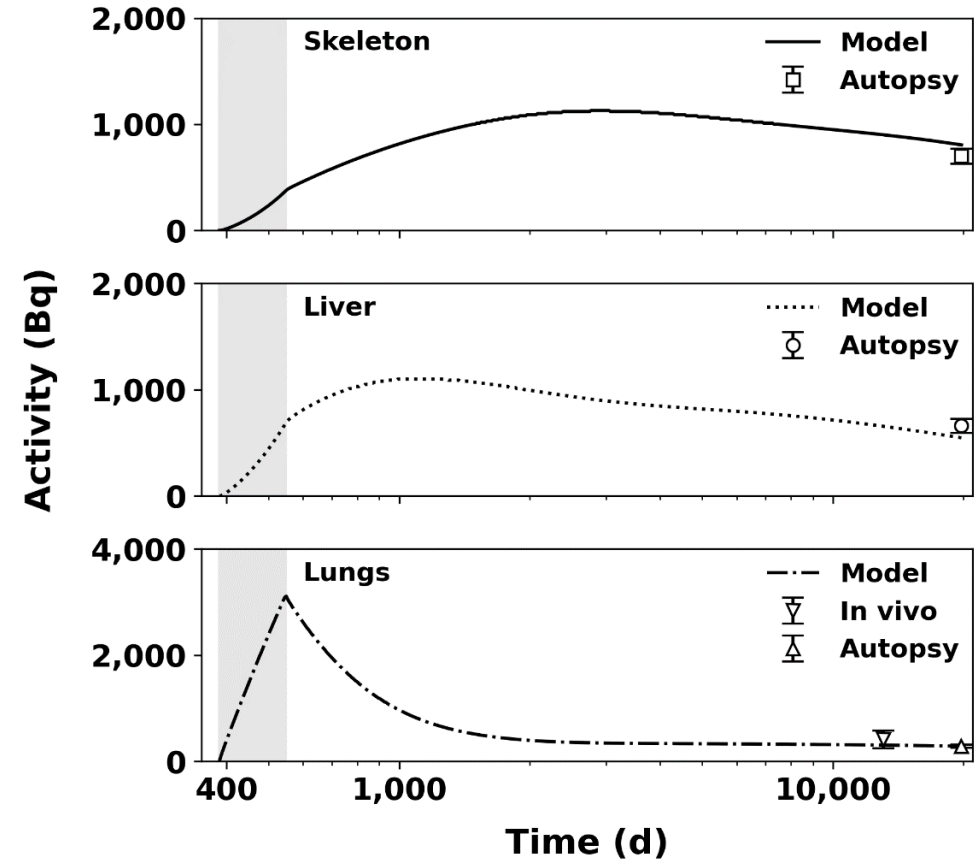
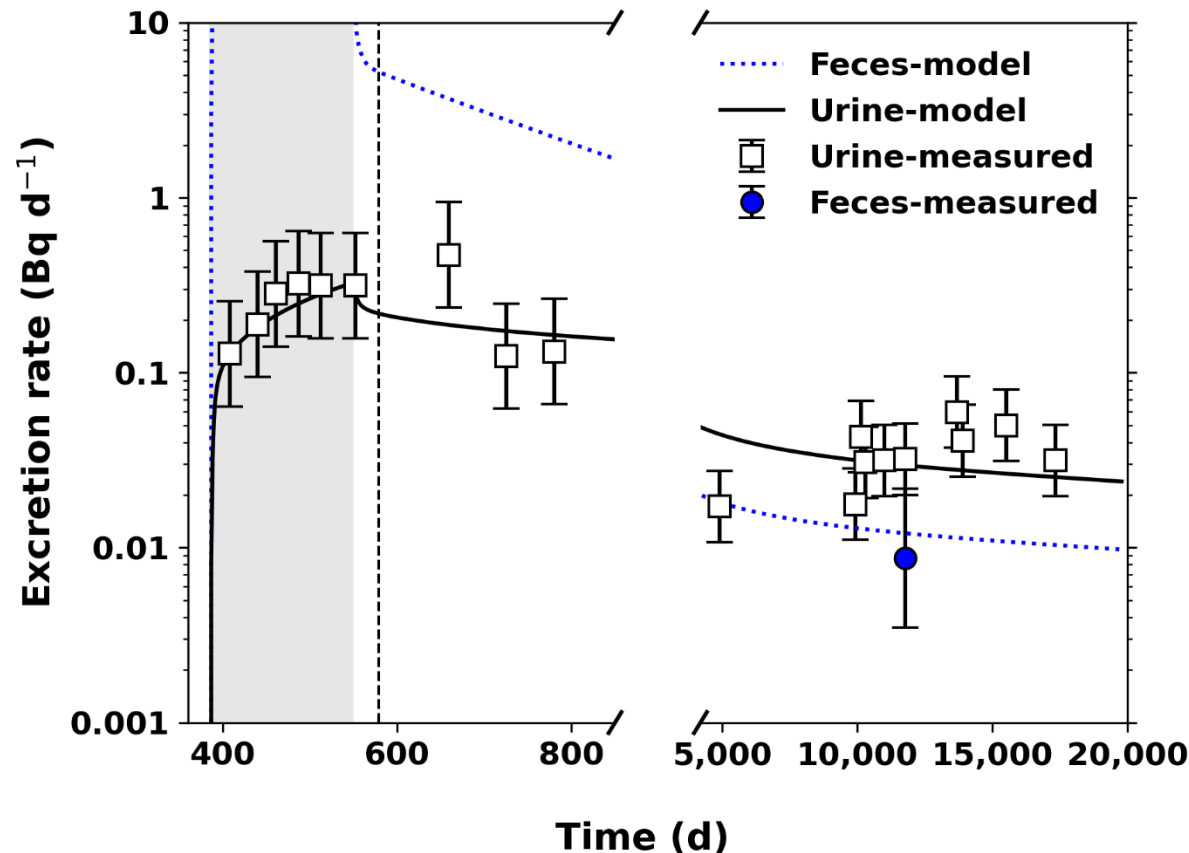
Public Health England, UK



