Journal of Environmental Radioactivity 134 (2014) 61–65

Contents lists available at ScienceDirect

Journal of Environmental Radioactivity

journal homepage: www.elsevier.com/locate/jenvrad

Determination of the ^{137}Cs and ^{90}Sr radioisotope activity concentrations found in digestive organs of sheep fed with different feeds

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ARTICLE INFO

Article history:
Received 11 November 2012
Received in revised form
20 February 2014
Accepted 24 February 2014
Available online 28 March 2014

Keywords:
Radioactivity
^{137}Cs
^{90}Sr
Sheep
Transfer coefficient
Concentration ratio

ABSTRACT

In this study, 12 weanling lambs were fed for 6 months at the Vetenary Control and Research Institute of Elazığ in Turkey. Sheep were divided into two groups according to feeding type. Each group of sheep was fed a different amount of feed. The activity concentrations of ^{137}Cs and ^{90}Sr were determined in rumen, small intestine and large intestine tissue samples of sheep fed various feeds and quantities.

Transfer coefficients and concentration ratios were estimated. The highest average ^{137}Cs and ^{90}Sr activity concentrations were 82 ± 22 Bq kg^{-1} fw in the straw group small intestine sample and 74 ± 9.0 Bq kg^{-1} fw in the fresh lucerne group rumen sample, respectively. Radioactivity levels for ^{137}Cs and ^{90}Sr are under the maximum permitted radioactive pollution level for all the samples. The transfer coefficient of ^{137}Cs and ^{90}Sr in the samples of sheep ranged from 1.0×10^{-1} to 2.1×10^{0} d kg^{-1} and 1.7×10^{-1} to 2.3×10^{0} d kg^{-1}, respectively. Calculated transfer coefficients of ^{90}Sr and ^{137}Cs in the samples of sheep were higher than the expected values. Geometric means of F_f and CR for ^{137}Cs were maximum in the fresh lucerne group large intestine sample. Geometric means of F_f and CR for ^{90}Sr were maximum in the fresh lucerne group small intestine sample.

1. Introduction

Radionuclides may enter the terrestrial environment via atmospheric releases or releases to aquatic systems not only from nuclear installations but many applications of radioisotopes, and even terrorism may be a threat. Radioactivity released to and dispersed in the atmosphere enters the terrestrial environment due to dry and wet deposition on soil and vegetation causing dose either for humans and biota. Internal exposure of humans occurs largely from the use of contaminated plants as food or as feed for domestic animals (Varga, 2008).

Radioactive substances enter the body through the lungs, gastrointestinal system, and skin and are then transported through the body via extracellular fluids. 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 (Howard et al., 2009a). Radionuclides accumulate in certain body parts according to chemical properties particular to the element. For example, iodine accumulates in the thyroid gland, alkaline-earth metals accumulate in bone, plutonium accumulates in bone and liver, and alkaline metals accumulate in soft tissues. Radionuclides, after entering the body, are excreted in urine and feces over potentially long periods (Çetiner, 1990).

Man-made radioactive material is generated by a variety of activities. By far the largest quantities of radioactivity have been created by nuclear reactors operated either for electric power generation or weapons production (UNSCEAR, 1993). Radioactivity from reactors includes fission products, activation products, and transuranic nuclides. Other radioisotopes for use in research and medicine are produced by particle accelerators. To some extent, all of these man-made radioisotopes contribute to the generation of radioactive waste, often as a result of contaminating other materials, e.g., soil, building materials, protective clothing, body fluids (Roberts, 1998).

