A Bayesian Method for Identifying Occupational Intakes for Uranium Workers

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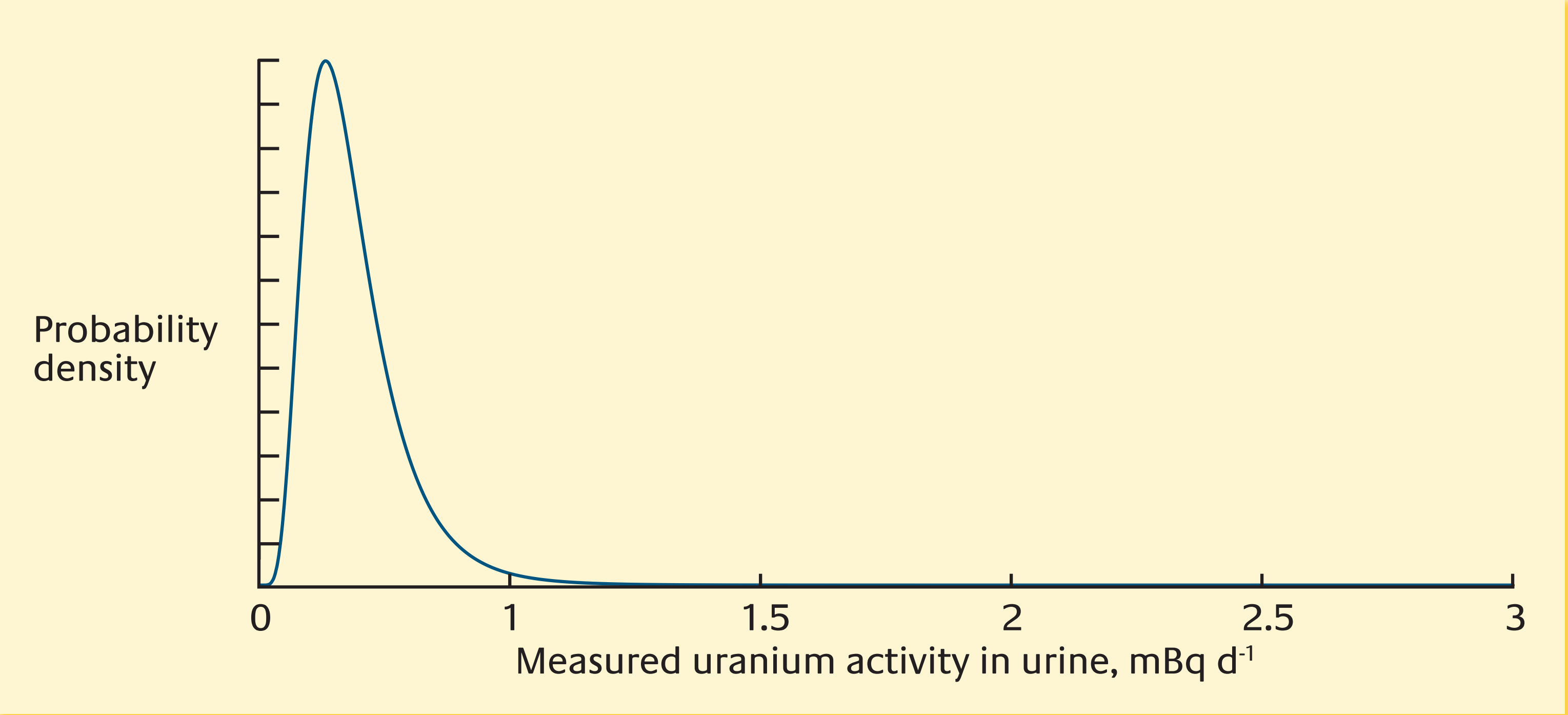
Introduction

Routine monitoring for intakes of uranium is complicated by the natural background of uranium in any bioassay sample taken. For example the figure below shows the background urinary uranium excretions for workers at AWE Aldermaston(1).



To determine if an occupational intake of uranium has occurred, a decision level for total uranium content in urine is set so that the number of false positive results due to background measurements is kept at an acceptable level. However, this approach does not take into account uncertainties in the intake or other biokinetic parameters; Bayesian methods provide one approach to addressing this problem.

