Investigation of the geochemical behaviour and soil to food-chain transfer of various man-made radioisotope

Doctoral (Ph.D.) Thesis

Doctoral School of Chemical Engineering and Material Sciences

Candidate:

Ganbaatar Tuvshinsaikhan

Supervisor:

Dr. Király Amin (Ph.D.)

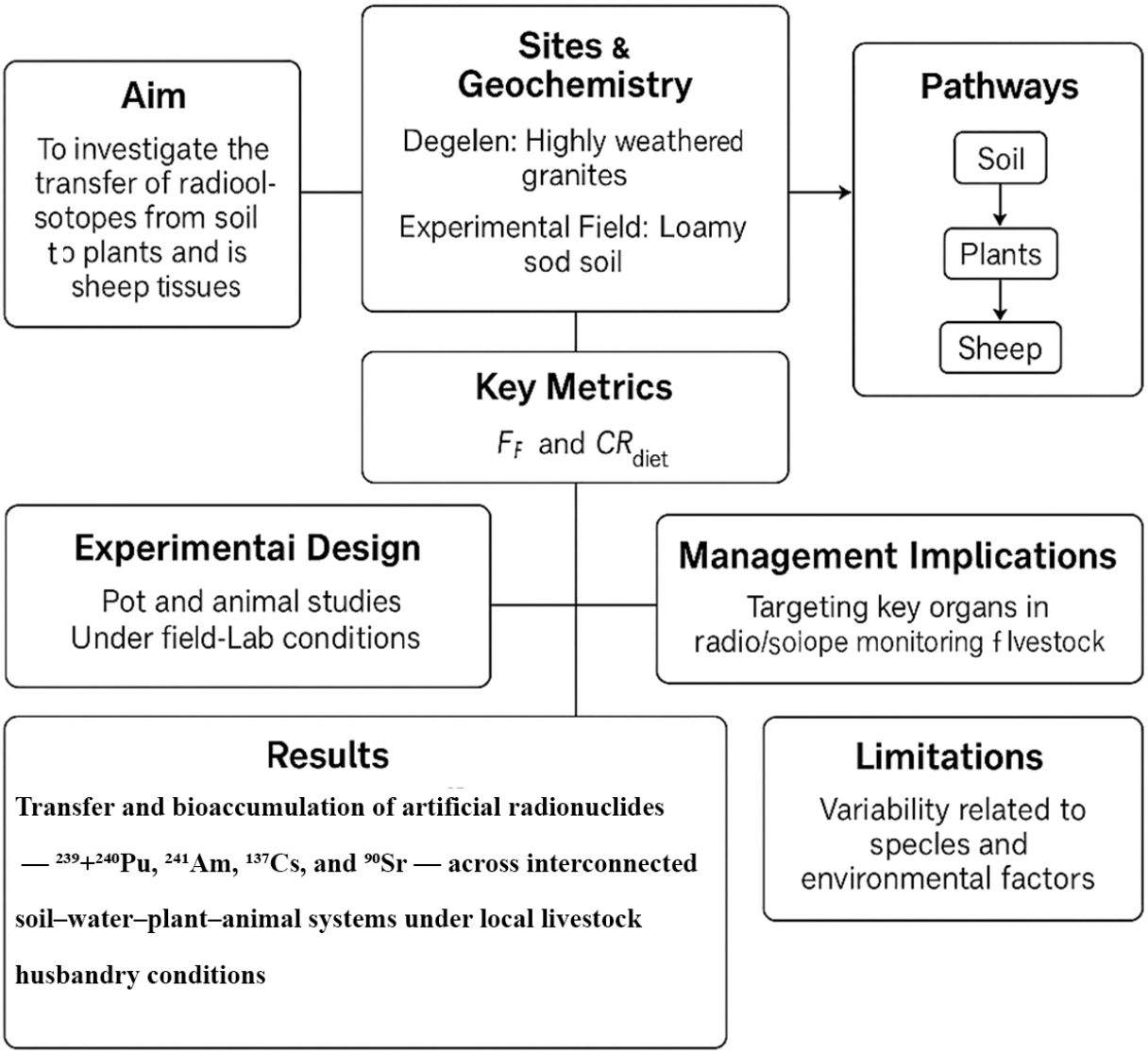
Dr. Tóth-Bodrogi Edit (Ph.D.)

