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Energy Metabolism and Transfer of ^{3}H and ^{14}C in Mammals and Birds

Anca Melintescu[1], Dan Galeriu[1], Nicholas A. Beresford[2]

[1] *"Horia Hulubei" National Institute for Physics and Nuclear Engineering, Department of Environmental Physics and Life, 30 Reactorului St., POB MG-6, Bucharest-Magurele, RO-077125, Romania, ancameli@ifin.nipne.ro, melianca@yahoo.com*

[2] *NERC Centre for Ecology & Hydrology, Lancaster Environment Centre, Library Av. Bailrigg, Lancaster LA1 4AP, United Kingdom*

INTRODUCTION

Increasingly nuclear facilities and other sites releasing radionuclides have to demonstrate conservation of biodiversity. Among the radionuclides of interest, tritium (^{3}H) and radiocarbon (^{14}C) transfer in environment needs to be modelled differently than that of other radionuclides released from nuclear facilities because hydrogen and carbon are the main components of biological tissues and enter the life cycle.

The model previously developed for ^{3}H (in both forms tritiated water (HTO) and organically bound tritium (OBT)) and ^{14}C dynamic transfer in farm animals (Galeriu *et al*., 2009) has been extended for few types of wild animal (Galeriu *et al*., 2005; Melintescu and Galeriu, 2010; Galeriu and Melintescu, 2011). Using the limited information regarding organ specific metabolic rates (SpMR) for domestic animals, allometric relationships were established in relation to body mass and thereafter applied to wild species. The aim of the present study is the revising of the scientific basis of the previous model and the assessment of uncertainty of input parameters, in order to test the model for a larger range of mammals and birds. The present version of the model has the same compartments as the previous one (blood plasma, muscle, viscera, red blood cells, adipose tissue, and 'residual') excepting brain, which is considered separately in the present version. In the previous version brain was bulked in the viscera compartment together with liver, kidney, heart, stomach and the walls of gastro-intestinal tract (GIT). Part of the food energy is taken by animals and transformed for using in specific processes in order to minimize the entropy increase and defines the basal metabolic rate (BMR). The addition of brain as a specific compartment in our revised model acknowledges that brain significantly contributes to BMR for birds and mammals. The present study is based on a data base of wild mammals and birds (Navarrete *et al*., 2011; Daan *et al*., 1990) and is focused on the requirements regarding the input information for BMR, field metabolic rate (FMR), and organ mass for model application to a larger range of animals.

MATERIALS AND METHODS

The BMR of the whole body is a sum over all organs metabolic rates and consequently, the organ mass and organs SpMR must be known ($BMR = \sum_i OM_i * SpMR_i$, where OM is organ mass). These are well known for humans, but rarely for other species. In the present study, the first systematic approach for BMR in rat (*Ratus norvegicus*) is carried out, because there is a large data base for BMR and organ mass (Even *et al*., 2001) and information regarding the organs SpMR is available (Wang *et al*., 2001; Galeriu *et al*., 2005).

Data for adult Wistar, Zucker and Sprague-Dawley rats, as well as food-restricted Wistar rats were considered to test the "healthy adult" organ SpMR. For mammals, the data base for organs mass (Navarrete *et al*., 2011) did not provide the muscle mass, which was derived in the present study based on an extensive literature search. In the present study, we used organ SpMR provided elsewhere (Galeriu et al., 2005). The assessment of the best estimate for BMR was obtained taking into account the influence of taxonomic order and family, habitats and body temperature on BMR.

For animals in active state, the metabolic energy and its partition differ from the basal state with consequences on the dynamics of radionuclides. The present study discusses endotherm animals with constant mass for which information on the FMR and metabolisable energy intake (MEI) are needed. The energy partition in each model compartment is based on compartment contribution to basal metabolism, heat increment of feeding (HIF), need to keep the body temperature constant and need for locomotion. The brain and residual compartment have quite constant energy metabolism in active state comparable to that of the basal state. For the adipose tissue some data for domestic animals were found (Galeriu *et al*., 2005) and the contribution of brown adipose tissue can also be added where it is needed (e.g. small mammals in cold environments). The rest of energy is used by muscle for activity or shivering in cold conditions.

