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# ENERGY METABOLISM – AS A GENERAL PRINCIPLE – FOR MODELING THE TRANSFER OF CARBON AND TRITIUM ACROSS ANIMALS

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For the safe and clean future of nuclear energy robust models of environmental transfer of radionuclides are needed. Tritium and Carbon are life elements and must be treated separately from trace elements. We have analyzed available data and theories to test the hypothesis that both $^{3}H$ and $^{14}C$ metabolism in mammals can be accounted for by an understanding of energy metabolism. We started with a theory for how metabolic rate varies with body size and temperature, combining this with arguments from ontogenetic growth, energy consumption, zoogeographical and multilevel regulation effects on metabolism. Our hypothesis was that the loss rate of organically bound tritium and carbon from tissues can be assessed from the knowledge of specific metabolic rate and enthalpy of combustion of selected tissues. From organ mass and stable element composition, a generic model has been developed for mammals. Using a simplified milk production and a single metabolic rate for organs, the model can be applied generically across mammals with a minimum of input information. Tests of the model, without calibration, show a remarkable agreement with available experimental data. The model has been applied to humans, farm and wild animals, but it also have been exploratory used for birds.

## INTRODUCTION

Nowadays challenges are climate change, environmental protection and the future and control of energy resources needed for a sustainable development of human society. Nuclear energy must be preserved in the future, including the ongoing research on fusion reactors, as it is benign, widely applicable and essentially inexhaustible electricity, while simultaneously greenhouse gas emissions must be reduced. As for today heavy water reactors, tritium and radiocarbon are key radionuclide and enhanced safety is a prerequisite for any further commercial application. More robust safety assessment models are required and, as hydrogen and carbon, are life elements, appropriate approaches are needed. Previously, for the equilibrium transfer of $^{3}H$ in farm animals, we advanced a metabolic approach [1], including both forms, tritiated water (HTO) and organically bound tritium (OBT). This last form of tritium into the environment has longer retention time and is intimately linked with organic carbon. In recent years we used the metabolic approach for the dynamic transfer modeling on both radionuclides in mammals [2]. The present paper summarizes past results but gives also a first scientific background of our approach and an extension to birds.

## ENERGY METABOLISM AND ORGANIC MATTER TURNOVER RATE

After a review of past results in modeling C&T transfer in mammals, we concluded that a common approach to all mammals is needed and this must be based on energy need and on the relation between energy and matter. In atomic and quantum physics, the link between energy and matter is well established and energy and matter turnover rate are the same. Extension to life science seems fortuitous at a first glance. We will argue in the following that this can be considered at least as a useful working hypothesis. Metabolism refers to the countless chemical processes going on continuously inside the body that allow life and normal functioning. These processes require energy from food. Consider the mammal demand for net energy in order to assure its normal life. It includes basal metabolism, thermal regulation, activity and production. The minimal net demand for mass stasis must be assured for surviving. This is the maintenance net energy demand. For mature, non gestating-lactating mammals the Field Metabolic Rate include maintenance, activity and thermoregulation. The important fact is that we are dealing with NET ENERGY DEMAND. We don't discuss the (gross) energy supply and absorption and transformation in net energy. These are fully dependent on the mammal taxon, environment supply and adaptation. For example a ruminant is using low quality food (with a large fraction of carbohydrates) but it was developed its gastrointestinal tract (GIT) in order to prepare this food with microbial help and long rumen digestion. A carnivore is using high quality food (mostly fat and protein) and consequently its GIT is adapted. For both ruminant and carnivore the NET energy demand is similar while the energy supply differs. In case of shortage in energy input, the mammal will consume its own body energy resources in order to satisfy the energy demand for maintenance. The energy content of the whole body or any organ can be assessed from the composition (lipid, protein, carbohydrates) and the combustion energy of average lipid (39.6 MJ/kg), an average protein (23.7 MJ/kg) and glycogen (as standard carbohydrate) 17.7 MJ/kg. It is now naturally to consider the *energy turnover rate* as given by the *Relative Metabolic Rate ReMR:*

$$\mathrm{Re}MR = \frac{FMR}{EBW * BED} = \frac{SMR}{BED} \qquad [1]$$

with ReMR the relative metabolic loss rate ($d^{-1}$) ; FMR the field metabolic rate (MJ/d); SMR the specific metabolic rate (MJ/khfw/d) ; EBW *Empty* body mass (kg) and BED body energy density (MJ/kgfw)

