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Plutonium in Rocky Flats Workers: Using Post-mortem Tissue Analyses to Evaluate Organ Content and Dose Estimates Based on Monitoring Data

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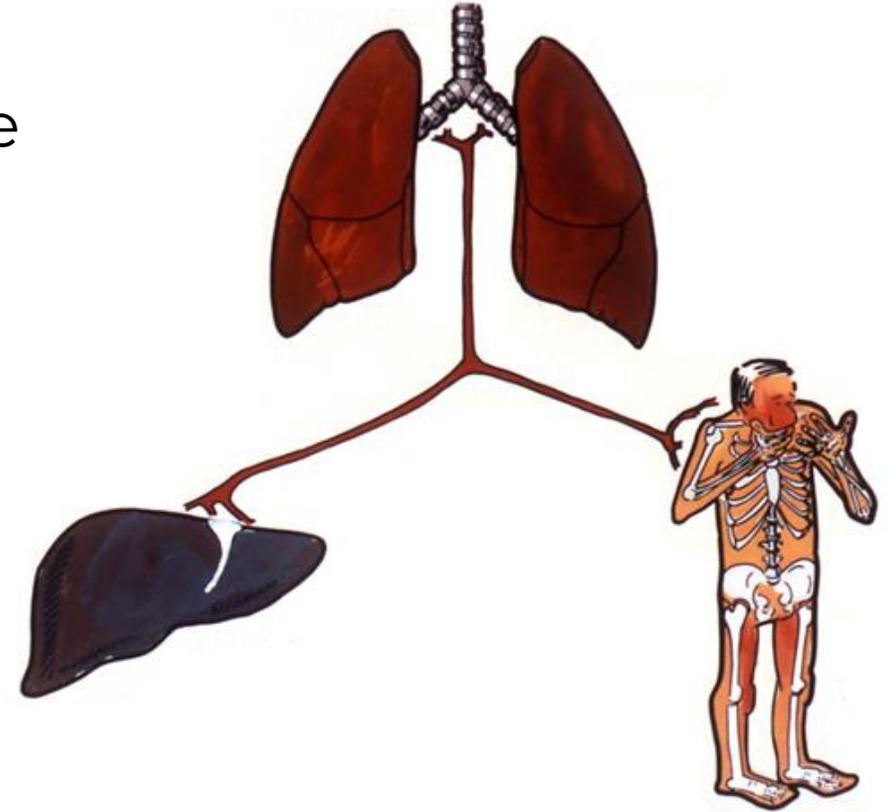
Motivation

- In radiation epidemiology, worksite records and bioassay measurements are used to estimate the radiation doses
- Post-mortem tissue/organ analyses can be used to evaluate the accuracy of the reference biokinetic models and radiation dose estimates for epidemiology



Objectives

- What are the uncertainties in organ activity predictions and radiation dose estimates using the urine/chest count bioassay data?



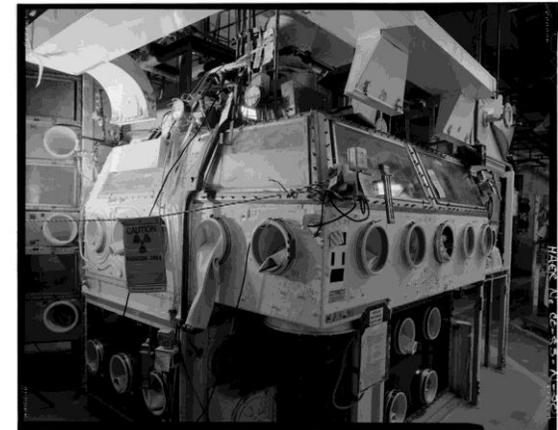
This Study: Rocky Flats Workers

1965 Rocky Flats glove box fire accident[†]

- High-fired refractory PuO_2 aerosols: $1\ \mu\text{m}$ AMAD
- 23 out of 400 potentially exposed workers are USTUR Registrants
- Nine individuals were selected for this study: four (4) whole-body and five (5) partial-body tissue donors



<https://coloradoencyclopedia.org/article/rocky-flats-nuclear-facility>



<https://www.loc.gov/resource/hh.h.co0855.photos/?sp=20>

[†] Mann and Kirchner. *Evaluation of lung burden following acute inhalation exposure to highly insoluble PuO_2* . Health Physics 13(8): 877–882; 1967

