

# THE STATISTICAL DISTRIBUTION OF ASSESSED ACTINIDE INTAKES

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## Abstract

Over 200 cases of actinide intake, occurring over the last 25 years, have been re-assessed. Cases were selected for which the intake date was known, there was both urine and faecal data and there was negligible interference from earlier intakes. The IMBA software was used to obtain a best fit to the data and establish an estimate of intake for each case. It is found that the magnitudes of the intakes are very well fitted by a lognormal distribution and that this fit extends over 4 orders-of-magnitude in intake. Therefore small intakes are much more likely than large ones. This fact is of significance in the assessment of routine monitoring results and in dose assessments for epidemiology. The distribution of intakes found here could be used as a prior distribution in a Bayesian analysis.

## INTRODUCTION

Since the introduction of the 1985 Ionising Radiation Regulations <sup>(1)</sup> hundreds of internal dose assessments have been performed for workers on the Harwell site. Full records of these assessments have been retained and so they provide a valuable resource for studying trends in intake and characteristics of internal hazards on the site. Recently about 200 of these cases were reviewed and a subset was selected from which information on lung absorption parameters was gathered <sup>(2)</sup>. In this paper the magnitudes of the total intakes are considered and their statistical distribution is evaluated. Attention is focussed on the higher actinides.

In the second part of the paper the application of these statistical distributions is discussed. They may prove to be useful as prior probability distributions in Bayesian approaches to intake assessment. This method is of particular value when the excretion data are sparse and the intake pattern is unknown. An informative prior distribution can help to constrain the posterior probability distribution of the intake.

## METHODS

Over 200 historical internal dose-assessment cases from the period 1986 to 2005 were examined. Those chosen for further study were selected using the following criteria:

- (1) The intake date should be well known. Such cases are usually triggered by high activities on air samples or by detection of contamination on or near the worker.
- (2) Both urine and faecal data should be available, even if the urine data show only limit-of-detection activity. In a few cases lung monitoring data were available.
- (3) There should be minimal interference from earlier intakes.
- (4) The most likely route of intake should be via inhalation. In fact inhalation is very much the dominant route of intake for our cases.
- (5) In this study only intakes of the higher actinides were included. The intakes were usually mixtures of <sup>238</sup>Pu, <sup>239/240</sup>Pu and <sup>241</sup>Am. A small number of cases had contributions from <sup>242</sup>Cm and <sup>244</sup>Cm and there are a very few intakes which include <sup>237</sup>Np and <sup>252</sup>Cf.

95 cases satisfied these criteria. Each case was analysed using the computer code IMBA <sup>(3)</sup>. This software allows estimates of intake to be made, once parameter values have been specified, via maximum likelihood fitting to the urine and faecal data. The optimum mixture of lung absorption types (F, M or S) needed to fit the data set was established and the intakes for each of these types were summed. A particle size (activity median aerodynamic diameter, or AMAD) of 5 microns was used in almost all cases. The activities of each nuclide were summed to give the total intake for the case. Only the alpha-emitting nuclides were included. Estimated intakes of <sup>241</sup>Pu, based on plant fingerprints, were not included in this study.

## RESULTS

Results are presented for the site as a whole, for a radiochemistry building (RC) and for a waste handling facility (WH). Results from other facilities are included in the overall site statistics, but are too few for individual facility distributions to be calculated. The total intakes ranged over more than four orders of magnitude, from 0.03 Bq to 755 Bq.

The collections of intake values were presented as input to the statistics package ProUCL version 4.0 <sup>(4)</sup>. This software uses the Lilliefors and Shapiro-Wilk test statistics to test for normality or lognormality of the data. All three datasets (whole-site, RC and WH) are found to be lognormally distributed. Normal statistics did not fit the data.

The three datasets are presented as quartile-quartile plots in Figures 1-3. A perfect lognormal distribution would correspond to the straight line on each graph.