A recent review [3] (Rolfe and Brown 1997) has estimated that, of the oxygen consumption associated with the basal metabolic rate, at least 70% is consumed for mitochondrial ATP production used for protein synthesis, $Na^+$,$K^+$-ATPase and $Ca^{2+}$-ATPase activity, gluconeogenesis etc. In all above processes Carbon and Hydrogen are parts of molecules involved in various chemical reactions. Their radioactive isotopes will follows closely (disregarding the isotope effect in the reaction velocity). Outside the basal metabolism, the normal life of a mammal needs activity energy- this implies and enhanced ATP turnover – and consequently an enhanced turnover of C14 and OBT. Due to above facts we are now advancing the *working hypothesis that ReMR can be used also for the assessment of the loss rate of C14 and OBT* and, for simplicity, the proportionality factor is taken to be one. Indeed, Brown et all [4] in "Metabolic Theory of Ecology" analyzes energy flux and biomass production while in a revision of ontogenetic growth, Makarieva et all [5] uses our equation [1] for basal metabolism and notes that the inverse "gives the mean residence time of chemical elements in the living body". This is exactly our hypothesis and is supporting our approach.

The Metabolic theory [4] explains the ¾ power exponent in the mass dependence of basal metabolic rate as given by the fractal structure of network of blood vessels and that metabolic rates are supply limited. The theory, while very attractive, does not satisfy from some point of views [6]. An alternative theory, "the allometric cascading" [7] reveals that basal metabolic rates (BMR) are driven by rates of energy expenditure within internal organs and that the allometric scaling of BMR can be understood in terms of the scaling of the masses and specific metabolic rates of internal organs, which depend on many competing and cooperating processes. Indeed, BMR of ruminants, rat, [8] or humans [9] can be reconstructed from organs' metabolism. There are much experimental evidence that alteration of the level of nutrition (food restriction and realimentation) alter both basal metabolism and visceral mass [10] and this supports the role of organs mass and specific metabolic rate in animal adaptation in order to satisfy the requirements of life. Same mammal specie, when living in various environments or adapting to different diet show alteration in basal metabolism and visceral mass. Portal drained viscera and liver (central organs) have high specific metabolic rate while their share in the body mass is low (6-10 %). Contrary, peripheral organs as muscle and adipose tissue have low specific metabolic rate but share a much larger proportion on body mass. In evolutionary biology there is a debate on the role of central or peripheral organs [11] and recent findings support equilibrium between them, i.e. the capacity of central organs to supply energy has evolved to supply expenditure capacity to peripheral organs, with same safe margin at maximal metabolic rate.

If organ mass and specific metabolic rate have a direct influence of mammal metabolism it is fully justified to consider that *the turnover rate of OBT and OBC in mammal organs is given by the turnover rate of organ metabolic rate* - so we expand our initial working hypothesis from whole body to each organ. To further justify this, in connection to agree mass dependence of basal metabolic rate, we use the (in vitro) mass dependence of organ specific rate [11,12] across mammals and note that with a knowledge of organ mass across mammals and specific metabolic rate, the well known Kleiber's relation can be reconstructed [13].

We advanced above a qualitative background for a novel approach in modeling the dynamics of tritium and radiocarbon in mammals but we must recognize that our approach suffers in respect of detailed knowledge of organ specific metabolic rate across mammals of various species and ages. Non invasive, in vivo, measurements are difficult to be obtained and the basic understanding is still limited while recent findings indicate that mitochondrial membrane processes and composition are relevant [14].