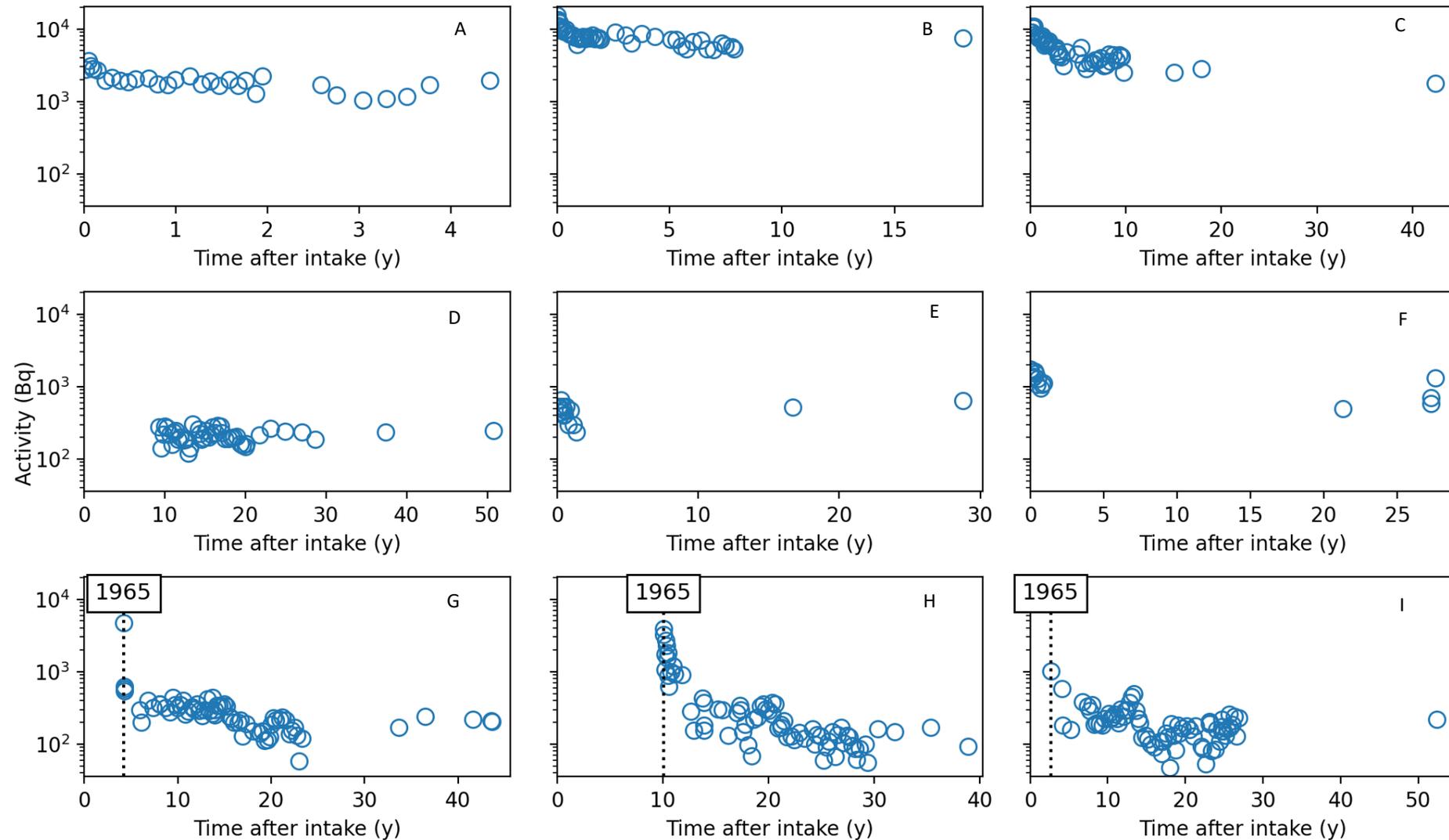


Study Group Overview

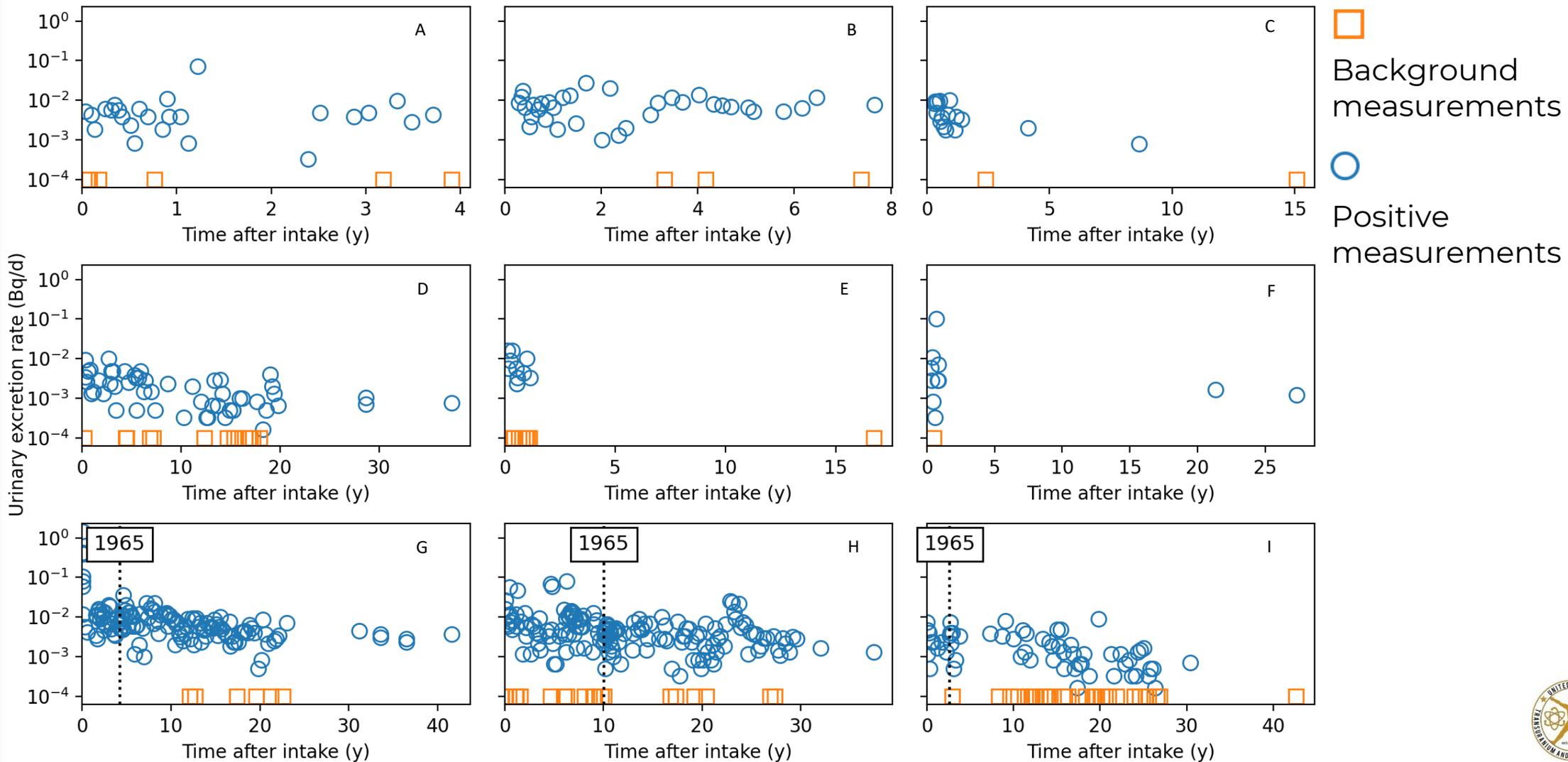
- Intake regimes:
 - ✓ Single acute inhalation due to fire – 6 cases
 - ✓ Additional wound prior to fire – 1 case
 - ✓ Additional inhalation prior to fire – 2 case
- Follow-up ranged from 5 to 50 years after fire accident
- Bioassay data: chest counts, urine
- Measured ^{239}Pu activities in lungs, thoracic lymph nodes (LNTH), liver, and skeleton



