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Quantifying the transfer of radionuclides to food products from domestic farm animals

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ABSTRACT

Databases have been compiled to derive parameter values relevant to the transfer of radionuclides from feedstuffs to domestic animal products to provide a revision to the IAEA Handbook on transfer parameters TRS 364. Significant new data inputs have been incorporated into the databases from an extensive review of Russian language information and inclusion of data published since the early 1990s. Fractional gastrointestinal absorption in adult ruminants presented in the revised handbook are generally similar to those recommended for adult humans by the ICRP. Transfer coefficient values are presented in the handbook for a range of radionuclides to farm animal products. For most animal products, transfer coefficient values for elements additional to those in TRS 364 are provided although many data gaps remain. Transfer coefficients generally vary between species with larger species having lower values than smaller species. It has been suggested that the difference is partly due to the inclusion of dietary dry matter intake in the estimation of transfer coefficient and that whilst dietary intake increases with size nutrient concentrations do not. An alternative approach to quantifying transfer by using concentration ratios (CR), which do not consider dietary intake, has been evaluated. CR values compiled for the handbook vary considerably less between species than transfer coefficient values. The advantage of the CR approach is that values derived for one species could be applied to species for which there are no data. However, transfer coefficients will continue to be used as few studies currently report CR values or give data from which they can be estimated.

1. Introduction

Contamination of animal food products from domestic animals is an important component of any assessment of the exposure of humans from planned or accidental releases of radionuclides. Radionuclide activity concentrations in animal food products depend primarily on the rate of intake, gastrointestinal absorption and turnover and retention in tissues.

In 1994, the International Atomic Energy Agency (IAEA) published the 'Handbook of transfer parameters for temperate food-chains' TRS 364 (IAEA, 1994)[1] which became a key international reference source for such assessments. For farm animal products, TRS 364 was confined to providing transfer coefficients describing the transfer of radionuclides from daily diet to animal products at equilibrium. Under the Environmental Modelling for Radiation Safety (EMRAS) programme of the IAEA, a revised handbook has been delivered in which we have revised the transfer parameter values for meat, eggs and milk, and extended the information given by presenting fractional gut absorption values in domestic farm animals and concentration ratios as an alternative method of quantifying transfer from feedstuffs to milk and meat.

In TRS 364, *c.* 50% of the F_m values and *c.* 80% of the F_f values given were derived from reviews. For the revised handbook, all references sources, including those used to derive the TRS 364 values, were evaluated and only original data sources were incorporated into a database. Significant new data inputs have been incorporated into the database from an extensive review of Russian language information (Fesenko et al., 2007a, b; 2009) and the inclusion of data published since the early 1990. Data from stable elements were used as well as those for radionuclides, although studies where stable element concentrations were relatively high or low were not included in the database. For all the parameter values, extensive use was made of agricultural animal nutrition literature (ARC, 1980; Church, 1980; NRC, 1989, 1996, 2001, 2005, 2007; Underwood, 1977 MAFF, 1990; McDonald et al., 1995) in

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[1] Subsequently referred to as TRS 364.

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addition to radioecological information. The TRS databases are consistently being revised and therefore we advise that the most recent paper on any TRS parameter is consulted to ensure any subsequent amendments to parameter values are taken into account.

The fractional gut absorption values are reported in detail in Howard et al. (in press) and the revised transfer coefficient values are reported in Howard et al. (2009). Here, we provide more detailed information on the concentration ratios presented in the revised Handbook and summarise the key information provided in Howard et al. (2009, in press).

2. Absorption

The extent of absorption from the gastrointestinal tract is one of the most important factors in determining the degree of radionuclide contamination of animal tissues and milk. In the new handbook, we have compiled information on fractional gastrointestinal absorption for use in compartment models which use absorption, retention and loss functions to predict the radionuclide content in the tissues of animals dynamically. Given the difference in gastrointestinal physiology and the importance of ruminants in animal food production, we compiled information specific to gastrointestinal absorption of radionuclides in adult ruminants. There is some indication of higher absorption in very young animals associated with factors such as high nutrient requirements (Howard et al., in press).