## MODELING THE DYNAMIC OF $^{3}H$ AND $^{14}C$ IN MAMMALS.

With our hypothesis on biomass turnover rate, we must establish now the minimum number of model compartments. We must explicitly consider muscle, as edible, and adipose tissue, as an energy storage body part. It is well known that some organs have high metabolic activity and implicitly high transfer rate of our radionuclides. We consider explicitly a "viscera" compartment for active metabolic organs, including heart. Blood (plasma and red blood cells) is the vector of metabolites transport in the body and a good bioassay media. The remainder of the empty body is mixed in a model compartment in order to assure a mass balance.

Organic contaminants enter the body through the stomach content, but are mostly absorbed from the small intestine. We introduced a simplified transfer through GIT content, in order to reproduce the delays between intake and absorption in the empty body.

Transfers from above empty body compartments to blood plasma are given by ReMR's and transfers from blood plasma to model compartments are assessed using stable radionuclide mass balance. While organic excretion in urine and milk are produced by specialised organs (kidney, mammary glands), we simply consider a direct transfer from blood plasma with a transfer rate obtained by stable radionuclide balance (blood plasma content or organic carbon or bound hydrogen and daily production of organics in urine and milk). From the direct intake of dry matter in the stomach, only the metabolisable fraction (diet and animal dependent) is transferred to blood plasma, the rest is excreted to large intestine and faeces. From this metabolisable fraction only a part is transformed in net input of energy and matter (limited maintenance and production efficiency). The rest is lost through respiration (C-14) or passed to body water (tritium). The respiration process is quite complex and produced in all organs. We oversimplify all by considering a single respiration rate from blood plasma which we can asses by mass balance of stable nuclide (org. C or OBH) and knowledge of dietary intake. The above description is the skeleton of the model, directly used in the case of C-14. For tritium we must consider the exchangeable and nonexchangeable phases. The body and organ content of OBH is taken into account now. We first add a body water compartment to account for tritium (hydrogen) in the body water and for the exchangeable organic tritium (hydrogen). While experimental data and actual metabolic understanding distinguishing between a fast and a moderate equilibration of exchangeable organic tritium with the tritiated water, we simplify again using only a fast equilibration. Consequently, the exchangeable fraction in the metabolisable diet input is directly transferred to the body water compartment. From hydrogen metabolism we know that a fraction (0.25-0.35) of OBH in the body is derived from the free (exchangeable) hydrogen, at equilibrium. Adopting a value in this range and using a mass balance for equilibrium situation, we can define a transfer rate from "body water" compartment to "blood plasma" in order to produce organically bound H (T) from the free one. From the water compartment there is also a loss rate and we can assess it by a knowledge of the intake of hydrogen in drink, food and respiration water. A full detailed technical description of the model is given elsewhere [15] as well as model limitations (e.g. ignoring the fast and slow component of organ specific metabolic rate). For laboratory and some farm animals, all model input are taken from literature on animal metabolism, nutrition and body composition and the model is "blind' tested with experiments on $^{3}H$ and $^{14}C$ transfer – without any calibration. The most complete data base is for laboratory rat, for which experiments with continuous food intake with labelled diet (organic $^{3}H$ and $^{14}C$, and HTO) have been analysed as well as experiment with unique intake of labelled compounds which were used to reconstruct intakes of labelled rat food. Comparing direct or reconstructed experimental data with model predictions (see table 1), we observe a reasonable agreement, in absence of "best' input data or calibration.