Data: Chest Counts



Data: Urine Bioassay



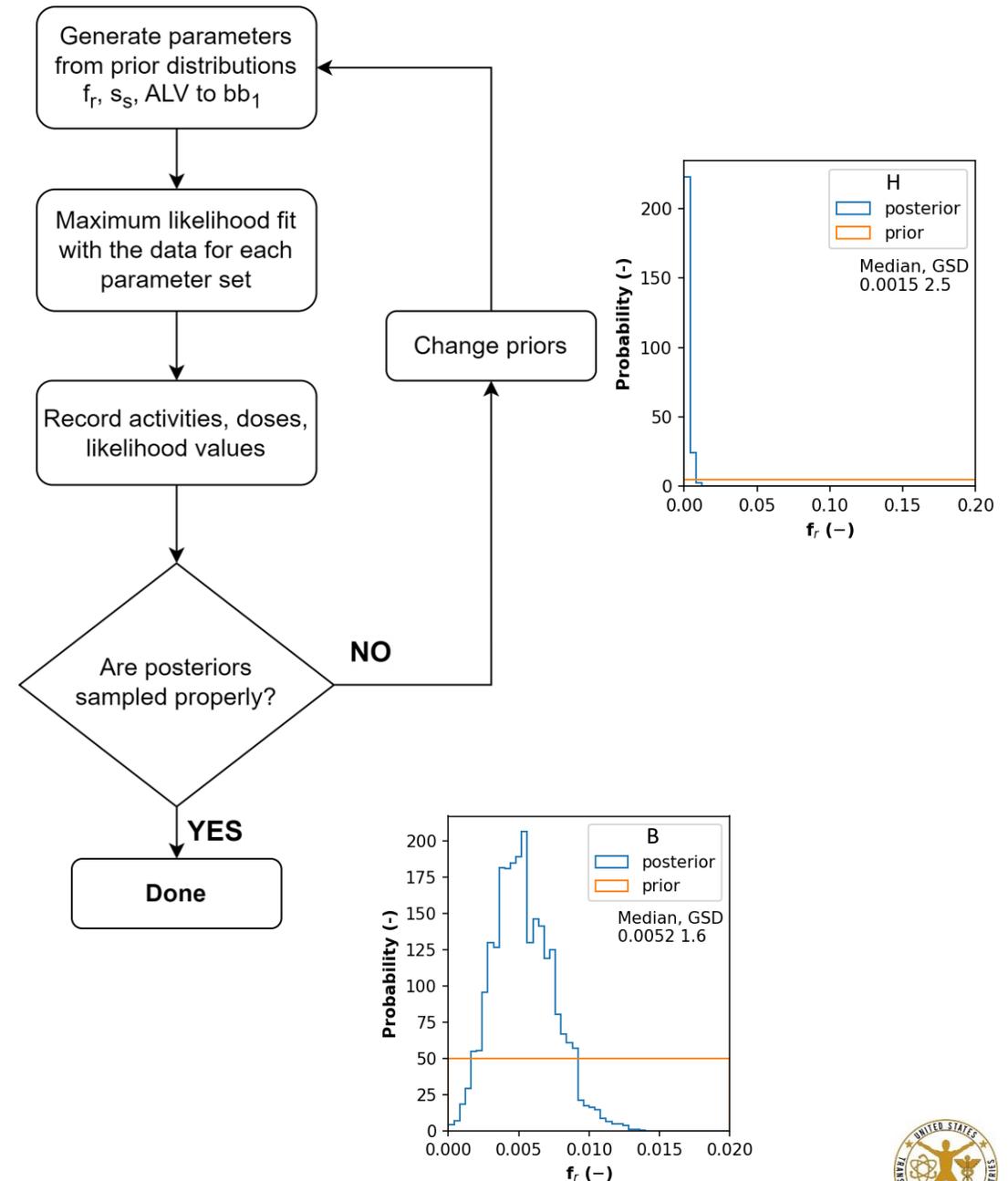
Data: Radiochemistry Results

Case	Measured activity (Bq)		
	Lungs+LNTH	Liver	Skeleton
A	1887	9.64	20.56
B	6550	102	217.7
C	1957	123	197
D	244	28.3	26.95
E	528	25.79	9.19
F	1046	28.58	19.31
I	155	19.97	19.10
H	93	29.97	87.1
G	241	70.9	110.9



Bayesian Approach

- Prior probability is the estimated probability before the data
- Posterior probability is updated by the data
- Can be used to find specific parameters for a group
- The result is not a point estimate, but a distribution

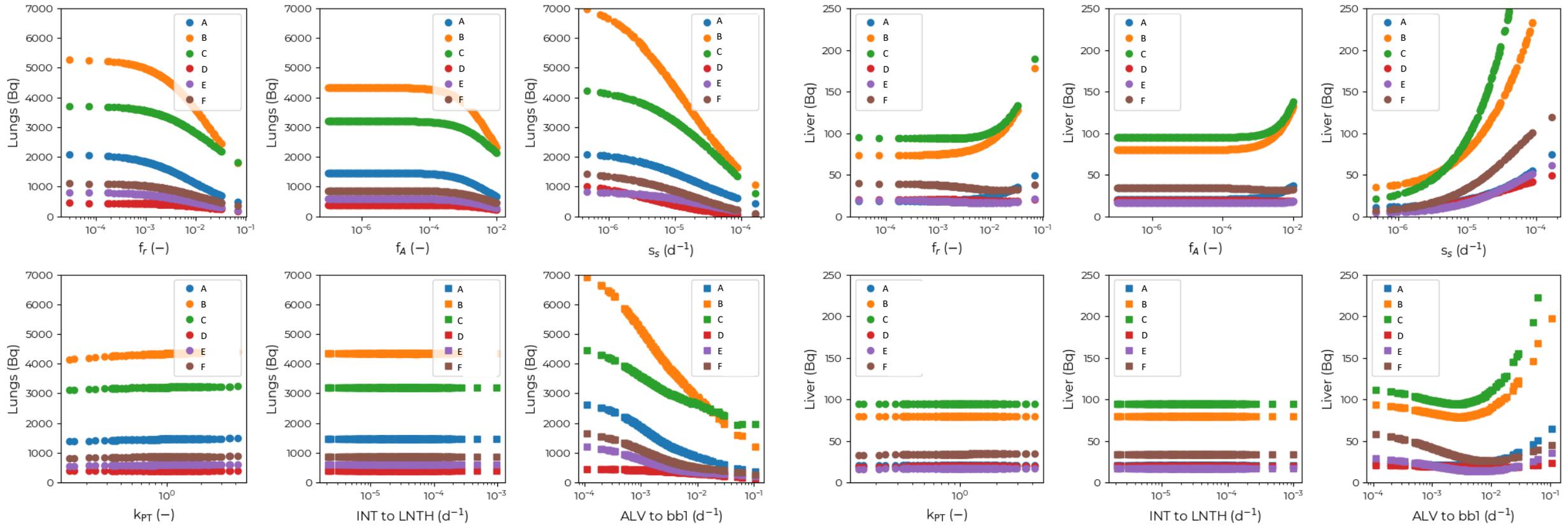


Methods

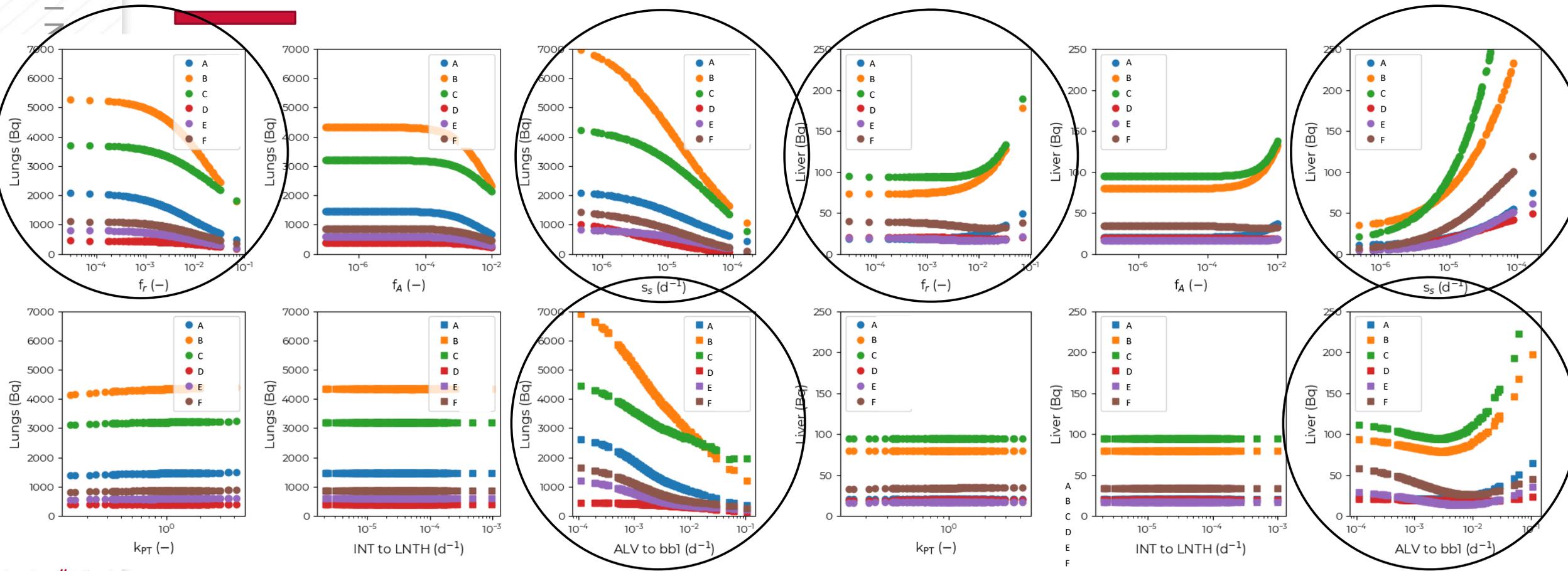
- Choice of priors: which parameters to vary – typical parameters to vary in literature are absorption parameters (s_s , f_r , f_A) and particle transport rates (k_{PT} , ALB to bb, INT to LNTH)
- Reduction of parameter numbers is highly desirable to reduce the overall complexity
- Fit of urine and chest counts bioassay
- Comparison to the post-mortem activity measurements



