Univerzita Karlova v Praze, Přírodovědecká fakulta
Ústav pro životní prostředí

Charles University in Prague, Faculty of Science
Institute for Environmental Studies

Doktorský studijní program: Environmentální vědy
Ph.D. study program: Environmental Science

Autoreferát disertační práce
Summary of the Ph.D. Thesis

Chování radioaktivních látek ve Vltavě a Labi při jaderné havárii
Behaviour of radioactive substances in the Vltava and Elbe Rivers during nuclear accident

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Praha, 2021

The dissertation thesis is based on the following publications:

1. Eva Juranová, Eduard Hanslík, Diana Marešová: Temporal development of radiocaesium and radiostrontium concentrations in the hydrosphere – methods of evaluation. Water, Air, & Soil Pollution, 2015, roč. 10, č. 226, ISSN 0049-6979.
2. Eva Juranová, Eduard Hanslík: Determination of sorption characteristics for artificial radionuclides in the hydrosphere. Journal of Radioanalytical and Nuclear Chemistry, 2015, roč. 304, č. 1, s. 21-26. ISSN 0236-5731.
3. Eva Juranová, Eduard Hanslík, Silvia Dulanská, Tomáš Grísa, Barbora Sedlářová a Diana Marešová: Sorption of anthropogenic radionuclides onto river sediments and suspended solids: dependence on sediment composition. Journal of Radioanalytical and Nuclear Chemistry, 2020, roč. 324, č. 3, s. 983-991. ISSN 0236-5731.
4. Diana Marešová, Eduard Hanslík, Eva Juranová, Barbora Sedlářová: Determination of low level tritium concentrations in surface water and precipitation in the Czech Republic. Journal of Radioanalytical and Nuclear Chemistry, 2017, roč. 314, č. 2, s. 681-687. ISSN 0236-5731.
5. Eva Juranová, Barbora Sedlářová, Diana Marešová: Tritium in the Vltava and Elbe Rivers – monitoring and modelling. In: Magdeburský seminář o ochraně vod 2021. Sborník.

Abstract

This work is focused in the research of the behaviour of radioactive substances released into the hydrosphere of the Vltava River and the subsequent Elbe stretch during a severe accident at the Temelín Nuclear Power Plant. The background values of anthropogenic radionuclides in surface water, residual contamination after the Chernobyl accident and after atmospheric tests of nuclear weapons, were evaluated using two methods and these methods were compared. The migration of the accidental radioactive contaminants in the watercourse would be mainly influenced by their ability to sorb onto the solid phase in the hydrosphere. Therefore, the sorption of particular anthropogenic radionuclides onto bottom sediments and solids suspended in the water column was monitored and evaluated at several sites along the Vltava and the Elbe Rivers. Furthermore, the possibility of using tritium, which is discharged during normal operation of the Temelín power plant, as tracers for the purposes of modelling the migration of pollution, was assessed.

1. Introduction

Nuclear energy is currently a significant source of electricity in the world. According to the International Atomic Energy Agency (IAEA), nuclear energy was approximately 13% of global energy consumption in 2020 [1]. Despite that, nuclear energy raises many questions, especially in terms of safety and its environmental impacts.

In the Czech Republic, nuclear energy accounts for about one third of electric power generation [1], which includes both Czech nuclear power plants (NPP), the Temelín and the Dukovany plants. The subject of this thesis is the Temelín NPP, which is located in southern Bohemia near the Vltava River, into which the NPP discharges its wastewater [2]. According to the documentation [15], the Temelín NPP must handle emergencies, including the maximum project accident. The probability of a more serious accident with a significant release of radionuclides into the environment could therefore occur with a very low probability. Despite that, it is important to gather knowledge about this kind of events, since their consequences could be serious.

2. Aims of the study

The general aim of this thesis is to gain and improve knowledge about the behaviour and transport of radioactive pollution in the hydrosphere during a nuclear accident. Specifically it is focused on the Temelín NPP and the related Vltava and Elbe River parts. This general objective was elaborated in three sub-objectives (SO):

SO 1. Existing (pre-accident) content of radionuclides in the vicinity of the Temelín NPP – comparing of the evaluation methods

In vicinity of the Temelín NPP, anthropogenic radionuclides are present as residual contamination originating from the atmospheric tests of nuclear weapons and the Chernobyl accident. Their amount in the hydrosphere has been monitored and evaluated long-therm. One of the goals of this study was to compare two alternative methods for evaluating of the activity concentrations of the anthropogenic radionuclides in the hydrosphere.