Table 1. Average and standard deviation (in parentheses) of predicted to observed ratios in rat viscera, muscle, blood, adipose tissue and whole body (except bone and skin) for the 6 intake forms

| Organ | $^{14}C$ chronic | $^{14}C$ acute | OBT chronic | OBT acute | HTO chronic | HTO acute |
|---|---|---|---|---|---|---|
| Viscera | 1.12 (0.15) | 0.51(0.4) | 1.06(0.15) | 0.67(0.56) | 0.43(0.07) | 0.87(0.34) |
| Muscle | 1.25(0.14) | 0.81(0.29) | 1.23(0.21) | 0.90(0.37) | 0.40(0.09) | 1.02(0.38 |
| Adipose | 1.11(0.15) | 0.61(0.12) | 0.97(0.2) | 0.75(0.13) | 0.3(0.1) | 1.33(0.3) |
| Blood | 1.12(0.27) | 0.4(0.1) | 0.88(0.12) | 0.38(0.03) | 0.37(0.09) | 0.62(0.18) |
| Whole-body | 1.18(0.08) | 0.7(0.1) | 1.08(0.11) | 0.8(0.1) | 0.36(0.08) | 1.09(0.18) |

Model tests (no calibration) include dynamics in cow milk under HTO or OBT intake, as well as slaughter data in meat of pig, sheep and cow after unique intake of HTO, OBT or OBC. In all cases the model gives reasonably predictions, within a factor 2 [15]. The exception is the sheep data after unique intake of labelled glucose and acetate. Here the model gives reasonably prediction for $^{14}C$ but under predicts by a factor 3-4 in the case of $^{3}H$ labelled food. This is explained by the specific of ruminant digestion of various compounds in the diet and our model limitation considering all diet components uniformly labelled. Of special interest are the predictions of $^{3}H$ in bioassay media (urine, blood) after various intakes as they can be used for dosimetry. Model results are close with data on OBT in blood after HTO intake but for a unique OBT intake the model mispredict in the first days. This reflects the simplified model assumption of a single, effective, metabolic rate and not details on fast and slow components.
As a conclusion of the model tests with available experimental data, our hypothesis on the link between energy and organic matter turnover rate is fully supported but inherent simplifications of the model limits the model robustness at a factor of two. For radiological assessment of food chain or biota radioprotection this is not a practical limit but for other applications more research is needed.

## APPLICATION FOR HUMAN TRITIUM DOSIMETRY

Concerns of increased risk from tritium intakes by humans have been claimed recently (www.Cerrie.org). Relative to dose coefficients recommended by the International Committee for Radiation Protection (ICRP), increases up to a factor 15 for HTO intake were argued and much more for OBT intake due to increased retention of OBT, role of hydration shell around biomolecule and high relative radiobiological efficiency. A full description of our contribution to the topics is given elsewhere [16,17] but here we summarize the model application for humans and will not include all the implication for tritium dosimetry. Humans generally differs from most other mammals due to their slow maturation, large brains consuming much of daily energy needs, and consumption of high quality diets [18]. We considered Caucasian and Japanese humans with model input parameters for body mass, organ mass, basal and active metabolic rate, food and waterintake taken from recent literature [9,18-21]. Reference humans are considered for child's of 1, 5, 10 years, male and female of 15 years and male and female adults. Before any model application we tested if the basal (resting) metabolic rate can be explained by the contribution of organs and associated specific metabolic rate.

In all cases the model prediction are very close with observed or recommended values. For assessment of tritium retention in human body a probabilistic approach has been taken, as natural variability of some parameters or incomplete knowledge of others must be considered when uncertainty are analyzed. For example, diet composition varies across human habits and influences the organic hydrogen intake as well as the metabolisable fraction of the diet. Digestion influences the non-exchangeable OBT transferred to systemic circuits in a complex manner and only a range can be assessed. Distributed parameters considered in the model are given elsewhere [17].
In radiation protection we are interested in the integrated activity in the body, up to 50 years after intake and this implies to include growth for child. Based on the body and organ growth pattern in the reference values [19] we added a growth sub-model in order to have the correct dynamic in child until full elimination of radionuclide from the body. Model outputs include integrated tritium activity or concentration in body water or organic model compartments, which are the basic input in dose assessment.