Individual Impact of Parameters on Liver and Lungs Activity



Individual Impact of Parameters on Liver and Lungs Activity



Shared Priors

- Latin hypercube sampling
- Sample size: 10,000

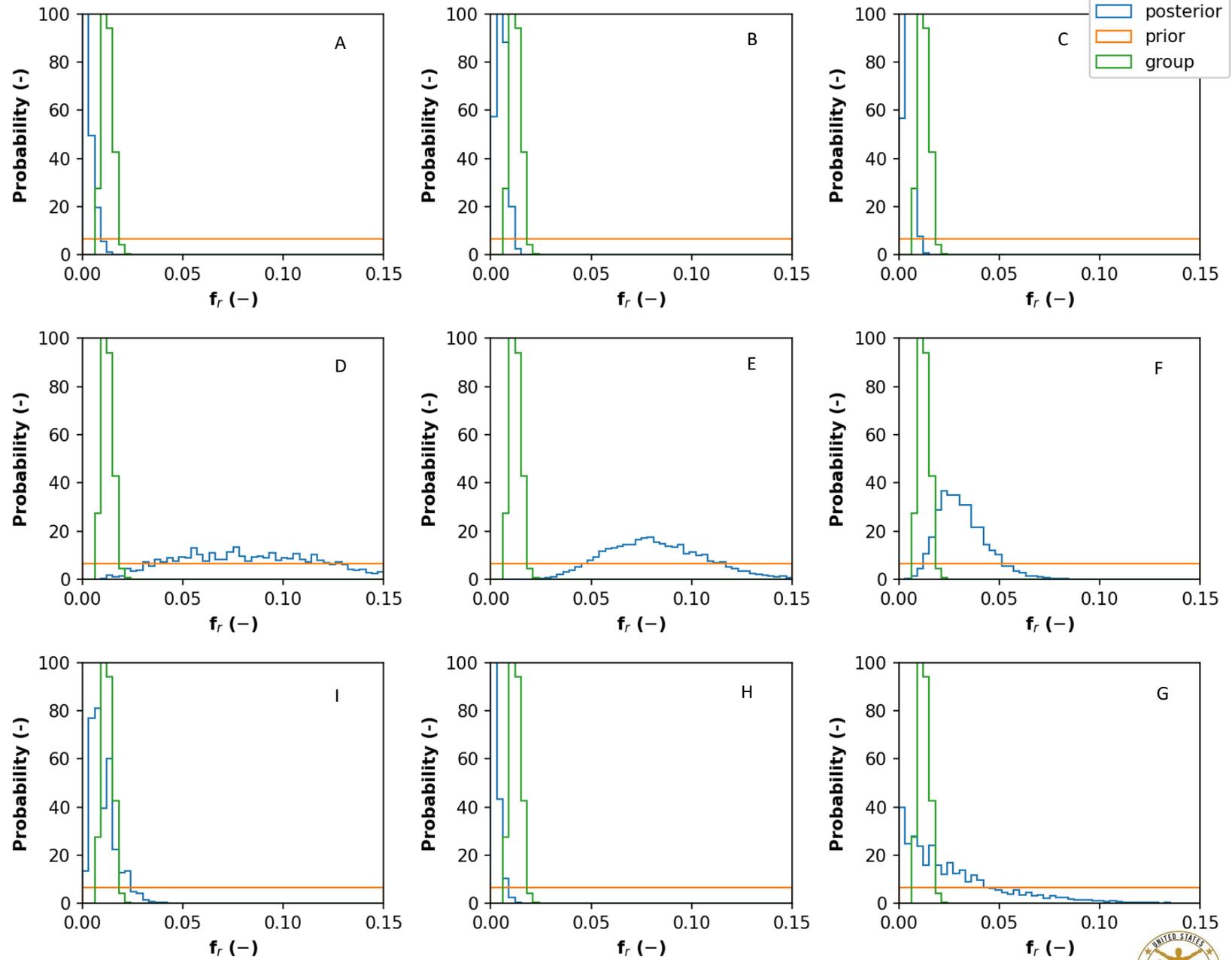
Parameter	Distribution
f_r – fraction dissolved rapidly	Uniform(min=0,max=0.15)
s_s – slow dissolution rate	Lognormal(median= 1×10^{-5} , GSD=2)
ALV to bb – particle transport rate	Lognormal(median=0.0027, GSD=2.5)
AI – deposition fraction	Lognormal(median=0.1066, GSD=2)



