THESIS BOOK

Modelling the environmental migration of radionuclides released from nuclear facilities, and calculation of the resulting doses

THESIS OF THE DOCTORAL (PhD) DISSERTATION

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TARTALOMJEGYZÉK

Introduction

Artificial radionuclides originating from nuclear explosions and nuclear facilities can reach the human body through numerous pathways once released into the environment. To track their migration in natural ecosystems, we need so-called dispersion models. Food chain models can be applied to examine the interactions between these substances and the elements of the biosphere. Due to the statistical nature of the physical-chemical processes describing dispersion and the varying degrees of conservatism among the parameters used in modelling, the results of model calculations are characterized by significant uncertainty.

Objectives

The aim of this work is to review and compare the dose calculation (food chain) models/recommendations found in available domestic and international publications.

Sensitivity analysis of the parameters used in the calculations. Development of an analytical method for determining site-specific bioaccumulation factor(s) and development of a dose calculation food chain model, which can be integrated into a graphical software.

Experimental Part (Materials and Methods)

In the literature review section, I present the relevant literature related to my original objectives. In the experimental part, I apply this knowledge to solve a specific problem. My work does not include modeling atmospheric dispersion or external radiation exposure. I primarily focus on modeling and determining the radiation exposure of the human body from the food chain.

The impact of the uncertainty of the parameters used for estimation is overestimated several times in order to protect the population and the environment during the determination of radiation exposure. Thus, it is necessary to examine how changes in the parameters belonging to the formulas affect the results. This can be determined by testing the sensitivity of the parameters.

I have identified a total of 15 different input parameters required for determining radiation exposure from the food chain, of which different values can be found in the available databases. Based on the results of statistical (partial correlation analysis and regression analysis) and analytical sensitivity analysis methods, I have determined that the parameters with a great influence on the result are the deposition rate (Dc) and the bioaccumulation factors ($F_{t\text{-}n}$, $F_{n\text{-}á}$). The values of the former differ within an order of magnitude in the case of wet and dry fallout, but with good adjustment, the difference can be eliminated. In the case of bioaccumulation factors, this is more difficult to solve, because in the case of different soil and plant types, as well as animal diversity, the existence of site-specific data is essential, as this is the main source of the several orders of magnitude differences.

I present in detail the applicability of neutron activation analysis and gamma spectrometry for determining stable cesium and stroncium in environmental samples (soil, plants, and animal origin). The method can be applied reliably with a low detection limit, a small sample amount (<1g), minimal sample preparation, and in a non-destructive manner. Based on the results presented in the dissertation, I verified that the bioaccumulation factors of stable cesium (^{133}Cs) and stroncium (^{84}Sr) correlate with those of radiocesium (^{137}Cs) and radiostroncium (^{90}Sr), making them suitable as input parameters for model calculations.

Based on my results, I developed a user-friendly, platform-independent software that implements a model for determining the radiation exposure from the food chain. Thanks to the method based on the remeasurement of stable elements that I developed, it is possible to achieve more accurate results in the model calculations.

THESIS OF THE DOCTORAL (PHD) DISSERTATION

Thesis 1

I have examined, compared, and reviewed various dose calculation models used in domestic and international guidelines and software. Through sensitivity analysis methods, I have analysed the input parameters that have a significant impact on the result and verified the importance of site-specific bioaccumulation factors.

Thesis 2

For the most significant input parameters (transfer factors), I have developed a low-detection-limit analytical method (using Neutron Activation Analysis and gamma spectrometry for small sample analysis) to determine stable elements. This allows for the determination of site-specific data for caesium and strontium in a potential accident scenario. I have also verified that this method can be used to survey areas that are not contaminated (areas with undetectable levels of radioactive elements).

Thesis 3

Using the models included in international recommendations and considering various accident and environmental factors, I have created a platform-independent software with a graphical interface and a model implemented in the corresponding code. With its help, the extent of radiation exposure resulting from the food chain following a given accident situation can be modelled on a site-specific basis. I recommend the software for estimating the impact of various radiation exposure events on the internal radiation exposure of the population.

