SIMPLIFIED EXCRETION FUNCTIONS FOR RECENT RECYCLING BIOKINETIC MODELS

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Abstract

Recent trends in biokinetic model development have seen the replacement of a simple, schematic one-way transfer of materials between compartments with more realistic and complex linkages, including "recycling". In its Publications 67 and 69, ICRP proposes the use of such models for Am, Np, Pu, Ba, Ra, Sr, Pb, Fe, Th, U and I. These models have been developed primarily with a view to providing time-dependent organ retention data which may be used as the basis for calculations of effective dose. However, these new models may also be of value in predicting faecal and urinary excretion rates, particularly if models are adapted for non-standard subjects such as children. In this paper simplified functions for organ retention and instantaneous excretion rates are obtained from the above models, and the latter are compared with excretion functions given in ICRP Publication 54[1]. The potential for using future biokinetic models to predict urinary and faecal excretion rates is discussed.

1 Background

The physiologically-based biokinetic models recommended in recent ICRP Publications have the potential for becoming useful tools in bioassay assessments. In most cases, excretion data are fed into the models at a development stage, since such data are relatively abundant. Models therefore carry within them bioassay information obtained from experiment, in addition to physiological information embedded within their formulation. It is possible to adapt the models for non-standard subjects when good physiological data is available. For example, bioassay data is not generally available for children, but copious physiological data does exist, allowing biokinetic models to be adapted for children.

The biokinetic models of ICRP consist of compartments which represent tissue groups of interest, linked by first order kinetics. Calculating retention and excretion from the simple, Bateman[2] type models of ICRP Publication 30[3] is straightforward, as general analytical solutions may be obtained. For models of the type represented by the recent recycling models of ICRP Publications 67[4] and 69[5] however, general solutions are not available and alternative methods are used. In this paper, an exact, eigenvalue method is used, which obtains organ retention functions in the form of the sum of decaying exponentials. These expressions, typically containing as many terms as there are compartments in the models, are reduced to shorter, approximate expressions by a least squares function minimisation procedure[6].

Exact curves of urinary and faecal excretion are obtained from the models of ICRP Publications 67 and 69 for injection of unit quantities of Am, Np, Pu, Ba, Ra, Sr, Pb, I, Fe, Th and U. Simplified excretion function are published elsewhere[7].

2 Results and Discussion

The models may be placed in two main categories; generic actinides, including Am, Np, Pu and Th, and generic alkaline earths, including Ba, Ra, Sr, Pb and U. The models for the remaining elements are treated individually. Plots of the excretion curves show that the functions can depart markedly from those of ICRP Publication 54. These differences are discussed briefly for a few representative elements below.

2.1 Generic actinide models

Urinary excretion rates predicted by the biokinetic models of ICRP Publication 67 for plutonium and americium are on the whole higher than the rates given by ICRP Publication 54, with the difference being particularly marked at times remote from the intake (see figure 1) e.g. for plutonium the difference approaches an order of magnitude at 10,000 days. The Pu data of the earlier report was obtained from experiments with humans by Langham[8] and later animal experiments reported by Durbin[9]. Good recent human volunteer data has become available however[10], and this has been incorporated in the Publication 67 biokinetic model. The rates predicted by the model

are therefore closer to the recent data than those of Publication 54. Faecal excretion rates predicted by the biokinetic models are also characterised by higher rates at times remote from intake (approximately t > 10years), though they do dip noticeably below those of Publication 54 in the range 1 - 100 days. These data, too, are consistent with recent experiments with humans.

2.2 Alkaline Earth models

The elements for which the generic alkaline earth biokinetic model is applied (Sr, Ra, Ba, Pb and U) generally follow the biochemical pathways of calcium in the body. A good deal of human and animal excretion data are available for all of these elements and much of these have been incorporated in the formulation of the models. To take an example, the excretion curves given by the model for strontium are generally similar to those in ICRP Publication 54, but are on the whole smoother (see figure 2). Differences of up to a factor of 3 occur at particular times. Simplified excretion functions given for strontium are so close to the exact functions as to be indistinguishable on a plot.

