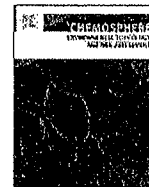




ELSEVIER

Contents lists available at ScienceDirect

Chemosphere

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

Levels of ^{210}Po and ^{210}Pb in fish and molluscs in Slovenia and the related dose assessment to the population

Marko Štrok, Borut Smodiš*

Jožef Stefan Institute, Jamova 39, SI-1000 Ljubljana, Slovenia

ARTICLE INFO

Article history:

Received 24 May 2010

Received in revised form 21 October 2010

Accepted 24 October 2010

Available online 20 November 2010

Keywords:

 ^{210}Po ^{210}Pb

Fish

Mollusc

ABSTRACT

^{210}Po and ^{210}Pb activity concentrations in fish from the Slovenian part of Adriatic Sea, in the vicinity of a former uranium mine at Žirovski vrh and from the Slovenian market were determined. In addition, ^{210}Po and ^{210}Pb activity concentrations in squid from the Slovenian market and in mussels from the Slovenian part of the Adriatic Sea were also determined. Fish, squid and mussel consumption in Slovenia was assessed from the data available from Eurostat and Food and Agriculture Organisation (FAO) and the data used for the corresponding dose calculation. Fish species with the highest activity concentrations were grilled to assess possible loss of ^{210}Po during the food preparation process. Samples were freeze dried and radiochemical separation of ^{210}Po and ^{210}Pb was performed. Measurements of ^{210}Po were performed by alpha spectrometry and ^{210}Pb by a low background gas-flow proportional counter. ^{210}Po activity concentrations in fish, squid and mussels were from 0.039 to 35.0 Bq kg⁻¹ fresh weight and ^{210}Pb activity concentrations were from 0.08 to 3.03 Bq kg⁻¹ fresh weight. Grilling of fish resulted in no significant loss of ^{210}Po at 90 °C. The assessed combined annual effective ingestion dose due to ^{210}Po and ^{210}Pb for fish, squid and mussels consumed in Slovenia is 47.6 μSv year⁻¹.

© 2010 Elsevier Ltd. All rights reserved.

1. Introduction

^{210}Po is one of the most radiotoxic radionuclides, which is evident from the committed effective dose per unit of intake. This value is about 10–10 000 times higher than for most other radionuclides (IAEA, 2003). The radiotoxicity of ^{210}Po is connected with the fact that it emits alpha particles with a relatively high energy of about 5.3 MeV and that it is concentrated in the soft tissues, such as muscle, liver and others (Stewart et al., 2008). Similarly to ^{210}Po , ^{210}Pb also has a quite high committed effective dose per unit of intake, being the second largest in the uranium decay chain (IAEA, 2003). ^{210}Pb is a beta emitter with a half-life of 22.17 years and decays into ^{210}Bi with a half-life of 5.01 d, which further decays into ^{210}Po with a half-life of 138 d (Magill et al., 2006). This means that if ^{210}Po is not determined immediately after sampling, the ^{210}Pb activity concentration should be determined for correct calculation of ^{210}Po activity concentration. ^{210}Po and ^{210}Pb enter the marine and freshwater environment mainly through the global fallout of aerosols and gases, through release from the earth's crustal material, through substances released due to activities related to the processing of uranium ore and as a by-product of fertilizers and oil industries. After ^{210}Po and ^{210}Pb enter the marine or freshwater environment, they are subjected to different biogeochemical

reactions (e.g., dissolution, hydrolysis, complexation, sorption/desorption, coprecipitation, speciation) (Stricht and Kirchmann, 2001). Which of these reactions will be dominant depends upon their chemical form and the characteristics of the marine and freshwater environment (Stricht and Kirchmann, 2001).