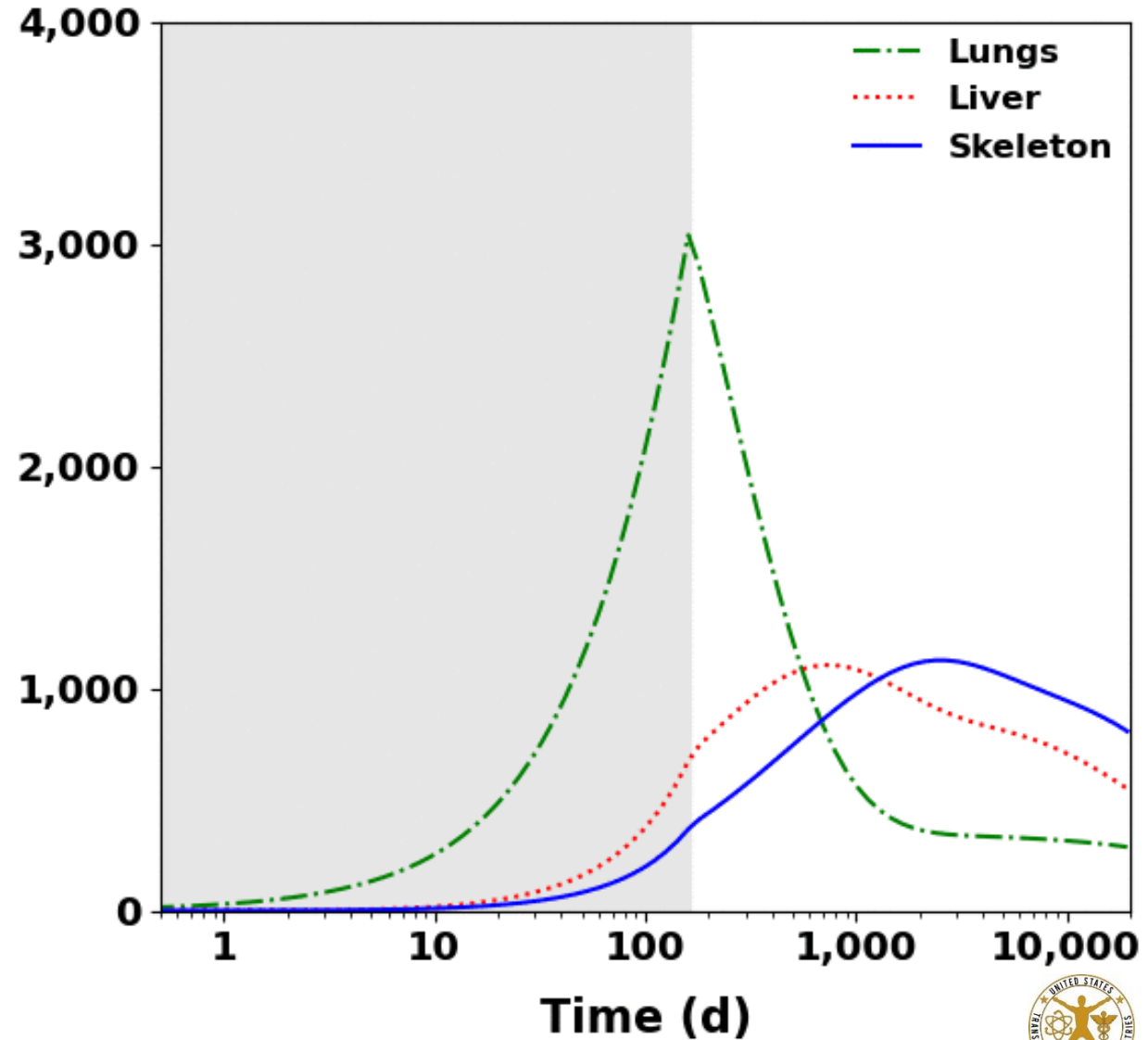