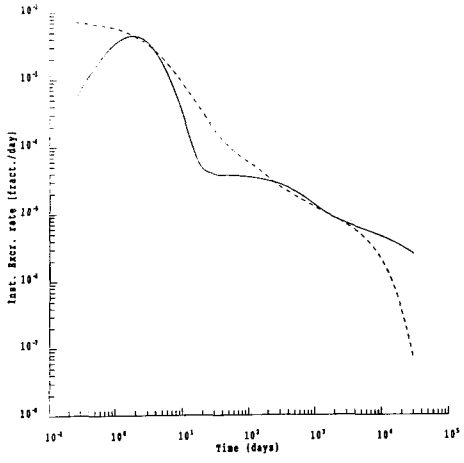

Figure 1 Faecal excretion rate of Pu: ICRP Publication 67 model (solid line) against Publication 54

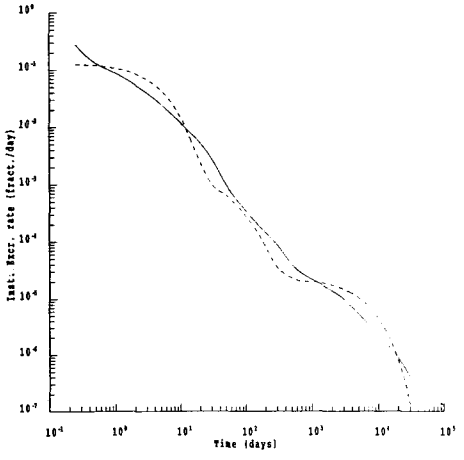

Figure 2 Urinary excretion rate of Sr: ICRP Publication 67 model (solid line) against Publication 54

3 Revised estimates of doses

Upon measuring levels of a radionuclide in urine or faeces at a particular time, a common procedure is to estimate the excretion rates and then use the function/curve for time dependent excretion rates to estimate the size of the original intake of the radionuclide. The latter is then used in conjunction with a dose coefficient to obtain an estimate of the effective dose likely to result from the intake.

From the viewpoint of a user of the excretion functions given in NRPB-M564[7] an important question would seem to be: "Where the new excretion rates differ substantially from the rates of Publication 54, will there also be a substantial differences in doses estimated from bioassay ?". Effective doses are calculated for an observed faecal excretion rate of 200 Bq/day 10 days after an intake of Pu-239 and a urinary excretion rate of 200 Bq/day 30 days after intake of Sr-90 using the excretion curves of both ICRP Publication 54 and the Publication 69 model. The results, given in table 1, demonstrate that the differences in the excretion rates predicted by Publications 54 and 67 are translated to differences in estimations of effective dose. As a general rule, effective dose varies with excretion rate.

Table 1 Effective doses for Pu-239 and Sr-90 following typical bioassay analysis

	Estimated intake Publication 54	Estimated intake Publication 67	Effective dose Publication 30	Effective dose Publication 67
Pu-239	2.22×10^5 Bq	1×10^6 Bq	1.22×10^2 Sv	4.93×10^2 Sv
Sr-90	2×10^5 Bq	6.67×10^4 Bq	17.6×10^{-3} Sv	5.85×10^{-3} Sv

Note that when this procedure for working back to doses is adopted it is necessary to use the appropriate dosimetric model for a particular excretion function. In the example given above, the urinary excretion rates for uranium given in ICRP Publication 54 were obtained from the biokinetic model presented in Publication 30. This same model should therefore be used to estimate the intake and effective dose.

4 Conclusions

Instantaneous excretion rates are obtained for the biokinetic recycling models of ICRP Publications 67 and 69 and are expressed as simple exponential functions. These rates are based on models which have in most cases been adjusted against recent human excretion information and can differ substantially from the rates given in ICRP Publication 54, which were largely obtained from the biokinetic models of Publication 30. It is expected that bioassay analyses utilising the new excretion rate functions will lead to estimations of effective dose which can be substantially different from those that would be obtained from the existing ICRP Publication 54 excretion rates. It is expected that in future more emphasis will be placed on the use of biokinetic models for predicting excretion rates.

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