According to Stewart et al. (2008), ^{210}Po and ^{210}Pb display very strong binding to particle surfaces, including organisms. ^{210}Pb is frequently associated with the mineral fractions of organisms (bones and shells) and with cell walls in single-celled organisms, which provide large binding surfaces. Unlike ^{210}Pb , ^{210}Po is primarily associated with proteins in living organisms and can also penetrate into the cytoplasm of cells. Because of that, ^{210}Po can be more effectively assimilated in higher marine organisms than ^{210}Pb , which causes $^{210}\text{Po}/^{210}\text{Pb}$ ratios higher than 1 in most marine organisms.

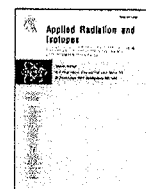
The present study concerned with the levels of ^{210}Po and ^{210}Pb in selected foodstuffs in Slovenia addressed four items.

1.1. Determination of ^{210}Po and ^{210}Pb in fish and bivalve mollusc species from the Slovenian part of the Adriatic Sea

Radionuclides such as ^{210}Po and ^{210}Pb are present in the marine or freshwater environment mostly in suspended matter. The most important process for their transport, beside advection and dispersion, is sedimentation. Therefore, radionuclides which are associated with larger particles are rapidly removed from the

* Corresponding author. Tel.: +386 15885363; fax: +386 15885346.

E-mail addresses: Marko.Strok@ijs.si (M. Štrok), Borut.Smодиš@ijs.si (B. Smodiš).



Radon in water measurements by sampling with sunflower oil

S. Georgiev^{*}, V. Todorov, H. Stoycheva, K. Mitev

Faculty of Physics, Sofia University "St Kliment Ohridski", 5 James Bourchier Blvd, 1164, Sofia, Bulgaria

ARTICLE INFO

Keywords:

Radon in water
Cherenkov counting
Sampling in oil
Liquid scintillation counting

ABSTRACT

A novel method for measuring radon in water is proposed. This method involves sampling radon from water into sunflower oil and subsequently measuring the radon in the oil using either Cherenkov counting or Liquid Scintillation (LS) counting. The high partition coefficient of radon between oil and water enables radon pre-concentration in the oil, significantly improving the Minimum Detectable Activity Concentration (MDAC) compared to direct Cherenkov or LS measurements in water. The estimated MDACs for the method are 0.20 Bq/l using Cherenkov counting and 0.04 Bq/l using gross alpha/beta LS counting.

The MDAC achieved with Cherenkov counting allows for radon-in-water measurements for the purposes of radiation protection, ecology, hydrology, and earth sciences without requiring LS cocktails.

The MDAC for LS counting facilitates radium-in-water measurements (via radon measurement) for radiation protection without chemical pretreatment of the water sample.

Additionally, the method enables direct estimation of the radon partition coefficient between water and oils. The partition coefficient of radon between sunflower oil and water at 20 °C is estimated at $K_{oil/w} = 23.2(16)$.

1. Introduction

The radioactive noble gas ^{222}Rn (hereafter referred to as radon) is the primary contributor to the annual effective radiation dose received by the general population and is recognized as a significant carcinogen (US Environmental Protection Agency, 2024a; World Health Organization, 2009, 2017). Together with its parent nuclide, ^{226}Ra (also known as a carcinogen (ICRP, 1993; World Health Organization, 2017)), these naturally occurring radionuclides are part of ^{238}U decay series. One of the pathways by which these nuclides enter the human environment is through tap water. Therefore, their concentrations in tap water sources are subject to control and monitoring.

To account for differing exposure mechanisms, the European Union has established a parametric value of 100 Bq/l and a remedial action level of 1000 Bq/l for radon in water, as well as a reference value of 0.5 Bq/l for ^{226}Ra (hereafter referred to as radium) in water, corresponding to an annual effective dose of 0.1 mSv/y (EU Council Directive, 2013). Similarly, the US Environmental Protection Agency recommends maximum contamination levels of 4000 pCi/l (~ 150 Bq/l) for radon (US Environmental Protection Agency, 1999) and 5 pCi/l (~ 0.2 Bq/l) for radium (^{226}Ra and ^{228}Ra combined) (US Environmental Protection Agency, 2024b). In addition, mineral water with high concentrations of radon or radium poses significant health risks, when bottled

(Chmielewska et al., 2020) or used in spa treatments (Sainz et al., 2016; La Verde et al., 2022).