Bayesian Methods

For a particular measurement of uranium in urine, there are two competing hypotheses that explain the data:

H_0 – environmental intake only
H_1 – environmental intake + occupational intake

The probability of either hypothesis H_k, given a measurement M, can be calculated using Bayes theorem(2)

$$P(H_k|M) = \frac{P(M|H_k) \times (P(H_k)}{P(M)}$$

where $P(H_k|M)$ should be read as the probability of H_k given M.

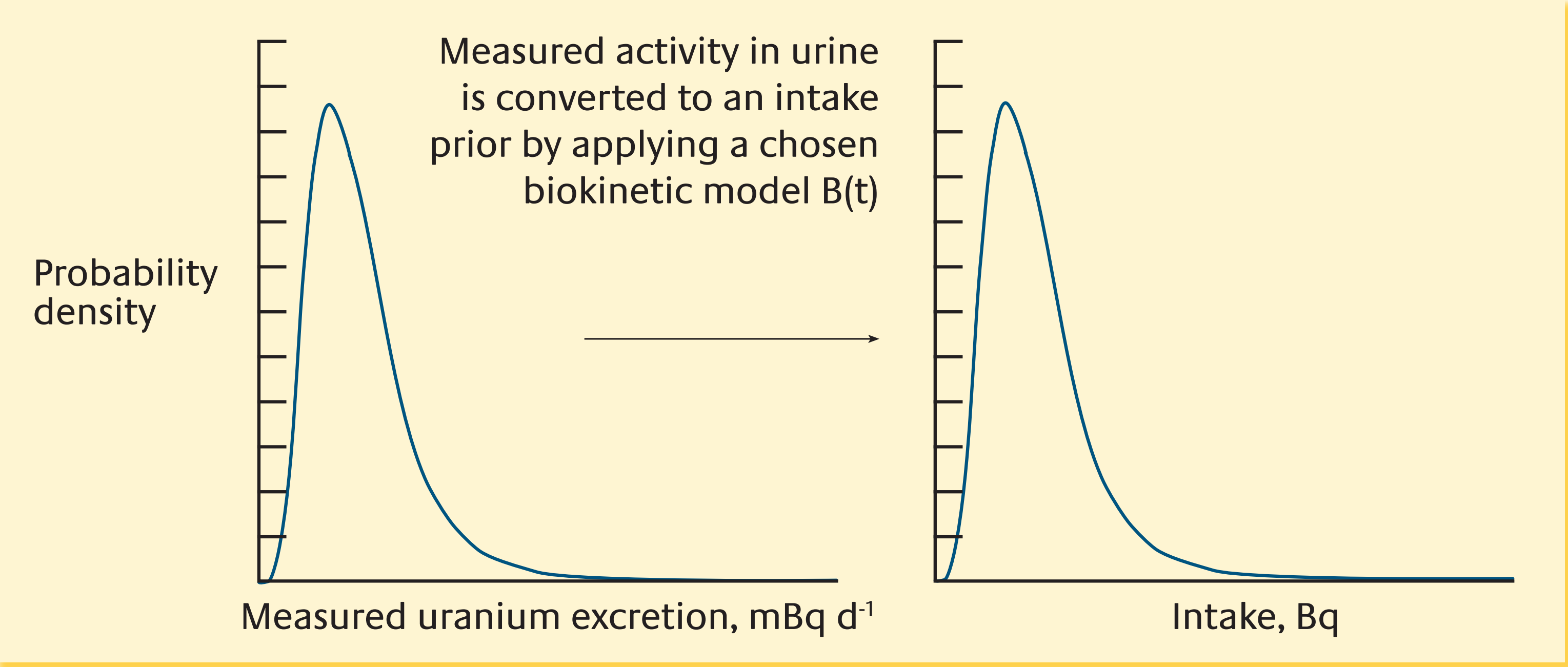
There are additional biokinetic parameters that link the intake of uranium to the measurement of uranium in urine. These are incorporated in the calculation of $P(M|H_k)$ as additional parameters (θ). A marginal distribution for $P(M|H_k)$ can be obtained by integrating out these parameters.

$$P(M|H_k) = \int P(M|\theta, H_k)(P(\theta)d\theta$$

Using this approach, the value for the measurement M can be found for which the occupational intake hypothesis is favoured over the environmental intake hypothesis. As a direct analytical solution is not available for the marginal distribution $P(M|H_k)$, the WELMOS(3) method is used to solve the integral.