SO 2. Sorption of anthropogenic radionuclides in the hydrosphere

The migration of radionuclides in a watercourse can be significantly influenced by their ability to sorb on solid parts of the hydrosphere - suspended solids and sediments. There are several water reservoirs built along the studied section of the Vltava River, the Orlík Reservoir is the most important. As the water flow slows down, the sedimentation of suspended solids carried by water

increases. Substances fixed onto them settle down together with the solid particles and become part of bottom sediments. Another sub-objective of this thesis was to quantify the sorption of selected anthropogenic radionuclides in the studied section of the Vltava and the Elbe Rivers, as an important factor influencing the migration of radionuclides in the stream.

SO 3. Transport of contamination and its evaluation using tritium as a tracer

During normal operation, the Temelín NPP discharges a low but measurable amount of tritium into the river. As a result of this release, variable tritium concentration can be detected in the wastewater recipient.
One of the aims of this work was to verify, whether tritium measured in surface water below the Temelín wastewater release could be used to model the migration of contamination in the Vltava and Elbe Rivers under the conditions of a nuclear accident.

3. Material and methods

SO 1. Existing (pre-accident) content of radionuclides in the vicinity of the Temelín NPP - comparing of the evaluation methods

In SO 1, this study uses data that were collected at the Department of Radioecology, T. G. Masaryk Water Research Institute (TGM WRI) and continues the work presented in [3].
1st order kinetics was used in the TGM WRI [4] and elsewhere [5-7] to describe the decrease of anthropogenic radionuclides in the hydrosphere. However, the rate of the decrease changes over time, so it was necessary to divide the long-term observation series into several time periods and evaluate them separately. This traditional approach has been compared with the Smith model [5, 8], which describes the complex process in a single time period.

SO 2. Sorption properties of anthropogenic radionuclides in the hydrosphere

For the purposes of this study, a method of distribution coefficient (K_d) determination was developed [9], considering the specific properties of the anthropogenic radionuclide sorption onto the sediment and suspended solids. The method was based on standard methodologies [10, 11], which were optimized and tested for the aquatic environment and anthropogenic radionuclides.
Using this method, K_d values were determined at seventeen sites along the Vltava and Elbe Rivers, for both, sediment and suspended solids. Seven representative

anthropogenic radionuclides were selected: ^{131}I, ^{134}Cs, ^{85}Sr, ^{60}Co, ^{241}Am, ^{139}Ce, ^{133}Ba.

SO 3. Transport of contamination and its evaluation using tritium as a tracer

To verify that tritium discharged from the Temelín NPP into the Vltava River can be used as a tracer, long-term data measured by TGM WRI were used. Tritium was monitored at several sites along the Vltava and Elbe Rivers which were affected by tritium water discharges from NPP Temelín: Kořensko, Solenice, Štěchovice, Podolí, Zelčín and Hřensko and at two reference sites: Hluboká and Lysá nad Labem.

Tritium was monitored at the above mentioned sites with a frequency from once a month to 2 times a week. In the laboratory, tritium was determined using liquid scintillation spectrometry. For samples from reference sites a unique pre-treatment by electrolytic concentration was included, which allows determination of very low tritium concentration [12].

Based on these data, the tritium concentration was modelled further downstream, in the German part of the Elbe River. The calculation was made based on the assumption that the amount that flows through a particular site per year did not change along the river.

4. Results and discussion

SO 1. Existing (pre-accident) content of radionuclides in the vicinity of the Temelín NPP - comparing of the evaluation methods

The amount of ^{90}Sr and ^{137}Cs, the residual anthropogenic radionuclides, decreases in the hydrosphere over the time, faster than it would correspond to their radioactive decay. Compared to the traditional 1st order kinetics equation, the advantage of the Smith model [5, 8] is that it describes the decrease continuously throughout the long-therm observation period and at the same time, it respects the changing rate of decrease. That means it corresponds better to the processes taking place in the environmental system. Therefore, it seems more appropriate to describe the decrease of the anthropogenic radionuclides from the hydrosphere. However, even this approach shows some limitations, which are mainly based on the length and quality of the processed data set. The Smith approach is suitable especially for long and consistent series of good quality data. If the datasets do not meet these criteria, the results provided by this model are not reliable, as they have too high uncertainty, as stated in the article [13].