Figure 1

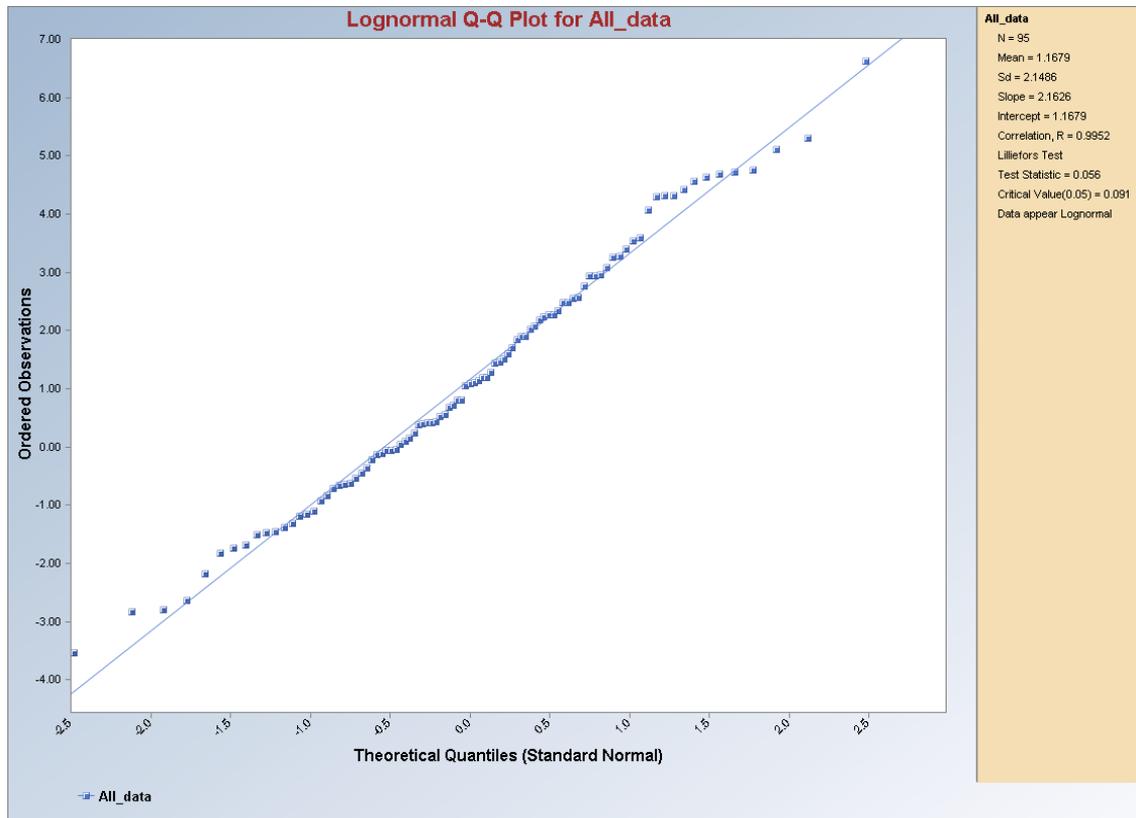


Figure 2