Strontium-90 (^{90}Sr) was deposited globally following the atmospheric nuclear weapons testing around the world during 1945–80. It is a beta-emitter with a maximum β-energy of 0.5 MeV and a half-life of 28.5 years. Due to its chemical similarity to calcium, it has

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http://dx.doi.org/10.1016/j.jenvrad.2014.02.023
0265-931X/

a high transfer rate to bone (Hardy et al., 1968). Due to its relatively long 50-year biological half-life in bone and its short-lived daughter ^{90}Y (half-life 64.1 h), which emits hard beta-particles with a maximum energy of 2.3 MeV, it can cause severe damage to bone and bone marrow. ^{90}Sr can enter the human body through various routes, such as ingestion, inhalation and direct contact. The behavior of strontium is strongly influenced by that of calcium. The absorption of radiostrontium from the diet should also be inversely related to dietary calcium intake of ruminants. Strontium absorption will be inversely related to calcium intake, an inverse relationship was fitted to the individual animal measurements. Radiostrontium availability is an important factor in determining the transfer of radiostrontium to animal products (Beresford et al., 2000). Daily average Ca intake in sheep is 3.40 $\pm$ 0.15 g d^{-1}.

Radioactive cesium isotopes are produced by nuclear fission. Cesium-137 (^{137}Cs) is a major radionuclide in spent nuclear fuel, high-level radioactive waste resulting from the processing of spent nuclear fuel, and other radioactive wastes associated with the operation of nuclear reactors and fuel reprocessing plants. ^{137}Cs's chemical properties resemble those of potassium. Myttenaere et al. (1993) summarized the relationship between radiocesium and K, and suggested the possible use of K behavior for the prediction of radiocesium behavior. Potassium might play an important role with regard to Cs uptake. ^{137}Cs has a half-life of approximately 30 years. Cesium can be taken into the body by ingestion or respiration. After being taken in, cesium behaves in a manner similar to potassium and distributes uniformly throughout the body (Whicker and Schultz, 1982; Çelebi, 1989). Gastrointestinal absorption from food or water is the principal source of internally deposited cesium in the general population. As a soluble cation in the digestive system, it is absorbed at a high rate; essentially all ingested cesium is absorbed into the bloodstream through the intestines. Retention occurs when radionuclides are bound to tissues within regions of the alimentary tract. While radionuclide retention is generally low and may be ignored in most cases, there is some experimental evidence of retention on teeth, and retention within the mucosa of the small intestine. Retention in the small intestine is pronounced in newborn animals and is associated with increased levels of absorption (ICRP, 2004).

1.1. *Estimation of transfer parameters*

Transfer coefficients (F_f) from sheep feed to tissue were estimated by dividing the concentration of radioactive caesium in tissues (Bq/kg) by the amount of radioactive caesium administered to the sheep (Bq d^{-1}) (Beresford et al., 2007).

The concentration ratio (CR) is the equilibrium ratio of the radionuclide activity concentration in food product (fresh weight (fw)) divided by radionuclide concentration in feed (dry weight (dw)). CR values can be derived by multiplying the transfer coefficient value by the daily dry matter intake (DMI) in kg d^{-1} (Howard et al., 2009a,b; IAEA, 2010; Sheppard et al., 2010).

So, the concentration ratios were calculated using Equation (1) (Howard et al., 2009b).

$$CR = F_f \times DMI \quad (1)$$

Musatavova et al. (1989) investigated the transfer of radiostrontium to bovine and pig meat. They calculated a F_f value to be 9.2×10^{-3} d kg^{-1} for bovine meat for groups of 5 or 6 animals from Czechoslovakian cooperative farms that were given fodder grown in 1987 and 1988 on an area contaminated by fallout from the Chernobyl accident (Musatavova et al., 1989).

Ham et al. (2003) researched ^{137}Cs, plutonium (Pu) and americium-241 (^{241}Am) content in sheep tissues taken from sheep raised along the Cumbrian and Lancashire coast. ^{137}Cs was, as expected, found mainly in the muscle tissue of the animals.

Assimakopoulos et al. (1993) investigated F_f for ^{137}Cs transport from a sheep's diet to blood, muscle, lung, liver, kidney, spleen heart, brain, rumen, intestines and fat, measured in a controlled experiment involving 50 adult ewes. The animals were fed dry grass and wheat, both contaminated with Chernobyl fallout debris, for a period of 60 days. During this period half of the animals were killed at regular intervals and samples of their blood and tissues were measured for ^{137}Cs concentration.