Results: f_r



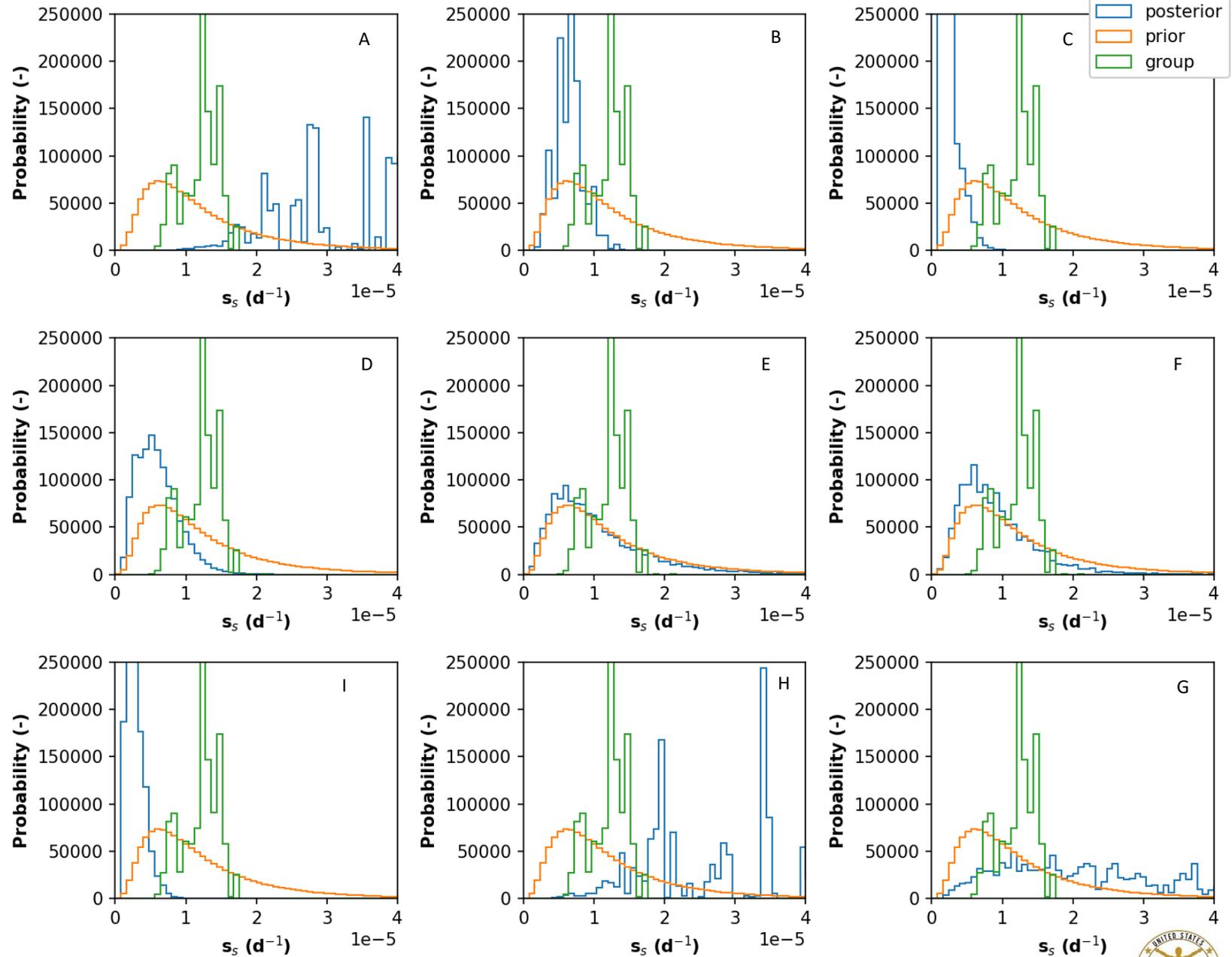
Fraction dissolved rapidly



Results: s_s

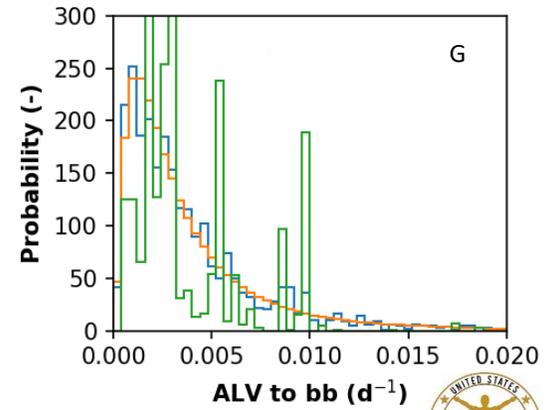
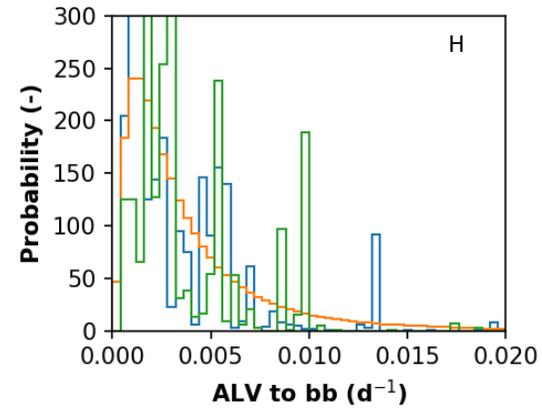
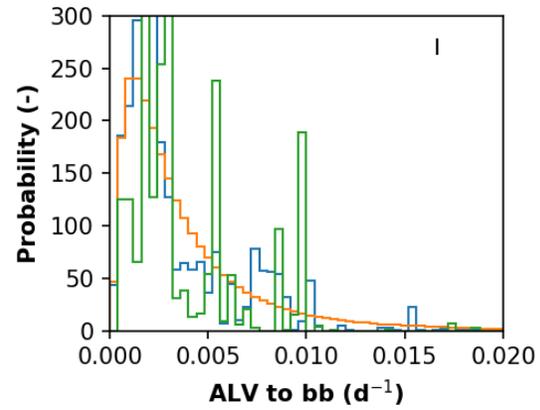
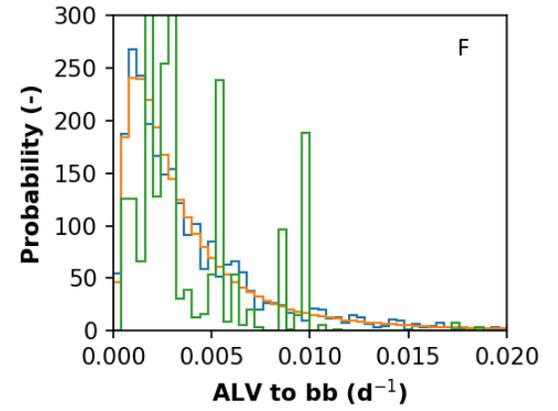
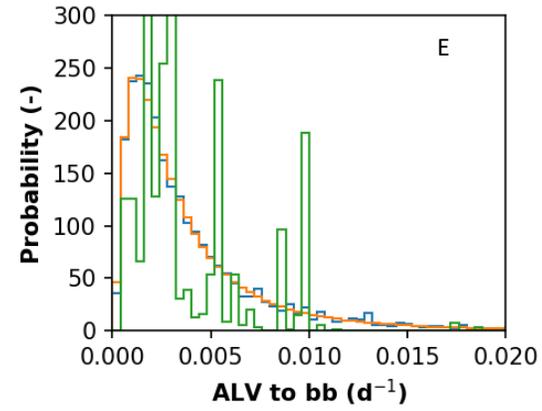
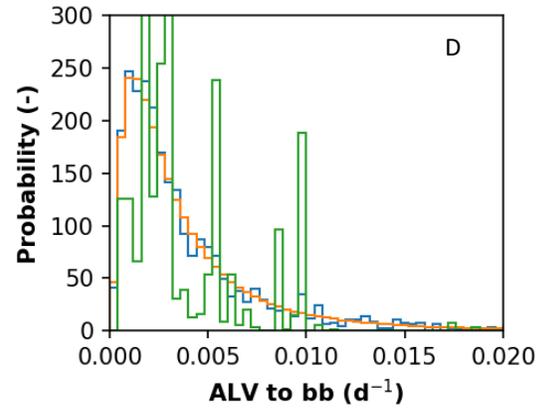
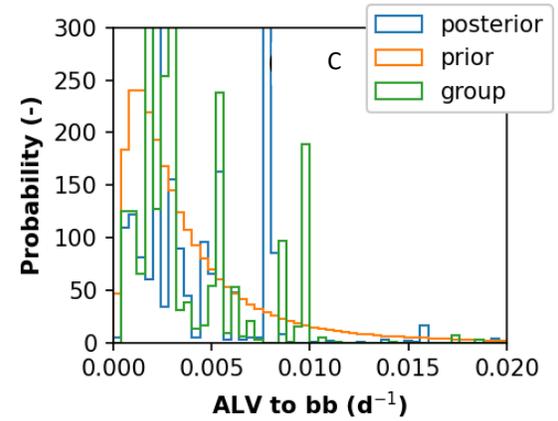
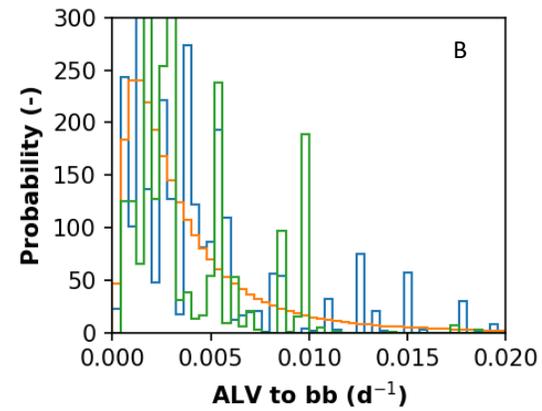
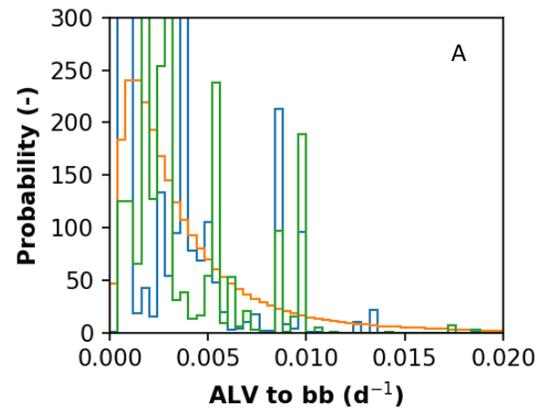