Department of Radiochemistry and Radioecology

University of Pannonia

Veszprém 2025-2026

Thesis Overview



Thesis Statements (tested & supported)

- **Mobility governs uptake:** ^{90}Sr mobile (Degelen) → bone; Pu/Am bound in soil yet enter via **soil ingestion** to liver/skeleton.
- **Pathway > total burden:** Tissue distributions depend more on **intake route** (water/forage/soil) than on ambient levels alone.
- **Manageable pathways:** Water-access control + soil-ingestion reduction **significantly** lower edible-tissue burdens.
- **Heterogeneity matters:** 15–75× variability demands **site-specific** monitoring & decisions.

Limitations (for defense Q&A)

- Inhalation (dust) not quantified; winter season not covered.
- Long-term post-exposure redistribution not tracked.
- Multi-radionuclide interactions not resolved; species-specific calibration required.

List of the publications in connection with the thesis

1. Akuo-ko, Esther Osei ; Otoo, Francis ; Glover, Eric Tetteh ; Amponsem, Eunice ; Tettey-Larbi, Lordford ; Ganbaatar, Tuvshinsaikhan ; Csordás, Anita ; Shahrokhi, Amin ; Kovács, Tibor. Radiological Implications of Industrial Activities on Soil and Water: An Environmental Analytical Chemistry Perspective in Artisanal Gold-Mining Regions of Atiwa West. Applied Sciences. 15 : 18 p. 9857 (2025). **Rank: Q2. IF: 2.5.**

2. Nguyen Dinh, Chau ; Duong, Van-Hao ; Chu Trung, Tien ; Pham Thi, Thanh-Xuan ; Nguyen Ngoc, Truc ; Nguyen Thi, Hoang Ha ; Hoang Dinh, Que ; Tran Danh, Hung ; Musthafa, Mohamed Saiyad ; Nguyen, Tien-Manh et al. Uranium isotopes and several heavy elements in selected waters in Quang Nam-Da Nang provinces, Central Vietnam. Journal of radioanalytical and nuclear chemistry. 2024. **Rank: Q2. IF: 1.6.**

3. Baigazinov, Zhanat ; Lukashenko, Sergey ; Silybayeva, Batiyash ; Zharykbasova, Klara ; Bukabayeva, Zhanylkhan ; Muhamediarov, Nurlan ; Kantbayeva, Bagdat ; Kozhakhmetova, Balzhan ; Ganbaatar, Tuvshinsaikhan ; Toth-Bodrogi, Edit et al. The transfer of 137Cs and heavy metals to tissues within the organs of snails. SCIENTIFIC REPORTS 13 : 1 Paper: 15690 (2023). **Rank: D1. IF: 3.9.**

Tuvshinsaikhan Ganbaatar's data (2025.11.06)
MTMT publication and citation summary table

Publication types	Count	
	All	Detailed
I. Scientific journal articles	3	
in international journal in foreign language		3
in international journal in hungarian		0
in hungarian journal in foreign language		0
in hungarian journal in hungarian		0
II. Books	0	
a) Book as author	0	
in foreign language		0
in hungarian		0
b) Book as editor[2]	0	
in foreign language		0
in hungarian		0
III. Book chapter	0	
in foreign language		0
in hungarian		0
IV. Conference in journal or conference paper	0	
in foreign language		0
in hungarian		0
Publications (I-IV.)	3	
Abstract[3]	28	
Research data	0	
Other scientific works[4]	0	
All scientific publications	31	

participated in 28 national and international conferences.

Introduction

Radioactive contamination originating from nuclear weapon testing represents one of the most complex environmental and health challenges in the former test sites of the world. Between 1949 and 1989, extensive atmospheric and underground nuclear explosions were conducted at the Semipalatinsk Test Site (STS) in Kazakhstan, resulting in the dispersion of significant quantities of fission and activation products into the environment. Decades after the cessation of testing, radionuclides such as cesium-137 (^{137}Cs), strontium-90 (^{90}Sr), plutonium isotopes ($^{239+240}$Pu), and americium-241 (^{241}Am) persist in soils, sediments, water bodies, and biota, posing potential long-term radiological risks through the terrestrial food chain.