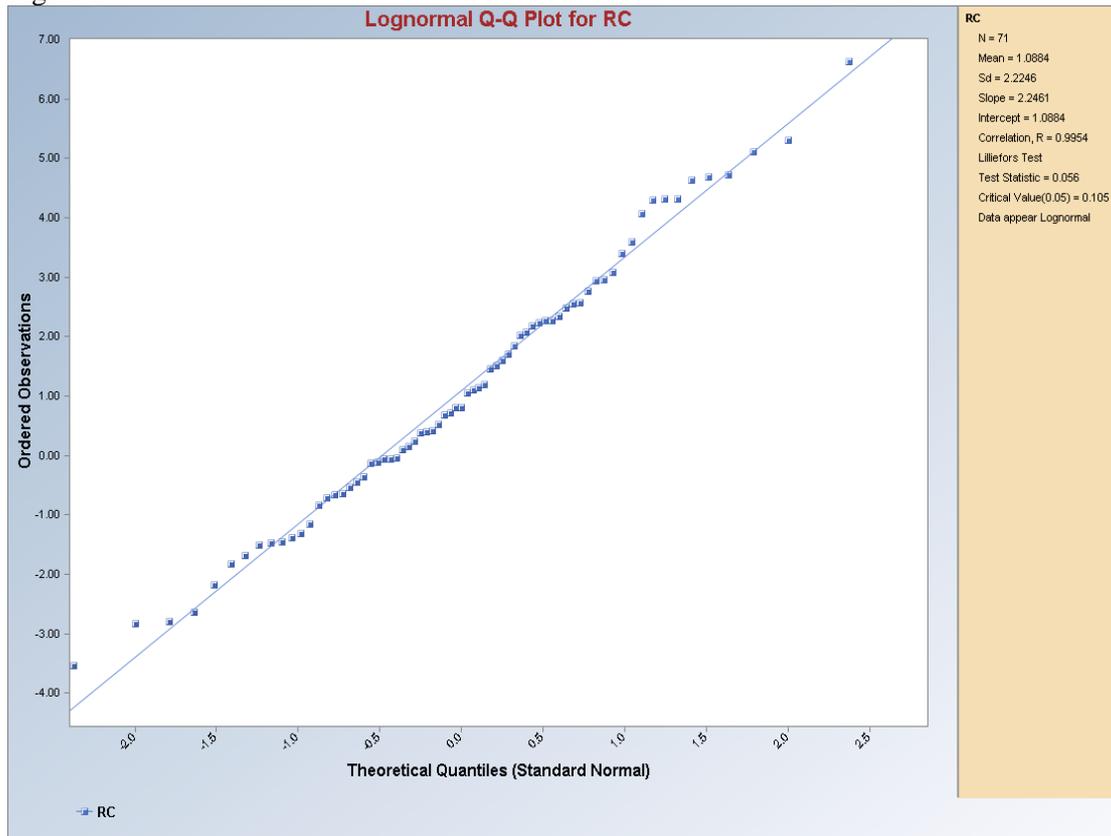
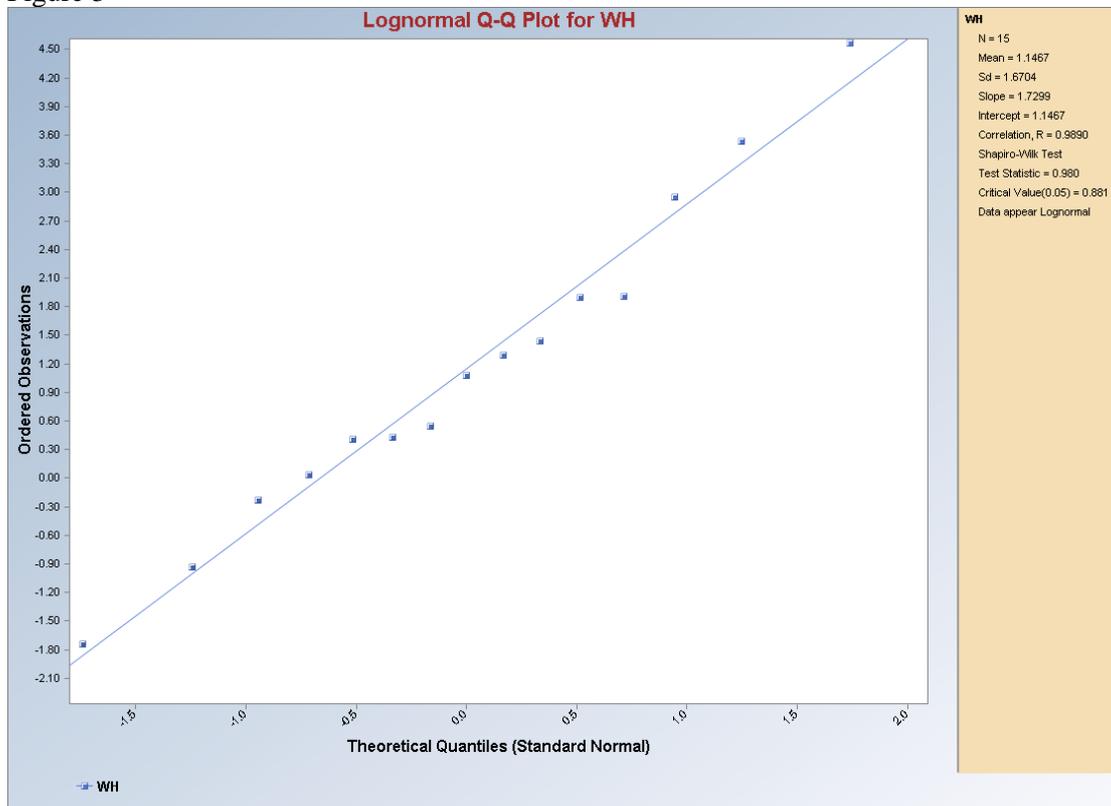


