Uncertainty in Internal Doses: Using Bayes to Transfer Information from One Worker to Another

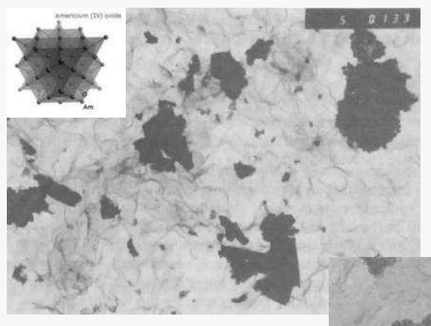
James, A.C.,[1] Birchall, A.[2] and Puncher, M.[2]

[1]United States Transuranium and Uranium Registries, 1854 Terminal Drive, Richland, WA 99354, USA

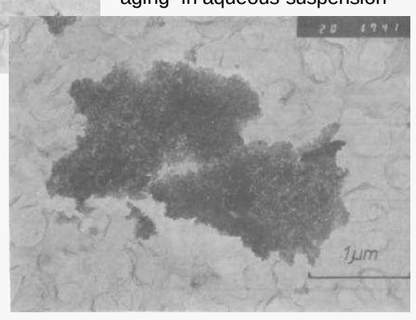
[2] Health Protection Agency-Radiation Protection Division, Chilton, Oxon OX11 0RQ, UK

1. Introduction

This study demonstrates how knowledge of the absorption behavior of a specific inhaled material (finely divided, crystalline $^{241}AmO_2$), based on comprehensive bioassay follow-up of one accidentally exposed individual, can be used to improve the reliability of dose estimates for other workers accidentally exposed to this material. The Weighted Likelihood Monte Carlo Sampling (WeLMoS) method[1] is applied here to derive posterior probability distributions of doses for a another worker whose time of intake is uncertain, and for whom relatively sparse bioassay data are available.



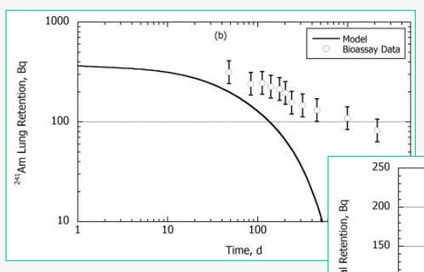
Electron micrograph of respirable $^{241}AmO_2$ (crystalline) particles[2]



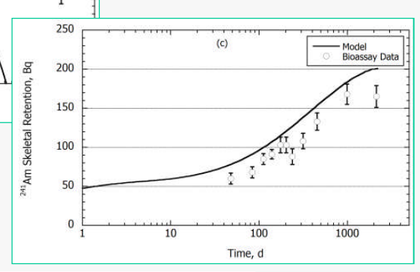
$^{241}AmO_2$ particles after 5-month "aging" in aqueous suspension

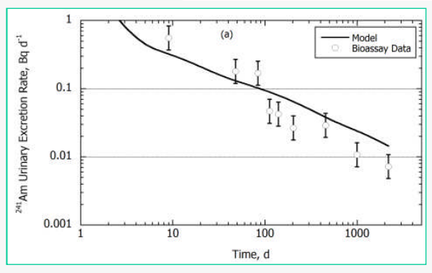
2. USTUR Case 0855

- Accidental, single acute inhalation—1996.
- Examining old 'sealed' $^{241}AmO_2$ powder source.
- Loose ^{241}Am contamination in work area (hotspots > 1 kBq/100 cm^2).
- Healthy, 38-y-old non-smoker.
- 6 weeks after intake volunteered for USTUR "Special Study"—long-term bioassay.
- 6-y follow-up published by Kathren et al.[3]
- Bioassay data re-analyzed here using IMBA Professional Plus (IPP).[4]