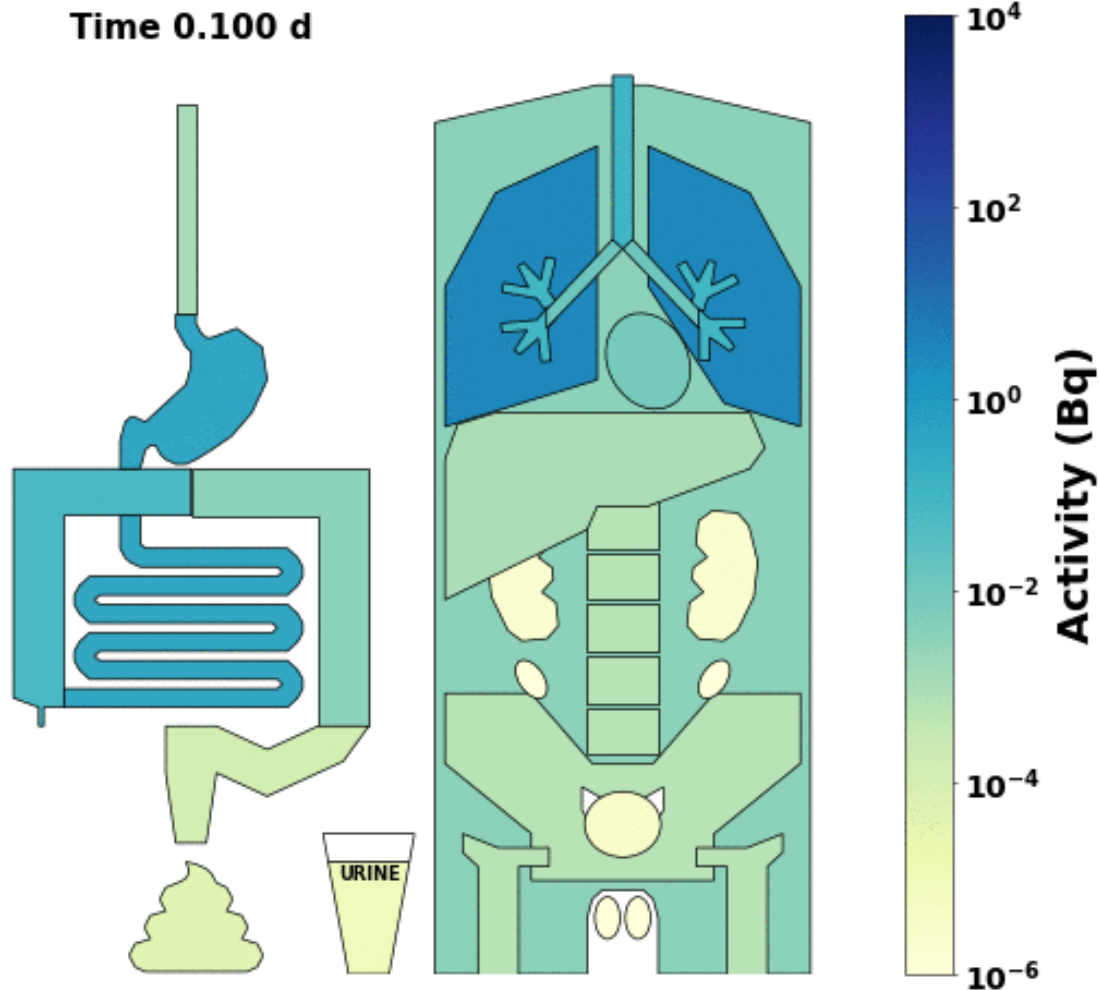