The measurement of radon in water is of scientific interest beyond the field of radiation protection. Typical radon concentrations in surface water are generally up to a few Bq/l, whereas concentrations in groundwater can range from tens to thousands of Bq/l (Ortega et al., 2015; Jobbagy et al., 2017; Hauksson and Goddard, 1981; UNSCEAR, 1993). This significant difference in radon levels, combined with its noble gas properties, makes radon measurements in surface and groundwater particularly valuable for studying the dynamics, mixing, age, and contamination of freshwater sources (Schubert et al., 2006a, 2006b, 2008, 2024; Hofmann et al., 2011).

Such measurements can also reveal anthropogenic ecological problems, including contamination of aquifers with Non-Aqueous Phase Liquids (NAPLs) (Schubert et al., 2007a, 2007b; Bonfim et al., 2017), groundwater contamination by volatile organic compounds (Schubert et al., 2011), and contamination of surface water through anthropogenic groundwater discharges (Santos et al., 2008; Hofmann et al., 2011). Furthermore, so-called "radon anomalies" (rapid increases in radon concentrations in groundwater) can be considered a potential precursor to earthquakes (Hauksson and Goddard, 1981; Papastefanou, 2002).

Due to its wide range of applications, various methods exist for measuring radon in water. The most widely used are liquid scintillation

^{*} Corresponding author.

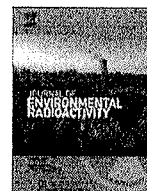
E-mail address: stahilg@phys.uni-sofia.bg (S. Georgiev).

<https://doi.org/10.1016/j.apradiso.2025.111752>

Received 3 February 2025; Accepted 24 February 2025

Available online 24 February 2025

0969-8043/© 2025 The Authors. Published by Elsevier Ltd. This is an open access article under the CC BY license (<http://creativecommons.org/licenses/by/4.0/>).



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

Halime Başkaya^{a,*}, Mahmut Doğru^{a,1}, Adnan Küçükönder^b

^a Bitlis Eren University, Faculty of Arts & Science, Department of Physics, 13000 Bitlis, Turkey

^b Kahramanmaraş Sıltçılı İmam University, Faculty of Arts & Science, Department of Physics, 46100 Kahramanmaraş, Turkey

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 Veterinary 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 $82 \pm 22 \text{ Bq kg}^{-1}$ fw in the straw group small intestine sample and $74 \pm 9.0 \text{ Bq kg}^{-1}$ 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 $2.1 \times 10^0 \text{ d kg}^{-1}$ and 1.7×10^{-1} to $2.3 \times 10^0 \text{ d kg}^{-1}$, 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.

© 2014 Elsevier Ltd. All rights reserved.

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

* Corresponding author. Tel.: +90 422 311 00 91.

E-mail addresses: halimebaskaya@hotmail.com (H. Başkaya), dogrums@gmail.com (M. Doğru), akucukonder@ksu.edu.tr (A. Küçükönder).

¹ Permanent address: University of Pirat, Faculty of Science, Department of Physics, 23169 Elazığ, Turkey.

(ESTRATO)

[Handwritten signatures]

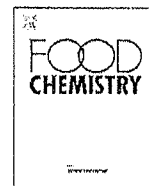
Food Chemistry 200 (2016) 293–300



Contents lists available at ScienceDirect

Food Chemistry

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



Identification of red pepper powder irradiated with different types of radiation using luminescence methods: A comparative study

Beom-Seok Song^{a,b,*}, Byeong-Keun Kim^c, Young-Min Yoon^a, Koo Jung^a, Jong-Heum Park^a, Jae-Kyung Kim^a, Cheong-Tae Kim^c, Yunjong Lee^a, Dong-Ho Kim^a, Sang-Ryeol Ryu^b

^a Department of Biotechnology, Advanced Radiation Technology Institute, Jeongseup 580-185, Republic of Korea