For adult male after an OBT intake, we illustrate the model results in table 3 for the 5, 50 and 95 percentile of probability distribution. At 50 % of the probabilistic distribution we predict an integrated concentration from OBT of 39.6 with the major contribution from adipose tissue. In the simplified model of ICRP the integrated activity of HTO is 7.25 while for OBT is 28.9, less than our prediction. The enhanced retention in our model results from the better consideration of human metabolism and physiology but is essential to observe that the largest contribution to OBT retention is from adipose tissue, with a low sensitivity to radiation health effects. To consider this, when the radionuclide is not uniformly distributed in body tissue, we must use a tissue radiation factor,$W_T$, in order to assess the effective dose for the health effect at the level of whole body. Using agreed value for each organ and our model compartment composition we have assessed each model compartment "tissue" weighting factor (column 6 in table 2 ) and the contribution to the effective dose (weighted integrated concentration- column 7 in table 2)

Table 2 Integrated activity and concentration and weighted values for adult male (OBT intake)

| | Integrated activity Bq*d | | | Total T int. conc. | $W_T$ | Weighted int. conc. |
|---|---|---|---|---|---|---|
| | Percentile | | | Bq/kgfw | | |
| Compartment | 5 | 50 | 95 | | | |
| HTO | 6.5 | 12.6 | 20.7 | | | |
| OBT | 36.9 | 39.6 | 42.5 | | | |
| OBT_adipose | 22.2 | 23.8 | 25.5 | 1.6496 | 0.008 | 0.013197 |
| OBT_muscle | 7 | 7.5 | 8.1 | 0.4954 | 0.008 | 0.003963 |
| OBT_viscera | 1 | 1.1 | 1.15 | 0.4867 | 0.45 | 0.219047 |
| OBT_remainder | 5.7 | 6.1 | 6.5 | 0.4877 | 0.42 | 0.204837 |
| OBT_RBC | 0.8 | 0.85 | 0.91 | 0.8406 | 0.12 | 0.100876 |

Comparing with ICRP dose coefficients for OBT intake, our model predicts higher values if we ignore the non-uniform tritium distribution in the body (equivalent dose H) but close values when tissue weighting factors are included (effective dose E), as seen in table 3 for the case with unit radiobiological efficiency as considered by ICRP. Our model predict a significant gender difference as well as a probabilistic distribution of dose coefficient but the close agreement between ICRP values and our central (50 %) prediction for the effective dose merits further considerations.

Table 3. Equivalent (H) and effective (E) dose for reference humans after OBT intake

| | ICRP | H | | | E | | |
|---|---|---|---|---|---|---|---|
| Case | | 5% | 50% | 95% | 5% | 50% | 95% |
| 1 y | 12 | 14.3 | 16 | 18 | 10.5 | 12.2 | 14.2 |
| 10 y | 5.7 | 8.3 | 9.5 | 10.9 | 4.8 | 6 | 7.5 |
| Adm | 4.2 | 4.2 | 5 | 5.8 | 3.2 | 3.8 | 4.7 |
| Ad-f | 4.2 | 9.1 | 10.2 | 11.5 | 4.7 | 5.7 | 7.1 |

There are no experimental data on humans after an OBT intake but concentration of OBT in urine after an acute HTO intake were observed in the past and our model give predictions very close with experimental data. Further development for human dosimetry of tritium and radiocarbon are ongoing.