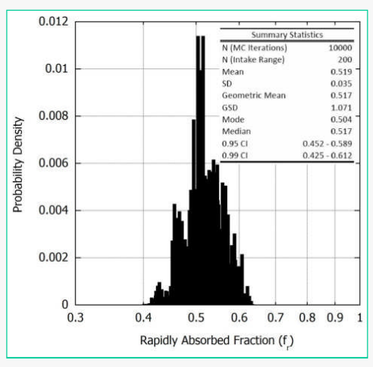
ICRP68 Type 'M':
χ^2 = 2,470; NDF = 30

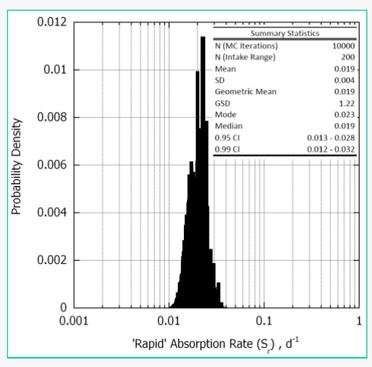


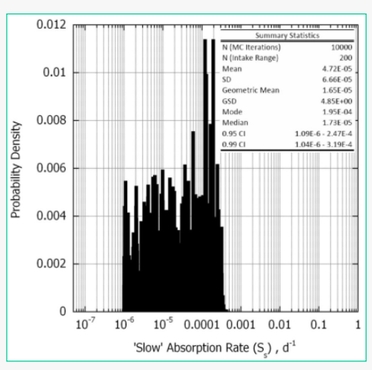


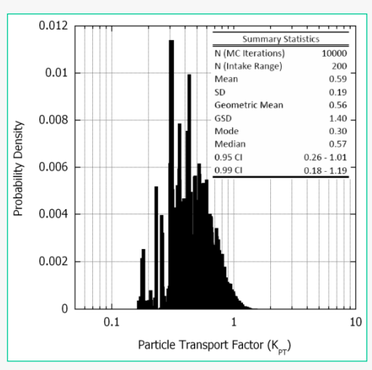
- **Does NOT behave like Type 'M' (or 'S') material.**

3. Bayesian Evaluation (WeLMoS)



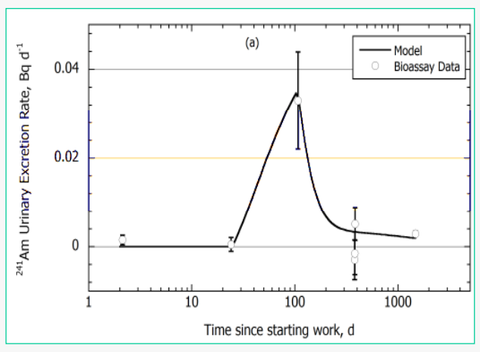


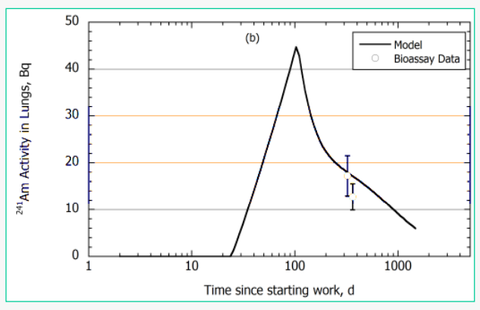




4. Clean-up Worker (Classical)

- Actual time-course of intake not known.
- Must be inferred from periodic (routine) urine samples.
- Earliest 'positive' urine collected at 106.5 d after start of employment.
- Previous 'negative' at 24 d.
- Assume constant chronic intake throughout this interval.[5]





Measured ^{241}Am activity as a function of time for clean-up worker, compared with values predicted for 'most likely' (modal) absorption parameter values from Case 0855 study.

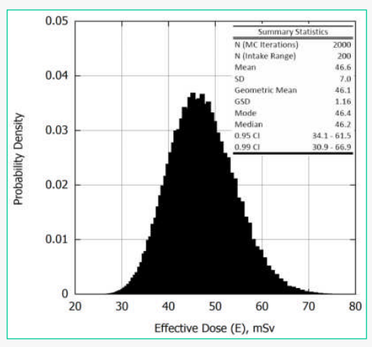
- **Assumed absorption parameter values:**
  f_r = 0.504
  s_s = 0.023 d^{-1}
  s_s = 1.95 × 10^{-4} d^{-1}.
- **Calculated χ^2 = 13.0; NDF = 8; P = 0.11.**
- **'Most likely' *point* estimates of intake/dose:**
  I = 1,229 Bq
  ***E* = 38 mSv**
  H_{BS} = 685 mSv
  H_{lungs} = 46 mSv.
- **What are uncertainties in these estimates?**

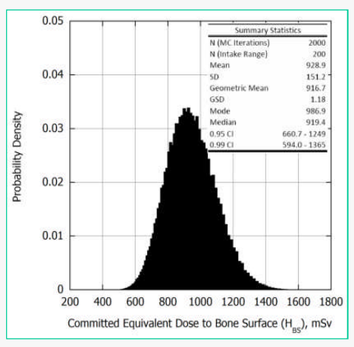
5. Clean-up Worker (Bayesian)

- First assume UN-INFORMATIVE priors for $^{241}AmO_2$ absorption parameters:

Parameter	Range	Distribution
Rapidly absorbed fraction, f_r	0 - 1	Lognormal
Rapid absorption rate, s_r (d^{-1})	0.01 - 100	Lognormal
Slow absorption rate, s_s (d^{-1})	1 × 10^{-7} – 0.01	Lognormal
Particle transport rate factor, K_{PT}	Median = 1, σ_g = 1.7	Lognormal

- With these resulting POSTERIOR PROBABILITY DISTRIBUTIONS of dose:





Note: The quantity, *E*, shown here is the ICRP (1994)[6] *tissue-weighted sum of committed equivalent doses, as* determined directly by the bioassay data (from 2,000 lung absorption/clearance model iterations). For each iteration, random values of the clearance rates were chosen from the un-informative priors shown above. However, ICRP (2007)[7] now *defines* effective dose (*E*) as having NO uncertainty. This assumes (purely for radiological protection purposes) that both the intake and the applicable dose conversion coefficient have no uncertainty.

