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Improving the quantity, quality and transparency of data used to derive radionuclide transfer parameters for animal products. 2. Cow milk

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A B S T R A C T

Under the International Atomic Energy Agency (IAEA) MODARIA (Modelling and Data for Radiological Impact Assessments) Programme, there has been an initiative to improve the derivation, provenance and transparency of transfer parameter values for radionuclides from feed to animal products that are for human consumption. A description of the revised MODARIA 2016 cow milk dataset is described in this paper. As previously reported for the MODARIA goat milk dataset, quality control has led to the discounting of some references used in IAEA's Technical Report Series (TRS) report 472 (IAEA, 2010). The number of Concentration Ratio (CR) values has been considerably increased by (i) the inclusion of more literature from agricultural studies which particularly enhanced the stable isotope data of both CR and F_m and (ii) by estimating dry matter intake from assumed liveweight. In TRS 472, the data for cow milk were 714 transfer coefficient (F_m) values and 254 CR values describing 31 elements and 26 elements respectively. In the MODARIA 2016 cow milk dataset, F_m and CR values are now reported for 43 elements based upon 825 data values for F_m and 824 for CR. The MODARIA 2016 cow milk dataset F_m values are within an order of magnitude of those reported in TRS 472. Slightly bigger changes are seen in the CR values, but the increase in size of the dataset creates greater confidence in them. Data gaps that still remain are identified for elements with isotopes relevant to radiation protection.

1. Introduction

The transfer of radionuclides from the environment to animal products is quantified for modelling using two transfer parameters published in the most recent international compilations by the International Atomic Energy Agency (IAEA) in its Technical Report Series (TRS) report 472 and Tecdoc 1616 (IAEA, 2009, 2010). The transfer coefficient, defined as the ratio of the fresh weight activity concentration in milk or meat against the daily dietary radionuclide intake at equilibrium. It has been widely adopted as the basis for quantifying transfer to milk (F_m, d l^{-1}) and meat and eggs (F_f, d kg^{-1}) for all radionuclides (Howard et al., 2009a,b). An alternative, the concentration ratio (CR), is defined as the equilibrium ratio between the radionuclide activity concentration in the animal food product (Bq kg^{-1} fresh weight) divided by the average radionuclide activity concentration in the feedstuff ingested (Bq kg^{-1} dry weight). Values for CR were first provided in TRS 472 and are now commonly reported for animal products.

The animal product tables are currently being revised in the IAEA MODARIA (Modelling and Data for Radiological Impact Assessments) programme. An initial motivation for the revision of the cow milk values was that recently improved information could be used for the IAEA's revision of the SRS 19 on Generic Models for Use in Assessing the Impact of Discharges of Radioactive Substances to the Environment (IAEA, 2001).

The revision process is outlined in Howard et al. (2016a) where the first revised MODARIA 2015 goat milk dataset has been described. In this paper, we provide the revised transfer parameters from the MODARIA 2016 cow milk dataset.

2. Revision of the cow milk data set

TRS 472 and Tecdoc 1616 are accepted by the research community as a robust source of information; the underpinning data from these sources were used as a starting point for the revision. Data from new sources were added, but all data items were

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assessed for their appropriateness and some of the original values rejected. The general approach to revision of the cow milk dataset followed that previously described for goat milk in Howard et al. (2016a). A targeted literature review for cow milk was undertaken to incorporate recently reported F_m and CR values. Reference sources providing data which have been added to the dataset are from Green et al. (1995), Gustafson (2000), Herwig et al. (2011), Juniper et al. (2006), Karunakara et al. (2013), Kinkaid et al. (2003), Kume (1989), Phipps et al. (2008), Rosas et al. (1999), Sheppard et al. (2010), Smith et al. (1991), Štrok and Smodiš (2012), Turtiainen et al. (2014), Ujwal et al. (2011) and Vidovic et al. (2003).

2.1. Inclusion of stable element data

Previously Ng et al. (1977) have used "unassociated milk and feed" element or radioisotope concentrations" to derive F_m values, but the source data are difficult to identify and probably utilise single values. Stable element concentrations in milk and various animal feed types are often reported in publications related to agricultural production of livestock compiled by research councils or government departments. We used such "Agricultural review" data to identify stable element concentrations for both milk and feed as well as peer reviewed sources. A single CR and Fm value for an element was only included in the MODARIA dataset when we identified more than 5 independent measurements of stable element concentrations in cow milk. The corresponding value used for the feed included stable element concentrations reported for either fresh pasture grass, forage or mixed herbage. The source publications used were Church (1980), NRC (2001, 2005), MAFF (1990) and Underwood (1977). As the reference sources for the milk element concentrations are from multiple sources they are given as footnotes in Tables 2b, 3b, 5b and 6b.