DYNAMICS IN WILD MAMMALS

In the past it was considered that protecting humans from the effect of radiation suffices but actually biota radioprotection is considered as a major task for a durable development and environmental protection. The protection of biota from ionising radiation needs reliable predictions of radionuclide dynamics in wild animals. Data for many wild animals – radionuclide combinations is lacking and a number of approaches including allometry have been proposed to address this issue. We have contributed to the European effort in this field by applying our model to selected wild mammals [22]. In contrast to laboratory of housed farm animals, wild mammals and birds are subjected to large environmental and dietary variability to which they must adapt. There are many studies demonstrating allometric (mass dependent) relations for basal metabolic rate, daily energy expenditure and organ mass [24,25]. A gap in the database for wild animals is the assessment of SMR for organs, in basal and active states. There are some measured values for laboratory and farm animals and humans, in basal or resting metabolism. We have derived allometric relationships on the basis of the available data for application to wild animals (Table 1 in [22]). Due to paucity of the available database we could expect some potential errors when using our crude allometry of specific metabolic rates of organs. For the few examples of wild animals where we have organ mass and BMR our predicted BMR values (Table 2 in [22]) are sometimes close to observed values but there are cases of 50 % discrepancies. This demonstrates that our knowledge on specific metabolic rate of organs across mammals is limited and body mass is not the only determinant factor in metabolism.

Our mammal list includes a large herbivore (reindeer), a carnivore (red fox), a small herbivore (rabbit or hare), and two rodents (chipmunk and a lemming). These are mostly in the list of representative mammals in current proposed assessment frameworks. The lemming is modelled as being in the Arctic with enhanced energy needs. Input model parameters are collected from literature and a unique intake of 1 Bq of OBT or $^{14}C$ is considered in assessing integrated activity in animal body (see Table 3 and 4 in [22]).

To compare the risks from exposure to $^{14}C$ and $^{3}H$, across mammals of various mass and diets, we have normalised the integrated whole body activity to body mass of each species and an activity concentration of 1 Bq $kg^{-1}$ (dw) of each of the two radionuclides in the diet). This is equivalent to the concentration ratio under equilibrium conditions. We observe a low variability of the normalised values, reflecting the metabolic regulation in the transfer of these radionuclides a result compatible with our earlier work on farm animals [1]. The values in the Table 4 are however subject to inherent uncertainties. The assessment of DEE, in absence of direct measurements will be best based on data for a similar mammal-diet combination; we estimate that this may be 50% in error. Changing the DEE value in this range we will induce change of a similar order in the integrated activity. In the case of dietary tritium intake, we need to consider the variability of water flux in mammals, which is influenced by diet quality and quantity, and ambient temperature. For the same species, the water flux can vary by a factor of *circa* 2 around the mean and because the water fraction in the body is quite constant, the water halftime will differ (by *circa* 2-fold).

Consequently, the integrated HTO activity in the body will be affected; doubling the water intake, the total integrated tritium activity decrease by 20 %. All other model parameters have less influence on whole body integrated activity although mass and energy partition in organs can influence the muscle-integrated activity (by a factor less than 2). Consequently we can conclude that the values predicted are likely to vary by less than a factor five.

Wild mammals generally have a lower fat content than domestic animals and must adapt to variable environmental conditions. Body mass remains the major factor in describing the radionuclide transfer and small mammals have a fast dynamics, as seen in Figure 1 for the $^{14}C$ retention functions of our example animals. Environmental temperature, taxon and diet must be also considered.