PUBLICATIONS THAT POSE THE BASE OF THE DISSERTATION

Foreign language articles published in international refereed journals (4)

1. Bátor, G., Bednár, A., Glover, T.J., Kovács, T., Landsberger, S., 2018. **Determination of cesium transfer factors by instrumental neutron activation analysis.** J Environ Radioact 187, 16–21.
2. Brennan, C., Haas, D., Landsberger, S., Artnak, E., Bátor, G., Bednár, A., Kovács, T., 2019. **A feasibility study on the determination of 90Sr food-chain transfer using stable strontium as a surrogate and neutron activation analysis**. J Environ Radioact 208–209, 105988.
3. Naofumi, A., Chie, I., Akemi, K., Masahiro, T., Hirofumi, T., Nagayoshi, S., Kimpei, I., Hegedűs, M., Bátor, G., Kovács, T., Hideki, K., 2020. **Low-volume Electrolytic Enrichment for Tritium Measurement Using Improved Solid Polymer Electrolyte System at NIFS and Its Application**. RADIATION ENVIRONMENT AND MEDICINE 9, 93–97.
4. Stojković, I., Todorović, N., Nikolov, J., Krajcar Bronić, I., Bátor, G., Kovács, T., 2019. **Investigation of fast screening LSC method for monitoring 14C activity in wastewater samples**. Radiat Meas 121, 1–9.

Conference publications (13)

1. Kovács, Tibor, Gergő Bátor, Edit Tóth-Bodrogi, Róbert Mészáros, and István Lagzi. 2023. **"Improvements of the Radionuclide Atmospheric Dispersion and Food Chain Model."** In *ABSTRACTS & SOUVENIR First International Conference on Radiation Awareness and Detection in Natural Environment (RADNET-IV)*.
2. Kovács, Tibor, Gergő Bátor, Zhanat Baigazinov`, Miklós Hegedűs, Anita Csordás, and Edit Tóth-Bodrogi. 2023. "**Selection of the Biomonitors for the Contaminated Sites.**" In The 10th Educational Symposium on RADIATION AND HEALTH by Young Scientists ESRAH2023 Program&Abstracts, 7–8.
3. Kovács, Tibor, Gergő Bátor, Edit Tóth-Bodrogi, Róbert Mészáros, and István Lagzi. 2022. **"New Possibilities for the Development of the Radionuclide Atmospheric Dispersion Model."** In Book of Abstracts The 9th Educational Symposium on RADIATION AND HEALTH by Young Scientists (ESRAH2022).
4. A, Bednár, Gergő Bátor, Edit Tóth-Bodrogi, and Tibor Kovács. 2016. **"Radiostrontium Monitoring in the Region of Bakony Mountains."** In V. Terrestrial Radioisotopes in Environment, Veszprem.

5. A., Bednár, Gergő Bátor, Edit Tóth-Bodrogi, and Tibor Kovács. 2017. "**Determination of Sr-90 Activity Concetration and Strontium/Calcium Ration in Different Matrices.**" In 4th International Conference on Environmental Radioactivity: Radionuclides as Tracers of Environmental Processes (ENVIRA 2017), 47.
6. Bátor, Gergő, Bednár A., and Tibor Kovács. 2019. **"Variance and Sensitivity Analysis of Fodd-Chain Models."** In 5th European IRPA Congress, Book of Abstracts, edited by Smetsers Ronald, 131. Hága: International Radiation Protection Association (IRPA).
7. Bátor, Gergő, Bednár A, Glover T J, Tibor Kovács, and Landsberger S. 2017. "**Determination of Cesium Transfer Factors by Instrumental Neutro Activation Analysis.**" In 7th International Symposium on IN SItu NUclear MEtrology as a Tool for Redioecology - INSINUME 2017, 85.
8. C., Brennan, Haas D., Landsberger S., Gergő Bátor, Bednár A., and Tibor Kovács. 2018. **"The Determination of 90Sr Transfer Factors in the Environment Using Stable Strontium as a Surrogate and Neutron Activation Analysis."** In VI. Terrestrial Radioisotopes in Environment, Veszprem.
9. Katona, Richárd, Krojer A., Gergő Bátor, and Tibor Kovács. 2019. **"Neutron Activation Analysis for Determining the Chlorine Content of Crude Oil."**

10. Landsberger, Sheldon, N Kaitschuck, Gergő Bátor, and Tibor Kovács. 2023. "**Overview of Neutron Activation Analysis for Environmental Radioactivity Measurements."** In Book of Abstracts: 7th International Conference on Environmental Radioactivity (ENVIRA 2023).
11. S., Landsberger, Gergő Bátor, and Asper N. 2020. "**On Using Neutron Activation Analysis to Determine 235,238U, 40K and 232Th and Monitoring 137Cs and 90Sr Employing Stable Element Surrogates in Various Matrices with Sub-Gram Quantities of Material: A Review."** In VII. Terrestrial Radioisotopes in Environment, Veszprem.