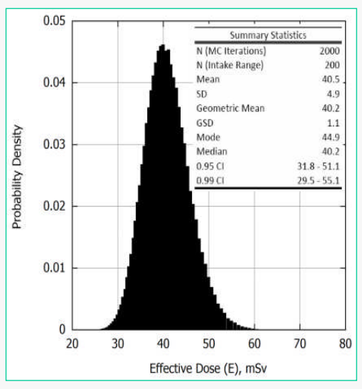
- Resulting mean estimates of dose:
  E = 47 mSv (95% credible interval 34 – 62 mSv)
  H_{BS} = 929 mSv (95% credible interval 661 – 1,249 mSv).
- These estimates were produced with NO explicit knowledge (assumption) of absorption rates from the lungs.

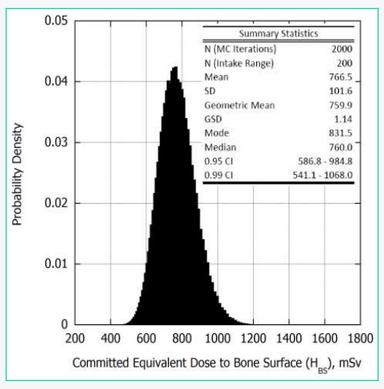
6. Using Informative Priors

- Now use posterior distributions of absorption rates for $^{241}AmO_2$ (determined for Case 0855) as INFORMATIVE priors for Bayesian analysis of the clean-up worker's bioassay data:

Parameter	Range	Distribution
Rapidly absorbed fraction, f_r	Med. = 0.517, σ_g = 1.07	Lognormal
Rapid absorption rate, s_r (d^{-1})	Med. = 0.0188, σ_g = 1.22	Lognormal
Slow absorption rate, s_s (d^{-1})	Med. =1.73 × 10^{-5}, σ_g = 4.85	Lognormal
Particle transport rate factor, K_{PT}	Med. = 1, σ_g = 1.7	Lognormal

- **Resulting posterior probability distributions of dose:**





7. Effect of Informative Priors

- Statistics of probability distributions of dose given by (a) un-informative and (b) informative prior knowledge of $^{241}AmO_2$ lung absorption parameters:

Statistic	Dose Distribution by Type of Absorption Prior			
	(a) Un-informative		(b) Informative	
	Effective (mSv)	Bone Surface (mSv)	Effective (mSv)	Bone Surface (mSv)
Mean	47	929	41	767
SD	7	151	5	102
Geometric Mean	46	917	40	760
GSD	1.16	1.18	1.10	1.14
Mode	**46**	**987**	**45**	**832**
Median	46	919	40	760
95% C.I.	34 – 62	661 – 1,249	32 – 51	587 – 985
99% C.I.	31 – 67	594 – 1,365	30 – 55	541 – 1,068

- The standard deviation (unrounded) of the probability distribution of effective dose is reduced from 7.0 mSv to 4.9 mSv (σ_g from 1.16 to 1.10).
- That for bone surface dose is reduced from 151 mSv to 102 mSv (σ_g from 1.18 to 1.14).
- The corresponding mean estimate of effective dose is reduced from 47 mSv to 41 mSv (median from 46 mSv to 40 mSv).
- The mean estimate of bone surface dose is reduced from 929 mSv to 767 mSv.
- The corresponding upper 97.5% credible value for effective dose is reduced from 62 mSv to 51 mSv, while that for bone surface dose is reduced from 1,249 mSv to 985 mSv.

8. Conclusion

- In this particular example (of an exposed clean-up worker), the quality of the bioassay data is sufficient to define reasonably accurately the posterior distributions of dose—even without any information on the absorption behavior of inhaled $^{241}AmO_2$.
- Thus, the reduction in uncertainty using specific information of absorption is not as great as it could be.
- In cases with less reliable bioassay data, the Bayesian method automatically places greater reliance on prior knowledge.
- In cases with no bioassay data, i.e., prospective dose assessments, absolute reliance must be placed on prior knowledge (or assumptions) about the applicable Human Respiratory Tract Model (HRTM) parameter values.

9. References

[1]Puncher, M., Birchall, A. A Monte Carlo method for calculating Bayesian uncertainties in internal dosimetry, Radiat. Prot. Dosim. (2008) 1-12 (doi:10.1093/rpd/ncn248).

[2]James, A.C., et al. Measurement of physical properties and retention in hamster lung of actinide oxides used in the manufacture of commercially available products, R & D Report 1976. National Radiological Protection Board, Harwell (1977) 31-44.

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[6]International Commission on Radiological Protection, Dose coefficients for intakes of radionuclides by workers, Publication 68, Ann. ICRP 24(4), Elsevier Science, Oxford and New York (1994).

[7]International Commission on Radiological Protection, Recommendations of the International Commission on Radiological Protection, Publication 103, Ann. ICRP 37(2-4), Elsevier Science, Oxford and New York (2007).

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