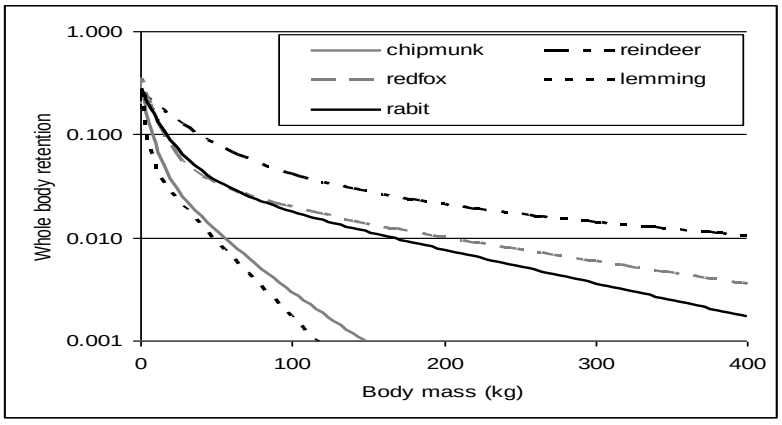


Figure 1. Retention dynamics of $^{14}C$ in representative mammals

Interpreting the model results in the frame of classical transfer function (see Table 4 for $^{14}C$) raises some interesting observations. We distinguish a fast and a slow component with the long halftime 6-14 times larger than the short one, reflecting the various balances between internal and peripheral organs. Neither the short half-time nor the effective half-time are determined simply by mass (compare fox and rabbit). This is the result of the effects of taxon and diet. Based on these results allometric relationships have been derived (Table 4). It is interesting that the effective halftime for carbon is about 4 times longer than for Cs, a radionuclide uniformly spread in the body and the turnover of which has previously been suggested as being linked to protein turnover rate [23].

The allometric relationship over predicts the transfer coefficient for reindeer; a consequence of considering only mass as the driving parameter.

Table 4. Parameters of $^{14}C$ transfer in test mammals; the allometric relationships are fits to these parameters.

| Species | Mass (kg) | T2 (d) | T1 (d) | F (d kg$^{-1}$) | Tef (d) | Norm. integrated $^{14}C$ activity | Norm. Integrated $^{3}H$ activity |
|---|---|---|---|---|---|---|---|
| Lemming | 0.06 | 18.4 | 2.0 | 38.0 | 5.2 | 0.26 | 0.041 |
| Chipmunk | 0.096 | 23.7 | 4.0 | 33.0 | 7.4 | 0.17 | 0.034 |
| Rabbit | 1.8 | 72.0 | 8.4 | 4.5 | 19.6 | 0.23 | 0.036 |
| Red fox | 6 | 95.5 | 6.6 | 1.5 | 17.1 | 0.23 | 0.054 |
| Reindeer | 150 | 153.5 | 19.6 | 0.1 | 47.2 | 0.24 | 0.035 |
| Allometry | | $56M^{0.21}$ | $5.5M^{0.24}$ | $7.9M^{-0.58}$ | $13.1M^{0.25}$ | N_A | N_A |

EXTENSION TO BIRDS

The model developed for mammals is based on energy metabolism and body composition with the assumption that the turnover rate of organics is linked with energy turnover rate. There are no rationales to restrict the model to mammals, if the assumptions are qualitatively correct. Indeed, the allometry of basal metabolic rate of birds has close mass exponent with mammals and the higher values are mostly explained by higher body temperature. The Field Metabolic Rate also has similarity with mammals [25]. As mammals have developed from birds, we expect some similarities for the specific metabolic rates of organs, but not identity. Indeed the hepatocytes cells in birds [26] shows a mass allometric relation similar to mammals but with a different exponent. As data on the specific metabolic rates of organs in birds are missing, we will take the risk to use the mammals systematic, as in the previous chapter. This is justified for a zero order assessment, in absence of any relevant model of T&C transfer in birds.

We started with a small passerine , the tree swallows, for which some data are published [27] and the preliminary results for an unique intake of $^{14}C$ (1 Bq) are given in the figure 3 for the dynamics of activity in model compartments. This example reveals that passerine, comparing with mammals of same mass [22], have a more sharp transition of whole body retention from the fast turnover at the beginning to slow turnover at the end, given by adipose tissue and remainder. The effective turnover time seems to be about 2 times shorter than for mammals of same mass.