Slow dissolution rate



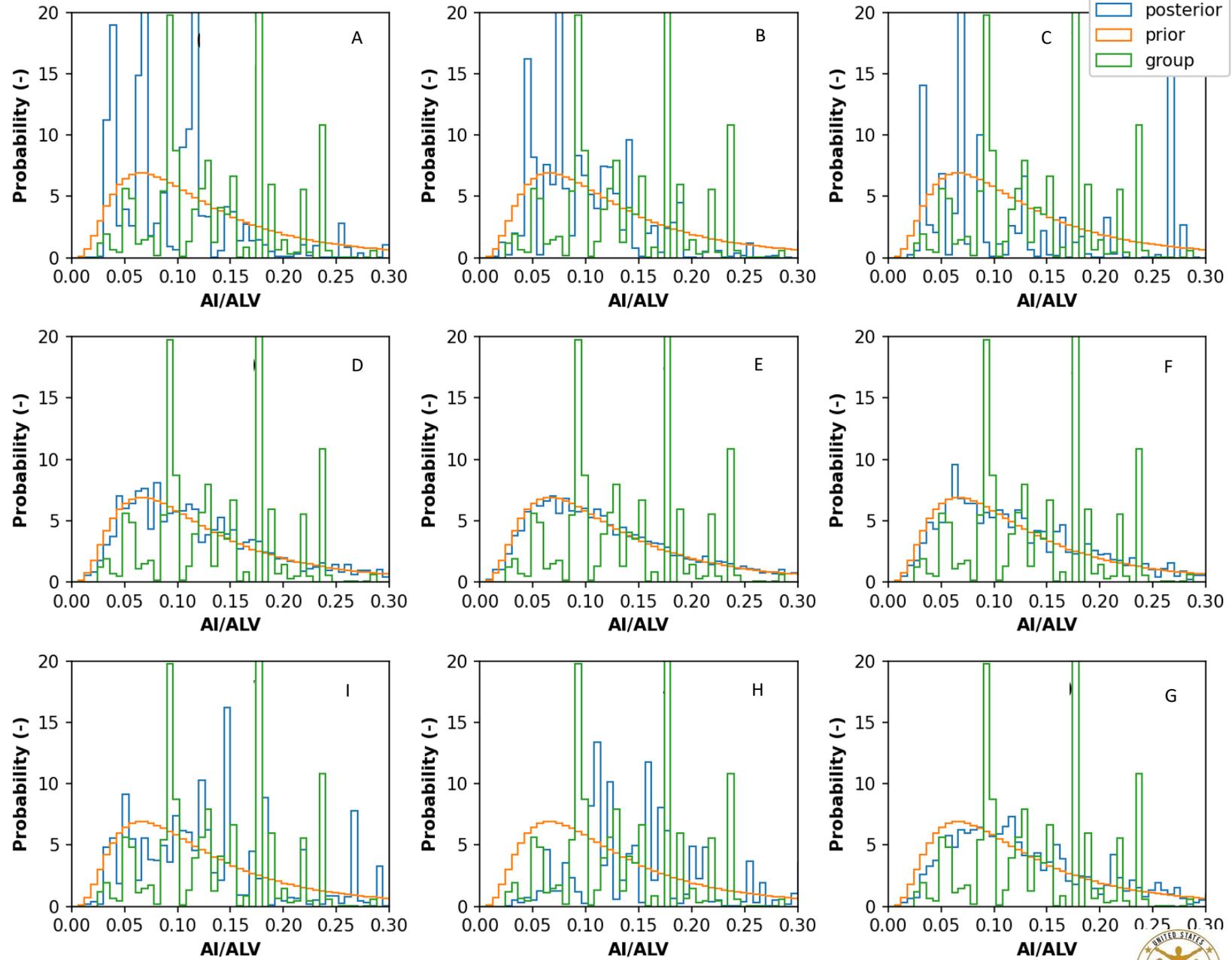
Results: ALV to bb

Particle transfer rate from alveoli to bronchioles

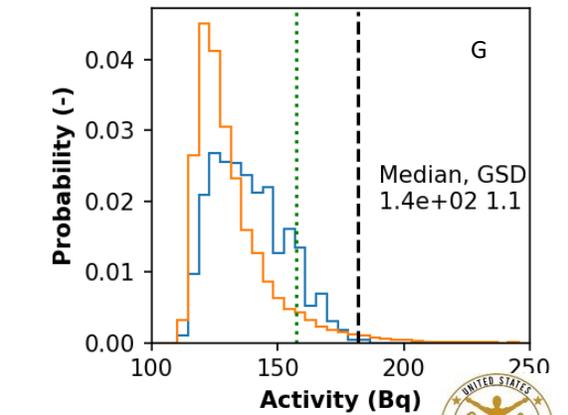
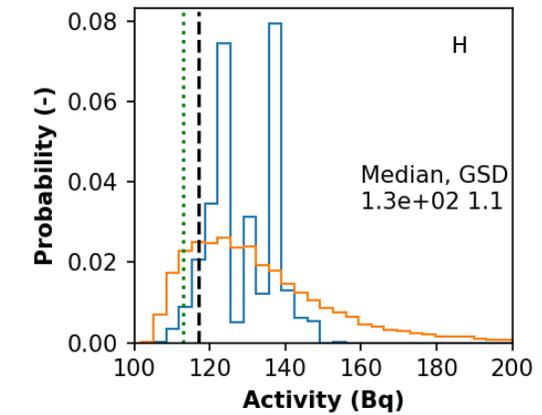
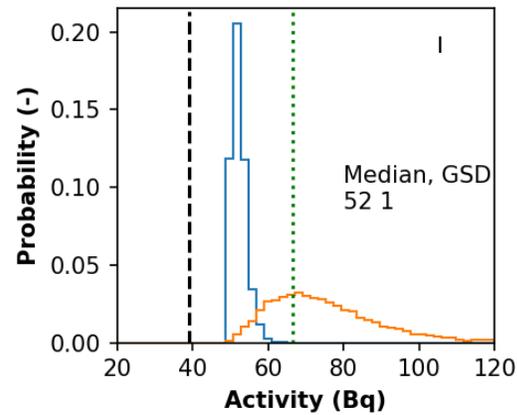