^b Division of Agriculture and Biotechnology, Seoul National University, Seoul 151-921, Republic of Korea

^c Food Safety Research Institute, Nong Shim Co., Ltd., Seoul 156-709, Republic of Korea

ARTICLE INFO

Article history:

Received 14 September 2015

Received in revised form 1 December 2015

Accepted 12 January 2016

Available online 13 January 2016

Keywords:

Red pepper powder

E-beam

Gamma ray

X-ray

Photostimulated luminescence

Thermoluminescence

ABSTRACT

The purpose of this study was to verify the reliability of photostimulated luminescence (PSL) and thermoluminescence (TL) methods for identifying irradiated foods, described in the European standards EN 13751:2002 and EN 1788:2001, respectively, which were established solely through interlaboratory studies on gamma-irradiated food. Red pepper powder samples irradiated with electron-beams (e-beams), gamma rays and high-energy X-rays were used as model foods. Samples irradiated with each radiation type at ≥ 4 kGy could be correctly identified by the PSL method, whereas samples irradiated at ≥ 0.5 kGy with each radiation type could be correctly recognized by the TL method when e-beams, gamma rays, or high-energy X-rays were used as normalization sources. However, different TL intensities were observed for minerals separated from red pepper powder for different irradiation sources, which was confirmed using pure quartz and K-feldspar minerals. Further interlaboratory studies are required to verify this phenomenon.

© 2016 Elsevier Ltd. All rights reserved.

1. Introduction

Red pepper powder (*Capsicum annuum* L.) is one of the most widely used spices in Asian countries. Red pepper powder is generally contaminated with microorganisms, which can cause food spoilage and foodborne illness outbreaks, during the cultivation, drying, grinding, and storage processes (Banerjee & Sarkar, 2003). Decontamination processes, including fumigation with ethylene oxide, steam heat sterilization and irradiation, have been used to eliminate such contaminants. Among these treatment procedures, irradiation is most suitable, because steam heat treatment is limited to decontamination steps prior to packaging and ethylene oxide fumigation is restricted in many countries, owing to the possibility of toxic residues (Diehl, 2002; Farkas, 1998; Farkas & Andrassy, 1998).

Irradiation technology is predominantly used to inactivate microorganisms in dried vegetables and spices (Arvanitoyannis & Tserkezou, 2010). Food can be treated with three types of radiation, namely gamma rays from radioisotopes, machine-generated

electron-beams (e-beams; maximum energy of 10 MeV), and X-rays generated by using electrons less than 5 MeV (7.5 MeV in the US). The three types of radiation exhibit different characteristics depending on their energy level and transferring material. Gamma rays and X-rays are types of photon-based radiation in the electromagnetic spectrum (Farkas & Farkas, 2011). Both of these types of radiation are in the short-wavelength, high-energy region of the spectrum and can penetrate foods to depths of several centimeters. However, the energies from gamma rays are 1.17 and 1.33 MeV from ^{60}Co and 0.66 MeV from ^{137}Cs , respectively, whereas X-ray is bremsstrahlung with a wide energy spectrum ranging from several keV up to the electron-beam energy (Cleland & Stichelbaut, 2013; Seltzer, Farrel, & Silverman, 1983). E-beams and X-rays are generated by an electron accelerator, such as a linear accelerator. E-beams with a maximum energy of 10 MeV are particulate radiation and, hence, have a cross-section many times greater than photons, as a result of which they do not penetrate the product beyond a few inches, depending on the product density (Fan & Sommers, 2013). In our previous study, e-beam irradiation was found to be more efficient at inactivating the total aerobic bacteria in red pepper powder compared to gamma and X-ray irradiation. Additionally, none of the tested radiation types changed the quality properties of the red pepper powder (Jung et al.,

* Corresponding author at: Department of Biotechnology, Advanced Radiation Technology Institute, Jeongseup 580-185, Republic of Korea.

E-mail address: sbs0110@kaeri.re.kr (B.-S. Song).

[Handwritten signature]