Understanding how these radionuclides behave in the soil–plant–animal continuum is essential for evaluating human exposure in affected regions. The mobility and bioavailability of radionuclides are influenced by geochemical conditions, soil characteristics, and ecological pathways. While elements such as ^{90}Sr and ^{137}Cs are known to migrate more readily within biological systems due to their chemical similarity to calcium and potassium, actinides like $^{239+240}$Pu and ^{241}Am tend to bind strongly to soil particles, limiting their plant uptake but potentially entering animals via soil ingestion. The livestock pathway—particularly sheep grazing on contaminated pasture—remains a sensitive indicator of environmental transfer processes and food chain contamination potential.

Given these complexities, this research focuses on assessing the transfer and accumulation of major anthropogenic radionuclides from contaminated soils and forage into sheep tissues under different environmental settings of the STS. By quantifying transfer coefficients (F_f) and diet concentration ratios (CR_diet), and analyzing the role of soil, vegetation, and water as intake routes, the study provides a scientific basis for evaluating exposure pathways, identifying critical organs of accumulation, and proposing risk mitigation measures for radiological protection of livestock and human consumers in post-nuclear test areas.

Aim

The aim of this dissertation was to investigate the transfer of ^{137}Cs, ^{90}Sr, $^{239+240}$Pu, and ^{241}Am from contaminated soils, vegetation, and water into sheep tissues within different STS environments. The study sought to determine radionuclide-specific transfer coefficients and concentration ratios, compare the influence of environmental and dietary pathways, and provide recommendations for reducing food-chain exposure in grazing livestock raised on legacy-contaminated lands.

I. THESIS

The mobility of radionuclides in STS soils governs their transfer into livestock tissues, with ^{90}Sr (mobile) showing greater uptake into bone, while $^{239+240}Pu$ and ^{241}Am (strongly bound) primarily enter liver and skeleton through soil ingestion. Findings showed strong site-specific geochemical contrasts: ^{90}Sr was highly mobile at Degelen, while transuranic and ^{241}Am were less mobile but still entered animals via incidental soil intake.

II. THESIS

Pathway of intake (forage, water, or soil) is a stronger determinant of radionuclide distribution in sheep tissues than total radionuclide burden in the environment. Finding demonstrated that ^{137}Cs and ^{90}Sr burdens were greatest when intake came via contaminated waters/vegetation, while actinides entered mainly through soil ingestion, regardless of overall site contamination levels.

III. THESIS

Livestock management interventions that restrict access to contaminated watercourses and reduce soil ingestion can significantly lower radionuclide burdens in edible tissues and offal. Findings highlighted the key management insights were: (i) hydrologically connected areas are critical control points for ^{137}Cs and ^{90}Sr, and (ii) soil ingestion drives actinide uptake into liver and bone.

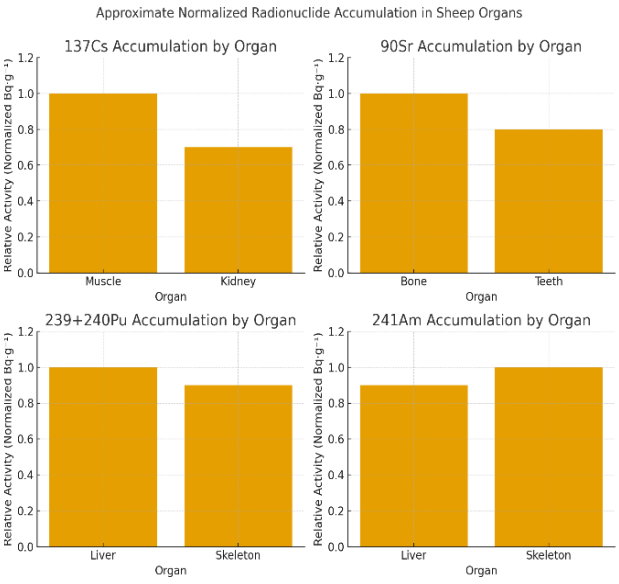
IV. THESIS

Spatial heterogeneity in radionuclide accumulation by vegetation at the STS leads to large variability (15–75 fold) in potential livestock intake, necessitating site-specific monitoring rather than uniform risk assumptions. Findings showed extreme variability in accumulation coefficients, which directly influences radionuclide transfer into animals and highlights the need for targeted, localized assessment.