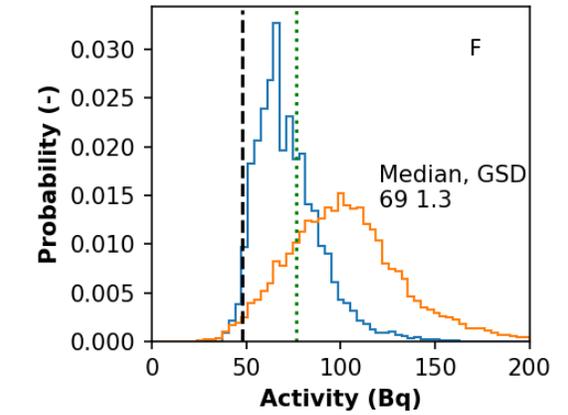
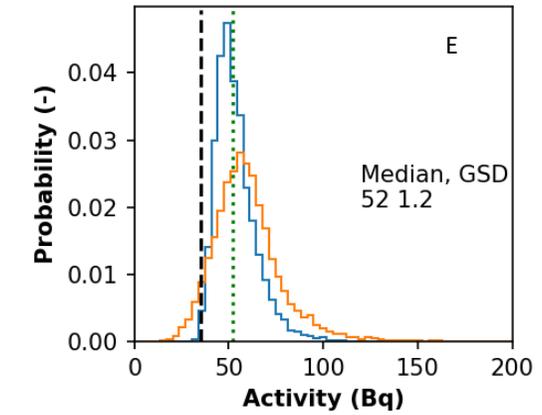
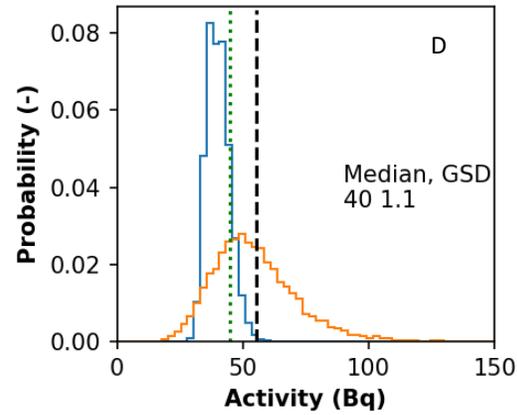
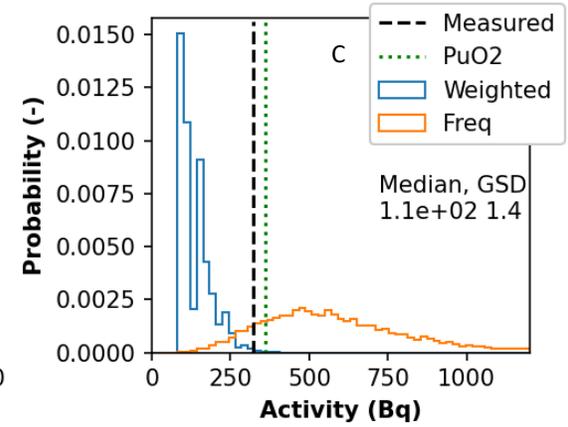
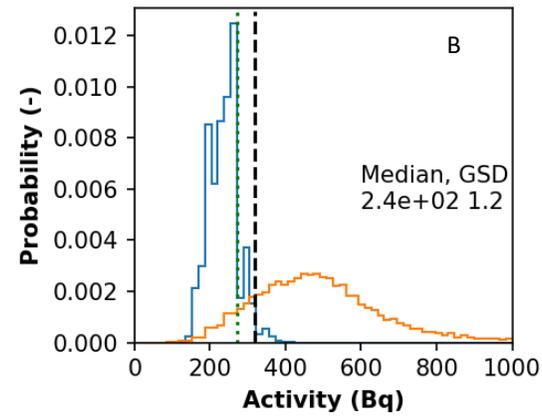
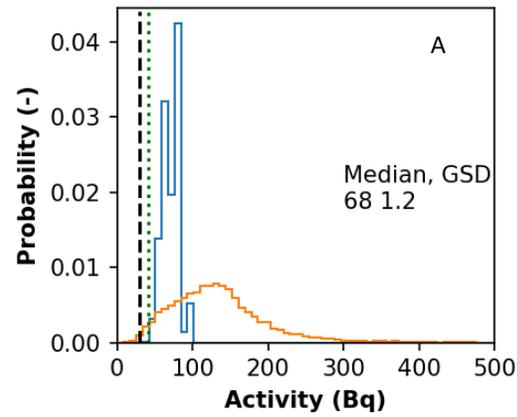