Semioshkina et al. (2006) have determined the ^{90}Sr activity concentration to be 57 Bq/kg fw and F_f to be 0.006 d kg^{-1} in the intestine samples of regionally fed horses in a study at the Kazakh Scientific Research Institute of Agriculture in 2006.

Howard et al. (2009b) provided updated recommended transfer coefficient values for the transfer of a range of radionuclides to milk of cows, sheep and goats, muscle (i.e. meat) of cattle, sheep, goats, pigs and poultry and eggs. The paper outlines the approaches and procedures used to identify and collate data and documents where assumptions have had to be made. Finally, the revised values are compared with those given in TRS 364).

Howard et al. (2009a) reported the F_f and concentration ratios (CRs) for various radionuclides in the meat of different domestic animals. Concentration ratio for sheep meat has been reported as $6.4 \times 10^{-1.}$ There is no consistent ranking between species in CR values as was found for F_f values which were consistently higher for sheep and goats compared to cattle. For most elements, the CR values available differ little between the species considered whereas, the F_f values typically varied by an order of magnitude (and by up to two orders of magnitude) between species. 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.

Semioshkina et al. (2007) investigated the transfer of ^{137}Cs and ^{90}Sr to rabbit meat in 32 rabbits that were fed regionally at the Kazakh Scientific Research Institute of Agriculture. The distribution of ^{137}Cs in the body was found to be homogeneous, while the ^{90}Sr concentration was determined to be highest in bones. Also, the F_f of ^{137}Cs to the muscles was determined to be lower than ^{90}Sr's.

The main purpose of this research was to measure the transfer of radionuclide activity to sheep which were fed with different fodders. In this study, the radioactivity concentration of two specific radioisotopes, ^{137}Cs and ^{90}Sr, were determined in samples of various feeds and sheep organs.

2. Material and methods

Twelve weanling lambs were fed twice a day (at 8.00 a.m. and 6.00 p.m.) for 6 months at the Vetenary Control and Research Institute of Elazığ in Turkey. There were two feed types, one based on straw and the other on fresh lucerne and 6 sheep were assigned to each feed type. The fresh lucerne was produced locally on the agricultural land of the Institute and no additional radioactivity was added. The harvest region is Elazığ which is located in eastern part of Turkey. Fig. 1 shows Elazığ in Turkey. Straw and concentrate feeds were purchased from another area of Elazığ. Sheep of each group was fed different amounts of feed and a different concentrated feed. The different concentrate feeds mixed into fresh lucerne and straw. Average live weight of the sheep was 30 kg.

After 6 months the sheep were slaughtered at a slaughterhouse in Elazığ on October 10th, 2008.

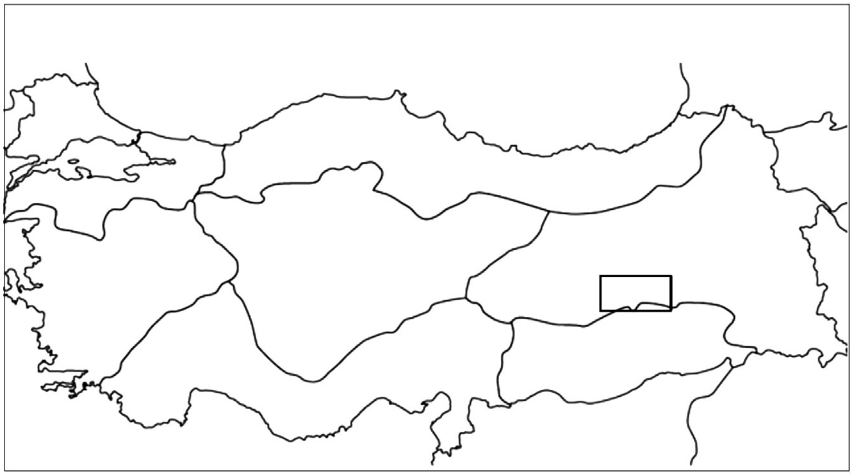

Fig. 1. Sampling area in Turkey map.

Concentrate feeds and the content of these concentrate feeds used in this study were shown in the Table 1.