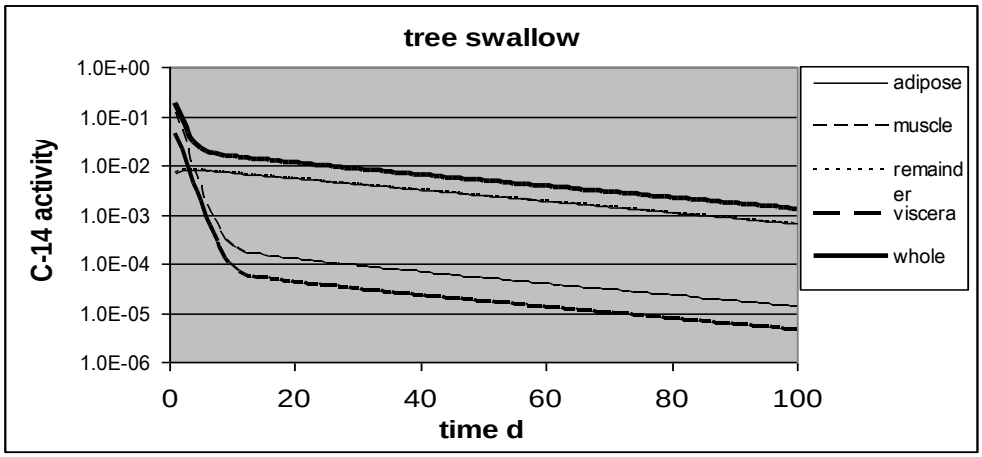


Figure 3. Dynamics of $^{14}C$ in tree swallows tissues after a unique intake

For food chain modeling, laying hens and broiler are of concern and there are no experimental data for egg or meat contamination with T&C. We collect available information from literature concerning growth, body composition, organ mass etc. and use the crude assumption that organ specific metabolic rate are age independent, and has the values for mature mammals in our systematic. For a fast growth broiler we consider a constant OBT concentration in food (1 Bq/kgdw) while for a laying hen we take a constant intake of OBT (1 Bq/d) and report the preliminary results in figure 4. Egg OBT concentration increases fast in the first 7 days corresponding with the duration of egg formation, and slowly after due to contribution of recycled body OBT. The dynamics of OBT in broiler muscle is close with whole body one but the decrease in late period can be an artifact of model simplicity (constant specific metabolic rate of organs).

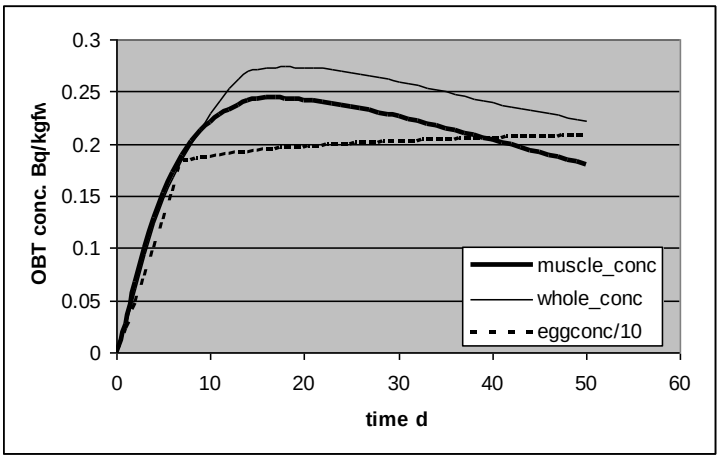


Figure 4. OBT dynamics in egg and broiler muscle and whole body after continue OBT intake

The results above are preliminary and subject to larger uncertainty than for mammals, due to paucity of data on organ metabolism in birds. In absence of any experimental data or previous modeling assessment, they give a first view on the transfer of T&C in birds.

CONCLUSIONS

A novel approach in modeling the transfer of $^{3}H$ and $^{14}C$ has been summarized here, using the energy metabolism and the link between energy and organic matter turnover rate at whole body and organ level. Despite inherent limitation, due to generic approach or limited knowledge of in vivo specific metabolic rate of organs across mammals' species, the results presented shows many practical implications for the improvement of radiological safety assessment covering food-chain modeling, biota radioprotection of human dosimetry. For better quantitative results, experimental efforts must concentrate on mass and age dependency of organs specific metabolic rate.

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