The maximum tolerable level of an element (or mineral) is defined by NRC (2005) as the dietary level that, when fed for a defined period of time, will not impair animal health or performance. Only data from animals with stable element dietary intakes below maximum tolerable levels have been used to derive transfer parameters (NRC, 2005; EC, 1991).

When using source publications which provide F_m data for a range of different heavy metal concentration in feed (e.g. Kume, 1989) we have only included the control data and treatments which are below the maximum mineral tolerance levels.

2.2. Dry matter intake (DMI)

In the first food chain handbook, TRS 364, a guidance value for daily dry matter intake (DMI) for dairy cows was given of 16.1 kg d^{-1} (range 10–25 kg d^{-1}). However, it was recommended that location specific information should be used where possible. In TRS 472, no guidance was provided, but the associated TECDOC 1616 (IAEA, 2009) quoted 16 kg d^{-1} and this value was used in TRS 472 to derive cow milk transfer coefficient (F_m) values from CR values for some stable elements.

There is a positive linear relationship between the body mass of an animal and the DMI (e.g. Clauss et al., 2013). In the MODARIA 2016 cow milk dataset, where a source publication does not provide information on the daily DMI of the dairy cattle (either directly or providing data that allows it to be estimated) then assumptions have been made to estimate the liveweight of the dairy cows (Table 1). This has then enabled an estimation to be made of the daily DMI. The approach we have used is simple and does not reflect the considerable variation in daily DMI of dairy cattle. However, variation in the daily DMI is unlikely to change derived F_m values by more than a factor of 2–3.

The liveweight and milk yields of cattle has increased over recent decades through improvements in animal breeding (AHDB, 2012). Therefore, where no liveweight, milk yield or daily DMI was given in the source reference the year of publication (or year of experiment) was used to allocate the daily DMI on the basis of Table 1. The data in Table 1 covers six decades over which data were reported and is most relevant for intensive agricultural conditions in developed countries. Where the source publication provided only the liveweight, the milk yield and then the daily DMI was estimated from the year of publication. Similarly, where the source publication provided only the milk yield, the liveweight and then DMI was estimated from the year of publication. To calculate an F_m value from the derived stable CR value, we used an 'average' dairy cow daily DMI value of 21.5 kg.

Details of experimental details for some source Russian language publications were given in Fesenko et al. (2007a) which showed that milk yield was generally much lower than 10 L d^{-1} and liveweight was often <500 kg. Therefore, we have assumed a lower daily DMI for dairy cows of 10 kg d^{-1} for Russian language sources, where the source publication did not include a daily DMI value. The data in Table 1, based on Western Europe agricultural conditions, are probably not relevant for these animals in lower productivity systems.

2.3. New records in the MODARIA 2016 cow milk dataset

The adoption of the above assumptions have enabled the conversion of previously reported F_m values to provide equivalent CR values and has considerably increased the CR data. In TRS 472, CR values were reported for 26 elements, four of which were based on agricultural stable element data (calcium; nickel; phosphorus; and uranium). In the MODARIA 2016 cow milk dataset additional agricultural stable element data (CR and F_m values) are included for cadmium; copper; iron; iodine; potassium; magnesium; manganese; molybdenum; nickel; lead; and zinc.

A major source of revised or new values was a review of Russian literature for milk by Fesenko et al. (2007a). In TRS 472, data from Russian publications in the 1970–1980's were used which had been translated into English by United States Atomic Energy Commission (USAEC). The Fesenko review paper (2007b) provided an improved summary of relevant data from Russian language studies in the USSR and FSU and was used to replace or revise all such studies previously included in the dataset used for TRS 472. Some duplicate data from the USSR was identified and removed from the dataset including 47 F_m values for strontium. The impact was much less for caesium and iodine where three and four values respectively were removed from the dataset.

Herwig et al. (2011) reported a number of stable data for cow milk and feed using ICPMS (Inductively coupled plasma mass spectrometry) measurements. Sheppard also reported cow milk F_m and CR values for 34 elements using ICPMS analysis except for chlorine which was measured by anion chromatography. Data for an element with more than seven measurable values in Sheppard et al. (2010) were included in the dataset namely: gold; barium; cerium; chlorine; cobalt; caesium; copper; iron; gallium; hafnium; magnesium; manganese; molybdenum; sodium; niobium; lead; rubidium; selenium; strontium; thorium; titanium; and zinc. However, iodine and zirconium were then excluded as the reported F_m and CR values differed by 3 orders of magnitude from other values in the dataset. When the number of reported values for an element in Sheppard et al. (2010) was <7 the element was excluded from the main dataset (arsenic; bismuth; calcium; chromium; lanthanum; neodymium; rhenium; tantalum; tellurium; and uranium). However, as transfer parameter values for some of these