2.1. Sampling and sample preparation

Tissue samples were taken from the small intestine, large intestine and rumen of the sheep and they were washed with distilled water to remove intestines and rumen contents. Then, they were preserved at −20 °C. Prior to analysis, these samples were transferred to petri dishes and dried in an oven at 80 °C for three weeks. Sample of fresh lucerne was taken for measurements on the day of slaughter of sheep. Fresh lucerne, straw and concentrate feed samples were packed into aluminum foil and completely dried in an oven at 100 °C. Both tissue and feed samples were completely pulverized in a mortar and placed in clean plastic bags. Subsamples not exceeding 5 mg cm^{-2} were placed on aluminum planchettes whose surface areas were 4.52 cm^2 for radionuclide concentration measurements. Distilled water was added to samples in the planchettes and planchettes were dried again. The samples were stuck to planchettes after dessication. Finally, the measurements of the radionuclide activity concentrations of all the samples were made.

2.2. Determination of the radioactivity

In this study, a gamma precision scintillator counter was used for ^{137}Cs radionuclide concentration measurements. The gamma spectroscopic system consists of a $2'' \times 2''$ NaI(TI) well-type detector which is housed in a cylindrical lead shield of about 13.7 cm and 15.5 cm in diameter and length, respectively. The lead shield thickness was about 3.5 cm, which is suitable for limiting the gamma background. The detector's entrance window consisted of 0.50 mm thick aluminum (Ne Technology Limited, 1991). The energy calibration was performed using ^{60}Co (1 μCi) and ^{226}Ra (10 μCi) point sources. The photopic efficiency of NaI (TI) detectors has been found to be 24%. The activity of each sample was determined using the total net counts and the counting time for each sample was 3000 s. Radiostrontium determinations were carried out using a radiochemical procedure involving the selective separation of ^{90}Sr from the bulk sample by acid extraction and then multiple precipitation, and beta-counting of the final precipitate of yttrium oxide after the ingrowth of the daughter product ^{90}Y. Before analysis, samples were ashed, and then activity concentration measured with a low background beta-counter (BP4 beta probe scintillating counter). Counting efficiency was 30% for ^{90}Sr.

Table 1
The composition of the two feed concentrates, shown per 100 kg dry weight (Başkaya, 2011).

The straw group	The fresh lucerne group
21.2 kg wheat bran	–
30.9 kg soybean pulp	–
44.9 kg ground corn	97.1 kg ground corn
1 kg salt	2.3 kg salt
0.2 kg trace minerals	0.6 kg trace minerals
1.5 kg DCP (dicalcium phosphate)	–
0.3 kg vitamin	–

3. Result and discussion

The ^{90}Sr and ^{137}Cs concentrations in the straw group total feed were higher than ^{90}Sr and ^{137}Cs concentrations in fresh lucerne group total feed. ^{90}Sr activity concentration in fresh lucerne group total feed was higher than ^{137}Cs activity concentration in fresh lucerne group total feed. Hence average ^{90}Sr concentrations of tissues of sheep in fresh lucerne group were higher than average ^{137}Cs concentrations of tissues of sheep in fresh lucerne group. There is reverse situation at the concentration of straw group total feed and the activity concentration in the tissues of the sheep fed with this feed.

The highest average ^{90}Sr radionuclide activity concentration was found in the rumen and the highest average ^{137}Cs radionuclide activity concentration was found in the small intestine, the average ^{90}Sr and ^{137}Cs radionuclide concentrations in the samples of sheep's large intestine were lower than those of other samples. This situation likely results from variable organ-specific radionuclide absorption rates.

The geometric means of CR and F_f for radionuclides in tissue samples are given in Table 2.

In TRS-364, the expected F_f value for ^{90}Sr was stated as 4.0×10^{-2} d kg^{-1} for sheep. The F_f values for ^{90}Sr for lambs over three months ranged from $(1.1–3.7) \times 10^{-3}$ d kg^{-1}. The expected F_f value for ^{90}Sr in TRS 364 is 3.3×10^{-1} d kg^{-1} based on Coughtrey (1990). In this study, the F_f values of ^{90}Sr in the samples of sheep varied between 1.7×10^{-1} and 2.3×10^{0} d kg^{-1}, which were higher than the expected values for sheep in TRS-364 and the TECDOC 422 (IAEA, 2008).