Biological half times (of ^{14}C, HTO, OBT or enhanced ^{13}C) can only be estimated in a dynamic situation when the activity in whole body or in an organ is measured at various times after a change in diet. In such situations, any organ (e.g. muscle or liver) is in interaction with other organs and has a complex behaviour. An organ has at least two types of cells: functional and structural with different half times. But also, as a part of the whole body, it is subjected to recycling together with other organs. Consequently, for example, carbon dynamics have two half times in a given organ. For rat, the ^{14}C (Galeriu *et al*., 2009) and ^{13}C data (MacAvoy *et al*., 2006) give similar turnover times for muscle and liver. . Carbon turnover measurements were available for rodents (*Mus Musculus*, *Peromyscus maniculatus*), gerbils (*Meriones unguienlatus)*, alpacas (*Lama pacos*), Japanese quail (*Coturnix japonica*) and zebra finch (*Taeniopygia guttata*). *Peromiscus maniculatus* has higher mass than *Mus Musculus* but shorter carbon half-time in muscle contrary to what may be expected.

RESULTS AND CONCLUSIONS

The calculated BMR for rat is compared with the experimental data (Even *et al*., 2001) (Fig. 1) and demonstrates a statistically significant relationship (BMR_{calc}= 6.77+0.951*BMR_{meas}) with an R^2 of 0.96; predictions were not significantly different from the observed data, one way ANOVA ($p>0.05$), $F = 0.025$.

In the model, muscle has a contribution of approximately 53% to BMR, while the viscera (liver, kidney, heart, GIT) contribute less (32%). There are differences between SpMR data used in the present study and those reported elsewhere (Even *et al*., 2001) but the calculated BMR values in both studies are close, pointing out the occurrence of the compensatory errors and the need to consider a large data base for species and mass range, in order to consider the SpMR values.

The normalised residuals ((P-O)/O, where P is predicted value and O is observed one) for wild mammals (Navarrete *et al*., 2011) (Fig. 2) must be carefully analysed: a) the data base used to derive the allometric relationships for organs SpMR do not contain wild species; b) basal metabolism is subjected to the hormonal control. Considering the previous

simplifications, the best BMR is reproduced with less than 30% in the normalised residuals. The cases with larger uncertainty (*Glaucomys volans, Neomys anomalus*, *Neomys fodiens* and *Sorex araneus*) can be also explained considering animal adaptation to its habitat. The adaptation to ecological and climatic niche can modify the organ mass and organ SpMR. The muscle SpMR (basal metabolism) is important within our model and improved data are needed.

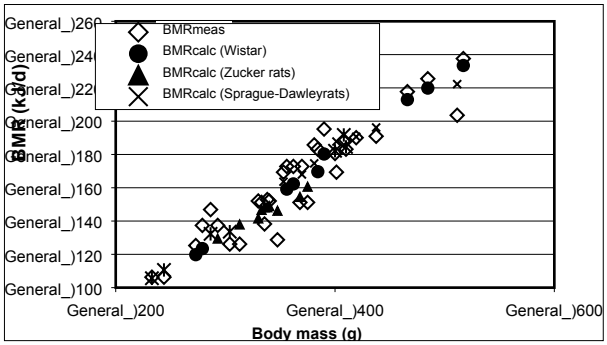

Figure 1. Comparison between measured (meas) and calculated (calc) BMR for Wistar, Zucker, Sprague-Dawley and food-restricted Wistar rats

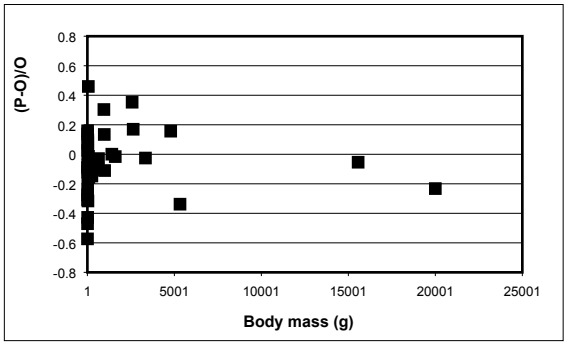

Figure 2. Normalised residuals ((P-O)/O) as function of body mass for wild species

No significant differences for calculated BMR of birds were observed between the revised model (present study), and the previous one (Galeriu and Melintescu, 2011) regarding predictions, but in both models, viscera use a large portion of energy from BMR. For birds, the model prediction for BMR has larger uncertainty than for mammals.