Prior Distributions for Intakes

There are a number of parameters that contribute to the recorded bioassay measurement. Of particular interest is the intake parameter I. For uranium intakes there are potentially two components to the intake: an environmental intake I_{env} and an occupational intake I_{occ}. The prior distribution for the environmental intake can be derived from the background bioassay measurements.



In calculating $P(M|\theta, H_k)$ to obtain the marginal distribution $P(M|H_k)$, the intake is converted back to a measurement using the inverse of the function B(t). Therefore the calculation is independent of the choice of biokinetic model for environmental intakes. This removes a significant uncertainty in the hypothesis test.

Unlike environmental exposures, there is no equivalent data set that can be used to precisely derive a prior distribution for occupational intakes. For this study, the prior distribution for occupational intakes was represented by a broad lognormal distribution with a geometric standard deviation of 4 and a median value of 50 Bq y^{-1}. This prior was based on personal air sampler data.

The Effect of Lung Solubility

How quickly inhaled materials dissolve in the lungs determines the amount taken up to blood and subsequently excreted in urine. Insoluble materials therefore need to be inhaled in larger amounts than soluble materials to give comparable measurements of activity in urine. The assumed solubility of the material will therefore affect the outcome of a test based on urine bioassay.

The International Commission on Radiological Protection (ICRP) classifies the lung solubility of inhaled materials as Type F (fast rate of absorption to blood), Type M (medium rate of absorption to blood) or Type S (slow rate of absorption to blood). This study investigates the effect of assuming different ICRP solubility types along with specific values for uranium materials used in the nuclear industry, including values assumed at AWE.

Future analysis will consider the effects of uncertainties on these and other key parameters, by assigning them prior distributions.

Results

It was found that for materials assumed to be ICRP Type F and M compounds, and the other typical uranium compounds, the measurement required to give a positive result is fairly close to the classical decision level. This reflects the high lung solubility of these compounds.

For slow solubility, Type S material, the measurement required to give a positive result was notably higher. This is because the low lung solubility of Type S materials leads to only small increases in the uranium in urine content following an occupational intake. Therefore, very high (and improbable) intakes are required before the hypothesis test favours an occupational intake.

Uranium Material	Measurement, mBq d^{-1} Decision level (evidence of an intake)	
	Strong	Decisive
Clasical decision level		*2.5*
Type F	1.5	2.4
Type M	1.4	2.3
Uranium tri-butyl-phosphate	1.3	2.3
Default material type at AWE(1)	1.3	2.5
UO_2 (ceramic)	1.4	2.7
Type S	2.0	4.0

Conclusion

- The lung solubility of the inhaled material must be known to ensure the correct identification of occupational intakes.
- Soluble uranium: decisions levels are similar to the classical decision level; doses at these levels are low.
- Insoluble uranium: a significant intake is required before the increase in uranium in urine is sufficient to provide statistically valid evidence that an intake has occurred.

Future Work

- Investigate the effect of uncertainties on other biokinetic model parameters and how sensitive the test is to the choice of priors, particularly intake.
- Investigate approaches to derive a prior probability that an occupational intake has occurred, $P(H_k)$.
- Evaluate the method as a tool for Bayesian biokinetic model selection

References

(1) Nicholas T and Bingham D. (2011). Assessment of uranium exposure from total activity and ^{234}U:^{238}U activity ratios in urine, Radiation Protection Dosimetry 144(1 - 4).
(2) Kass RE and Rafferty AE. (1993). Bayes Factors and Model Uncertainty, University of Washington Department of Statistics Technical Report No. 254
(3) Puncher M and Birchall A. (2008). A Monte Carlo method for calculating Bayesian uncertainties in internal dosimetry, Radiation Protection Dosimetry 132(1)

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