Results: Estimated Intake

Days	Material	Intake		Goodness of fit χ^2 p -value
		Rate (Bq d ⁻¹)	Cumulative (Bq)	
385 – 548	Pu-nitrate	152.5	25,570	0.808
	PuO ₂	42.1	9,485	



Results: Plutonium Organ Distribution over Time





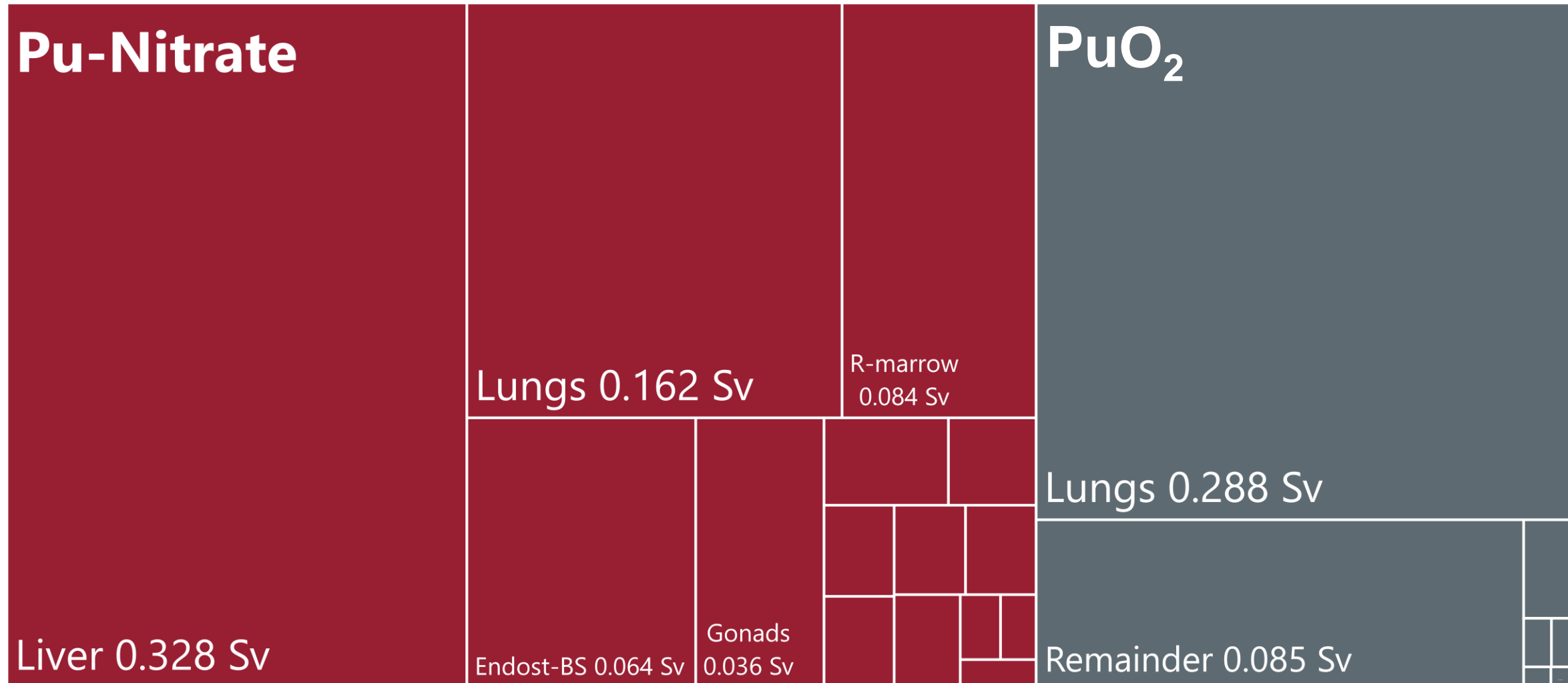
Effective dose

- Radiation protection quantity
- Used to compare the stochastic risk of exposure to radiation
- Depends on:
 - energy deposited
 - type of radiation
 - radiosensitivity of irradiated tissues
- Unit: Sievert (Sv)
- ICRP annual effective dose limit for general public: 1 mSv



Results: Organ Contributions to Effective Dose

- Committed effective dose: 1.22 Sv





Summary

- ICRP reference biokinetic models adequately described the long-term plutonium retention and excretion for this individual
- Chronic inhalation of 78% Pu-Nitrate and 22% PuO₂
- 53 years post intake total body activity: 1,765 Bq
- Total body distribution: systemic organs 84%, respiratory tract 16%
- Systemic distribution: skeleton 47%, liver 45%, other 8%

Šefl, M, Avtandilashvili, M, Tolmachev, SY. Inhalation of Soluble Plutonium: 53-year Follow-up of Manhattan Project Worker, Health Physics 2021:120(6); 661-670.





Acknowledgements

Internal Dosimetry Group, Public Health England, UK

Anthony Riddell, Demetrio Gregoratto, Public Health England, UK

The USTUR is funded by US DOE, Office of Domestic and International Health Studies (AU-13), under grant award DE-HS0000073 to College of Pharmacy and Pharmaceutical Sciences at Washington State University

Thank you!

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