Absorption has often been estimated as the difference in dietary intake and faecal output of an element expressed as a ratio of the daily element intake (the *apparent absorption coefficient*). However, faecal output of an element may include significant contributions endogenously excreted from the circulatory system into the gastrointestinal tract (i.e., absorption may be underestimated) (Mayes et al., 1996; Beresford et al., 2000). We have compiled fractional gastrointestinal absorption values preferably determined as the *true absorption coefficient* (A_t) which presents a more accurate estimate of absorption and is not influenced by endogenous excretion (Mayes et al., 1996; Beresford et al., 2000). Some previous publications have derived values of absorption from tissue retention only, after single oral administrations (sometimes with considerable time gaps between administration and measurement) or daily ingestion of radionuclides. We have not used such data because losses via excreta and milk are not accounted for. A significant input to the database was the Russian language publication review of Fesenko et al. (2007a). The recommended fractional absorption values given in Howard et al. (in press) for the different radionuclides in adult ruminants have been grouped into orders of magnitude as shown in Table 1.

Gastrointestinal absorption values recommended for humans have been reported by ICRP (2006) and this provides the most relevant values recommended for monogastric animals. For most radionuclides, the values recommended by ICRP are similar to those in Table 1 for ruminants, with the exceptions of the six and nine fold lower values derived for Pu and Ru, respectively in ruminants compared with the ICRP values. In the case of Pu, all the data for ruminants originate from studies in which animals were administered contaminated soil/sediment and this may contribute to the difference seen between ruminants and non-ruminants. However, it is difficult to directly compare values as the ICRP values are based on literature reviews of data for both monogastric animals and ruminants and expert judgement.

Table 1
Grouping of fractional absorption values for different elements in adult ruminants (Howard et al., in press).

Fractional absorption magnitude	Radionuclide
10^{-1}–1	I, Cl, Na, Cs, P , Se, Ca, Te, Zn, Sr, Fe
10^{-2}–10^{-1}	Ag, Ba, Co, Pb, U
10^{-3}–10^{-2}	Mn, Ru, Cd, Y
10^{-4}–10^{-3}	Zr, Ce, Pm, Am, Nb
10^{-5}–10^{-4}	Pu

3. Transfer coefficient values

The transfer coefficient, defined as the equilibrium ratio of the fresh weight activity concentration in milk/meat to the daily dietary radionuclide intake, has been widely adopted as the basis for quantifying transfer to milk ($F_{m,}$ d l^{-1} or d kg^{-1}) and meat ($F_{f,}$ d kg^{-1}) and eggs for all radionuclides. Source information for the database included F_m and F_f values derived from:

i. Experiments involving the daily administration of radionuclides or stable elements to animals, for which the estimated plateau concentration could be divided by the daily intake to estimate $F_{f/m}$;
ii experiments (of an adequate length) where, following a single oral administration of an isotope, the time-integrated activity concentration in milk could be estimated from the fraction of the total administered activity recovered in milk divided by the daily milk production rate. Single administration studies were not used for meat unless sufficient time series data were available.

For elements where we did not have F_m values, we compared unassociated stable element concentrations in milk with those in feeds reported by agricultural science review publications and assumed a daily herbage intake.

Details of guidelines used for data selection are outlined in Howard et al. (2009). Radionuclides sources of low bioavailability sources for Cs F_m values were excluded as were experimental data where the animal's diet was deficient in the element considered. We also excluded data from animals with experimentally increased stable element intakes. A decision was made not to conduct a review of values for H and C because the transfer coefficient approach is not appropriate to describe transfer for these elements (Galeriu et al., 2007). Specific activity approaches were used to derive values for these radionuclides in the new handbook (see Galeriu et al., 2007 for details).

The complete set of tables of F_f and F_m values are given in Howard et al. (2009). However, since publication, the value for Sr transfer to eggs has been revised as the database was found to contain some data which included shell. The revised value of 3.5×10^{-1} d kg^{-1} is the reference value within the revised IAEA handbook.

In Table 2, we present the reference transfer coefficient values in the revised handbook which vary by at least one order of magnitude from the expected values given in TRS 364. Note the list of radionuclides and animal food products in the table differs slightly from that given previously in Howard et al. (2009). In addition to the values listed below, the values for Pu (beef), Sr (sheep meat) and Co (poultry meat) were nearly one order of magnitude lower than those in TRS 364 and the values for Pu for cow milk and egg contents and U for cow milk were nearly one order of magnitude higher than those in TRS 364.

In some instances where the new handbook values differs by more than an order of magnitude from the TRS 364 value, we now have considerably more data (Cd to beef, Zn to sheep meat and Sr to pork and Sr to sheep meat are now all based on a reasonable number of datasets). For example, we now have 25 data entries of F_f