Results

The results demonstrated clear differences in the behavior and bioaccumulation of the investigated radionuclides (^{137}Cs, ^{90}Sr, $^{239+240}$Pu, and ^{241}Am) among the Semipalatinsk Test Site (STS) subregions. The concentration of ^{90}Sr in environmental media and biological samples was highest in the Degelen area, where the nuclide showed high mobility through water systems and active uptake by vegetation. In contrast, the Experimental Field area displayed low radionuclide mobility, with ^{137}Cs, $^{239+240}$Pu, and ^{241}Am predominantly retained in surface soils due to strong particle binding and low solubility. Tissue analyses from controlled feeding experiments revealed that each radionuclide followed a distinct biological distribution pattern. The uptake of ^{137}Cs was highest in muscle and kidney tissues, consistent with its chemical similarity to potassium and its ability to diffuse through soft tissue. The ^{90}Sr activity concentrated overwhelmingly in bone and teeth, reflecting its affinity for calcium and rapid incorporation into mineral structures. For actinides, $^{239+240}$Pu and ^{241}Am exhibited dominant accumulation in the liver and skeleton, with negligible activity in muscle or adipose tissue, confirming their limited metabolic mobility and primary intake via soil ingestion rather than forage or water.

Quantitatively, the transfer coefficients (F_f) and dietary concentration ratios (CR_diet) varied widely between radionuclides and pathways. The F_f values for ^{90}Sr in bone via water ingestion were one to two orders of magnitude higher than those for feed or soil intake, indicating water as a critical vector. Meanwhile, ^{137}Cs transfer was strongly dependent on vegetation source and feeding conditions, whereas actinide uptake was driven by dust and soil ingestion levels. These findings emphasize the site-specific nature of radiological transfer processes and provide a data-driven foundation for evaluating potential internal doses to grazing livestock and associated food-chain exposure risks. Figure 1 shows showing how the radionuclides (^{137}Cs, ^{90}Sr, $^{239+240}$Pu, and ^{241}Am) accumulate in their main target organs on a per-gram basis.



The figure presents the normalized accumulation of the main radionuclides (^{137}Cs, ^{90}Sr, $^{239+240}$Pu, and ^{241}Am) in key sheep organs, expressed as relative activity per gram of tissue. Cs-137 shows the highest accumulation in muscle and kidney, indicating its mobility as a potassium analogue. Strontium-90 is concentrated in bone and teeth, reflecting its calcium-like behavior in mineral tissues. The actinides, plutonium and americium, are mainly retained in the liver and skeleton, showing strong binding to organic and phosphate-rich structures.

Discussion

The study confirmed that the mobility of radionuclides in the environment directly governs their biological uptake within the Semipalatinsk Test Site. Strontium-90, the most mobile radionuclide observed at the Degelen area, readily entered vegetation and surface waters and consequently accumulated in the bones and teeth of exposed sheep. In contrast, plutonium and americium, despite their low solubility and strong sorption to soil particles, still entered biological systems through indirect intake—mainly soil ingestion during grazing. Their retention in the liver and skeleton demonstrates that even immobile radionuclides can contribute to internal exposure when soil contact is frequent and persistent.

The findings further demonstrate that the route of intake is a stronger determinant of tissue distribution than the overall contamination level of the environment. Animals exposed through contaminated water sources showed markedly higher ^{90}Sr concentrations in bone compared with those grazing on contaminated vegetation or soil alone. Similarly, ^{137}Cs uptake was influenced more by the specific forage type and feeding condition than by total soil activity. These results emphasize that evaluating only ambient concentrations can be misleading if intake pathways are not clearly defined, and that exposure assessments must integrate behavioral and ecological factors.

The research also provides practical evidence that controlling specific exposure pathways can effectively reduce internal contamination. Restricting livestock access to contaminated surface water and reducing soil ingestion through improved feeding practices—such as providing clean feed, minimizing dust, and avoiding overgrazed pastures—significantly decreases radionuclide transfer into edible tissues. These management interventions are achievable under local husbandry conditions and offer immediate, low-cost means of lowering radiological risk without requiring large-scale soil remediation.

Finally, the data highlight the importance of site-specific monitoring and decision-making, as the observed variability in plant and water uptake factors reached between 15- and 75-fold across STS subregions. Such heterogeneity reflects differences in soil chemistry, hydrology, and vegetation type, and confirms that uniform regulatory limits or generalized transfer models cannot capture local realities. Future radiological protection strategies should therefore combine environmental measurements with locally validated transfer coefficients to ensure realistic and effective risk assessment in post-nuclear test areas.