Table 2
The dry matter intake, total and singular concentration in feed and average concentration, geometric mean CR, geometric mean F_f in the samples of sheep.

Parameter	Fresh lucerne group		Straw group	
Dry matter intake (kg d^{-1})	1.65–2.54		1.28–1.46	
	^{137}Cs	^{90}Sr	^{137}Cs	^{90}Sr
Concentration in total feed (Bq/kg dw)	27.0–29.20	39.33–41.65	55.34–56.49	47.39–52.50
Concentration in fresh lucerne (Bq/kg dw)	23 ± 16	46 ± 18		
Concentration in concentrate feed /fresh lucerne group (Bq/kg dw)	48 ± 6	19 ± 10		
Concentration in straw (Bq/kg dw)			48 ± 0	87 ± 10
Concentration in concentrate feed /straw group (Bq/kg dw)			60 ± 14	30 ± 12
Average concentration (Bq/kg fw) in rumen	54 ± 15	74 ± 9	61 ± 17	42 ± 5
in small intestine	49 ± 10	54 ± 9	82 ± 22	48 ± 7
in large intestine	55 ± 8	41 ± 13	36 ± 10	38 ± 11
Geometric mean CR (kg dw/kg fw) in rumen	1.28	1.29	0.82	1.03
in small intestine	1.41	1.64	0.80	0.90
in large intestine	2.23	0.99	0.63	0.67
Geometric mean F_f (d/kg fw) in rumen	0.59	0.59	0.59	0.77
in small intestine	0.61	0.78	0.65	0.65
in large intestine	0.97	0.46	0.48	0.48

The F_f values calculated for the samples of sheep in fresh lucerne group were lower than the F_f values calculated for the samples of sheep in straw group.

In this study, the F_f values for ^{137}Cs in sheep ranged from 1.0×10^{-1} to 2.1×10^{0} d kg^{-1}. The maximum geometric mean was 9.7×10^{-1} d kg^{-1} (in large intestine). For ^{137}Cs, the TRS 364 expected F_f value is 1.7×10^{-1} d kg^{-1} for adult sheep based on Coughtrey (1990). According to the International Atomic Energy Agency (2010), the transfer coefficient of radioactive caesium for sheep ranges between 5.3×10^{-2} and 1.3×10^{0} d kg^{-1}. The calculated F_f values were higher than the expected value.

The CR values of ^{137}Cs and ^{90}Sr in the samples of sheep varied between 1.8×10^{-1} and 5.4×10^{0} with 2.1×10^{-1} and 5.8×10^{0}, respectively. The geometric mean CR values calculated for the samples of sheep in straw group were lower than the CR values calculated for the samples of sheep in fresh lucerne group. According to the International Atomic Energy Agency (2010), the CR values of radioactive caesium for sheep ranges between 5.3×10^{-2} and 7.5×10^{0}. The CRs estimated in the present study were similar to these values.

Recommended transfer coefficients and transfer ratios for radiocaesium are 4.9×10^{-1} d kg^{-1} and 5.4×10^{-1} d kg^{-1} for lamb meat, respectively (IAEA, 1994).

4. Conclusion

In this study, the maximum average ^{137}Cs and ^{90}Sr concentrations were calculated as 49 ± 10 Bq/kg fw in small intestine sample of the fresh lucerne group and 82 ± 22 Bq/kg fw in small intestine sample of the straw group, respectively. In addition to, the maximum geometric mean F_f values of ^{137}Cs and ^{90}Sr were found to 9.7×10^{-1} d kg^{-1} in large intestine of the fresh lucerne group and 7.8×10^{-1} d kg^{-1} in small intestine of the fresh lucerne group, respectively (concentrations in the tissues are assumed to be in equilibrium) (Table 2).

Calculated F_f values for ^{90}Sr and ^{137}Cs in the samples of sheep were higher than the expected value.

The CR values for ^{137}Cs were similar to the International Atomic Energy Agency (2010).

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