Results: AI fraction

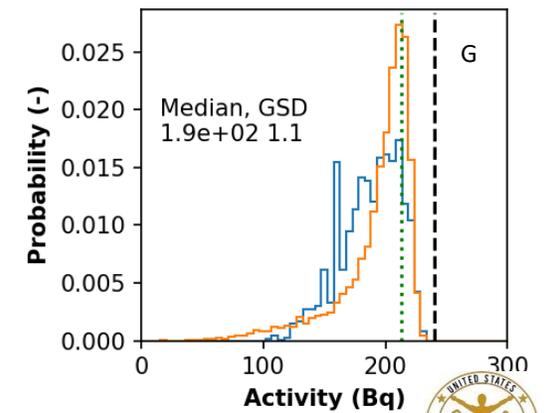
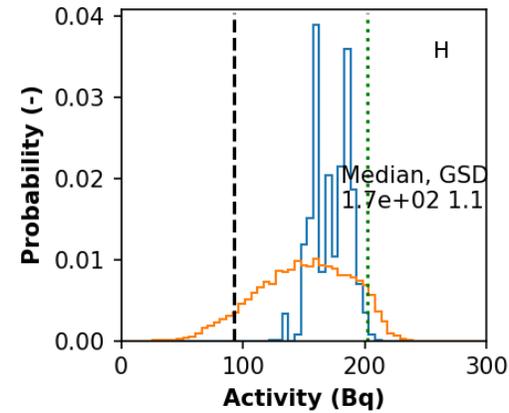
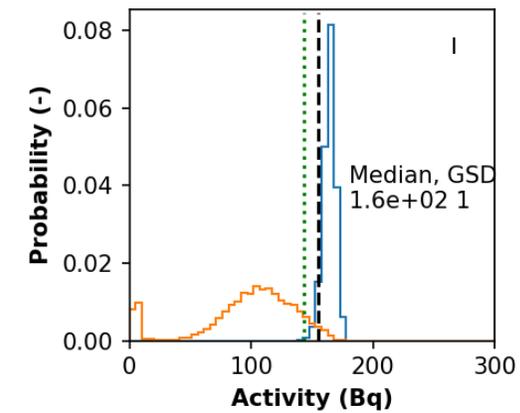
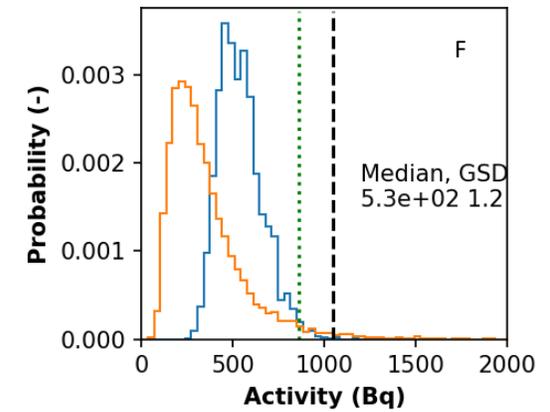
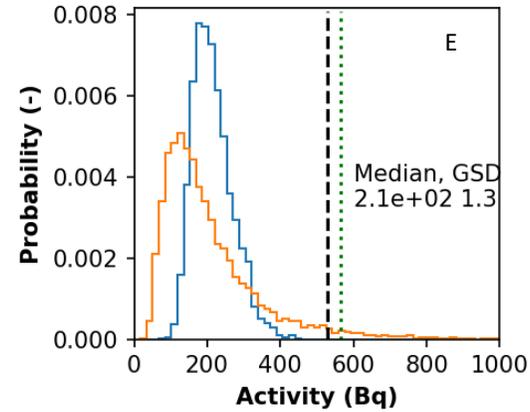
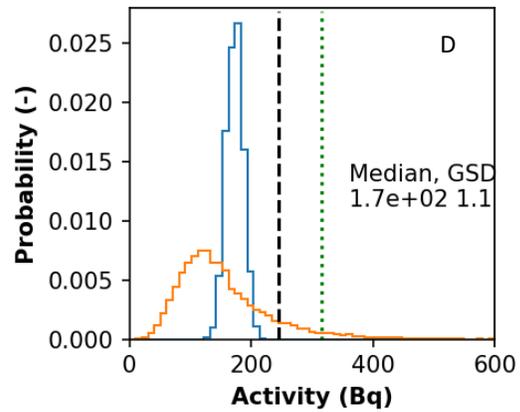
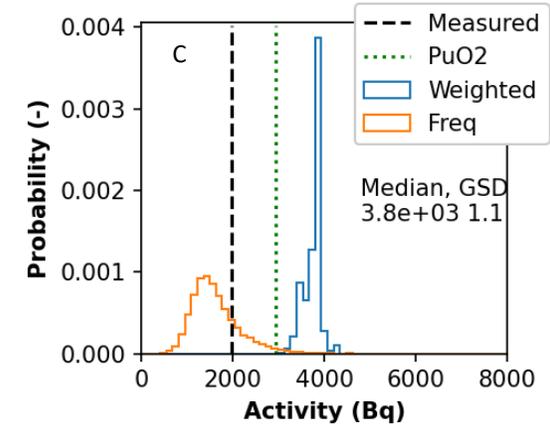
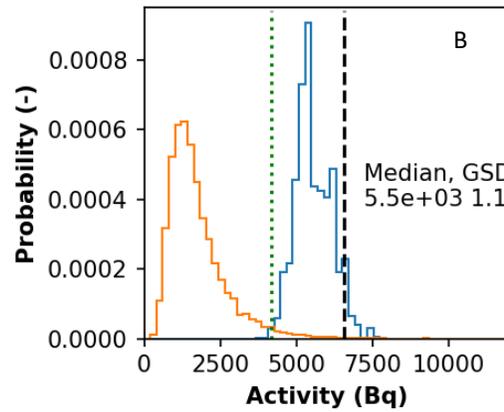
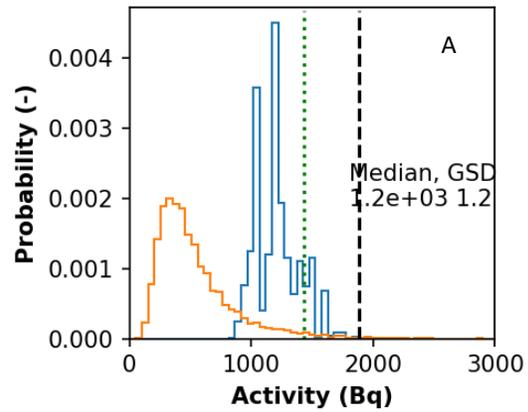
Fractional
deposition
parameter



Liver+ Skeleton



Lungs +LNTH



Summary

Case	Activity in Lungs (Bq)				Bias (%)		Activity in Liver+Skeleton (Bq)				Bias (%)	
	Median	Mean	GSD	Measured	Median	Mean	Median	Mean	GSD	Measured	Median	Mean
A	1193	1213	1.15	1887	-37%	-36%	67.9	70.8	1.13	30.2	125%	134%
B	5485	5578	1.11	6550	-16%	-15%	240.3	235.8	1.15	319.7	-25%	-26%
C	3816	3761	1.05	1957	95%	92%	109.9	134.3	1.27	320.3	-66%	-58%
D	173	173	1.08	244	-29%	-29%	39.8	40.3	1.09	55.3	-28%	-27%
E	208	216	1.28	528	-61%	-59%	51.7	53.7	1.24	35.0	48%	53%
F	531	543	1.24	1046	-49%	-48%	69.2	72.5	1.24	47.9	44%	51%
I	164	164	1.03	155	6%	6%	52.1	52.4	1.02	39.1	33%	34%
H	172	173	1.09	93	85%	85%	129.0	128.4	1.05	117.1	10%	10%
G	190	187	1.15	241	-21%	-22%	137.4	138.9	1.07	181.8	-24%	-24%
	Average absolute bias				44%	44%	Average absolute bias				45%	46%
	Average bias				-3%	-3%	Average bias				13%	16%

Conclusions

- Nine individuals involved in the same accident with 'high-fired' PuO₂ inhalation were modeled
- Priors may need to be case specific (especially f_r , and s_s)
- Posterior means for liver+skeleton and lungs+LNTH activity predictions differ from measured values by 45% and 46%, respectively
- Most of activity posterior distribution does not cover post-mortem measured organ activities
- Publishing the whole distribution should be preferred over just distribution parameters



Thank you for your attention