For animals in active state (where energy expenditure is given by FMR and not BMR), the energy partition to organs or group of organs (e.g. viscera) is obtained by addition of energy needs in basal state (BMR) and specific energy needs in active states (HIF and locomotion) and depends on the ratio between FMR and BMR. In most cases viscera metabolic rate is higher than that of muscle, higher metabolic rates for muscle are only estimated for animals eating good quality diets and having a high ratio between FMR and BMR. The revised model was applied to mouse (*Mus Musculus*) in order to assess the turnover rates for OBT in case of a continuous OBT intake of 1 Bq d^{-1} for 60 days (Fig. 3) and a single OBT intake of 1 Bq d^{-1} (Fig. 4). In Figs. 3 and 4, it is observed that the turnover rates in muscle and viscera are much shorter than the experimental ones for ^{13}C. The model application to ^{137}Cs (no transfer to adipose tissue) successfully reproduce the experimental data (about 5 days for the whole body). Any further development of the model and its potential adaptation to a specific site depends on the understanding of the sources of variability for basal (resting, standard) and sustained metabolic rates. The allometric mass relationship of metabolic rate (MR) ($MR=aMass^b$) is not a 'law' but a trend (Hulbert, 2014) and the scaling exponent "b" as well as the intercept "a" show a large variability especially due to the relative sizes of tissues and organs relevant for the measured activity (allometric models are proposed to represent qualitative trends over orders of magnitude of body mass (Higley and Bytwerk, 2007)).

For radionuclides emitting relatively short range radiations (such as alpha particles and low energy beta radiations) and for organisms above a certain size and complexity, doses to

radiosensitive tissues are likely to dictate the resultant radiation effect and consequently, a model based on organs is more appropriate than one based on the whole body as currently used in wildlife models.

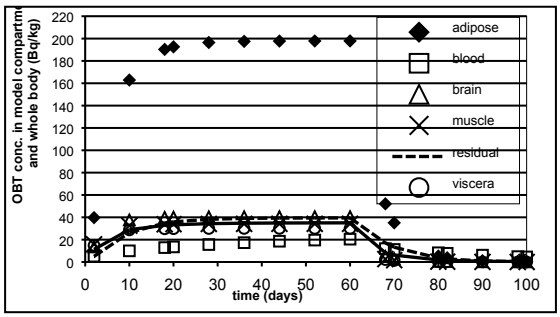

Figure 3. Predicted OBT concentration in model compartments and in whole body of rat (*Mus musculus*) for a continuous intake of 60 days

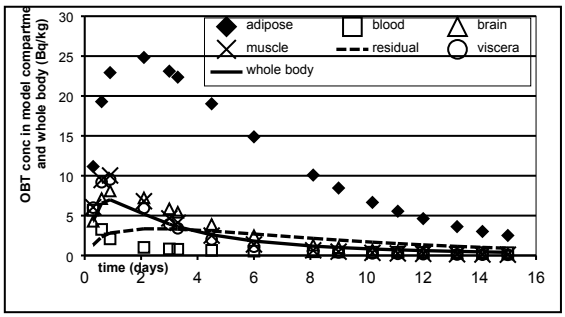

Figure 4. Predicted OBT concentration in model compartments and in whole body of rat (*Mus musculus*) after a single intake

Further efforts for model upgrades will be focused on the improving of the data base for organs SpMR of birds and the development of a strategy to assess the consequences of a hypothetical tritium accident for protected species around Cernavoda Nuclear Power Plant (NPP) (Romania).

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