Figure 3



The striking feature of all of these plots is the high degree of fit to a lognormal distribution over intakes spanning 4 orders of magnitude.

The median values and geometric standard deviations for each dataset are given in Table 1.

**Table 1**  
**Median and geometric standard deviations**

Dataset	Median Bq	gsd
Whole-site	3.2	8.6
RC	3	9.2
WH	3.2	5.3

The median in each case is around 3 Bq. This means that 50% of the intakes are below about 3 Bq. The wide spread in intakes is reflected in the large values of the geometric standard deviation.

## APPLICATIONS

The Bayesian method has found increasing use in internal dosimetry <sup>(5, 6)</sup>. The probability  $P(I|m)dI$  that the intake lies between  $I$  and  $I+dI$ , given a set of measurements  $m$ , is given by:

$$P(I|m)dI=C.P(m|I)P(I)dI$$

In this equation  $C$  is a normalising constant.  $P(m|I)$  is the probability of dataset  $m$  being obtained given an intake  $I$  and is known as the likelihood function.  $P(I)dI$  is the probability that the intake lies between  $I$  and  $I+dI$  and is known as the prior distribution of  $I$ . It reflects our knowledge of likely intakes before any measurement has been made. If no such information is available it is common to use a distribution which is flat up to some limiting intake. This is sometimes called a non-informative prior.

The results presented above suggest that, for intakes on the Harwell site, a lognormal prior distribution would be appropriate. The use of an informative prior like this is particularly valuable when the data are sparse. In many dose reconstruction cases the only data available may be, perhaps, a few years' worth of urine data, mostly below the limit of detection. In the recent Alpha-Risk project <sup>(7)</sup> lifetime internal doses from intakes of alpha emitters were calculated as part of a case-control epidemiology study. Uncertainties in both the data and in model parameters were used in a Bayesian analysis to produce posterior probability distributions of intake and dose <sup>(8)</sup>. When non-informative priors were used with sparse datasets, the resulting distributions of intake and dose were found to extend over several orders of magnitude. The use of informative priors such as those derived here played an important role in producing much narrower probability distributions of intake and dose.

A Bayesian prior may also be of use in interpreting positive results from routine monitoring programs, where the date of the intake is unknown. The pessimistic assumption of an intake early in the monitoring period can lead to very high estimates of intake and dose. If an informative prior, peaking at smaller intakes, is used then these pessimistic intakes are assigned a much lower probability.

## CONCLUSIONS

Based upon an analysis of past internal dose assessments the statistical distribution of intakes on the Harwell site has been established. The data are well fitted by lognormal distributions, with median activities around 3 and geometric standard deviations from 5-9. This information will be useful in Bayesian analysis of intakes as applied to dose reconstruction projects.

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