SO 2. Sorption properties of anthropogenic radionuclides in the hydrosphere

The measured K_d values showed that most studied radionuclides sorb to the solid particles in the hydrosphere significantly. It was found that the sorption of particular radionuclides onto bottom sediments and suspended solids varies considerably. The difference is mainly attributed to

the different grain sizes of these two components of the hydrosphere.
Furthermore, the K_d values differ among particular radionuclides, as well as among monitored sites. Despite variability was predicted, it exceeded all expectations. The K_d values varied even by an order of magnitude for the same radionuclide at particular sites. Detailed results are given in the article [14].
To explain the mentioned differences in K_d values, their relations to the sediment properties were evaluated. Most often, the sorption of radionuclides depended on grain size indicators, but this was not a universal finding, which was contrary to expectations. Universal dependencies were not found for the mineralogical composition either.

SO 3. Transport of contamination in the stream and its evaluation using tritium as a tracer

At the sites affected by discharges from the Temelín NPP, the tritium concentrations are increased above the reference level. The highest values of tritium concentration were measured at the Kořensko site, which is located just below the source of pollution. The lowest concentration was in Hřensko at the Elbe River, which is furthest from the source. At the monitored sites, the tritium concentration decreased with the distance from the Temelín NPP, as it was diluted by the tributaries [15].
Based on the tritium balance at the individual monitored sites, the tritium concentrations in the German part of the Elbe River were calculated. These modelled concentrations were then compared with the values measured by the local authorities, with which they were in good agreement [15].

5. Conclusions

The thesis is concerned with a situation of an accidental leakage of radioactive substances into the Vltava River and following section of the Elbe River. This situation is very unlikely, because the Temelín NPP meets all safety requirements for facility of this type. However, the consequences of such event would be serious, so they need to be dealt with.

In order to evaluate the impact of the Temelín NPP on the environment, if needed, it is necessary to know the hydrosphere reference state before the event. That includes very low residual activities of anthropogenic radionuclides, which come from the Chernobyl accident and the atmospheric nuclear weapon tests in the last century. The current evaluation method is not entirely convenient; therefore, an alternative approach was sought, which would take into account the complexity of the processes in the hydrosphere. However, it was found that the alternative approach was only suitable for certain data sets, in other cases it is necessary to maintain the current method of evaluation, even with its limitations.

The sorption of radionuclides onto the solid phase of the hydrosphere, bottom sediments and suspended solids, would play an important role in the transport of radioactive contamination, if it would be released from the Temelín NPP into the Vltava River. For most radionuclides, a high sorption on sediments and suspended solids was evaluated. This means that in such an emergency, the Orlík Reservoir could keep most of the contamination and reduce its penetration downstream. Searching for the relations among sorption and sediment properties did not bring satisfactory results, which could be used for

generalization of the local measured K_d values. These values are site-specific and have to be measured for the local conditions.

Further, it was assessed, whether tritium discharged from the Temelín NPP into the Vltava River can be used as a tracer for estimating the pollution migration. It was found that tritium amount along the stream changes mostly only because of dilution, it is not affected by sorption on the solid particles. Its decrease due to radioactive decay can be neglected in terms of flow times in the Vltava and Elbe Rivers, as well as losses due to evaporation. As a hydrogen isotope, tritium is part of water molecules, so by monitoring it it is possible to determine the movement of water itself.

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7. Curriculum vitae

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Education

2012 – present Ph.D. study
Institute for Environmental Studies, Faculty of Sciences, Charles University in Prague, Czech Republic
Study programme: Environmental Science
Ph.D. thesis: Behaviour of radioactive substances in the Vltava and Elbe Rivers during nuclear accident

1996 – 2001: Master degree.
Department of Water Technology and Environmental Engineering, Faculty of Environmental Technology, University of Chemistry and Technology, Study programme: Water Technology

Career

2017 - present: T. G. Masaryk Water Research Institute, public research organization, Head of Branch of Analysis and Assessment of Environmental Components,. Responsibility for research teams of hydrochemistry, microbiology, hydrobiology and radioecology and for Testing Laboratory of Water Technology and Environment Components.

2002 – 2017: T. G. Masaryk Water Research Institute, public research organization, Department of Radioecology. Researcher.

Selected Research Projects

VI04000017 - Wastewater monitoring used as an early warning tool for epidemic outbreak
TK02010064 - Conception of new system of modelling of anthropogenic radionuclide spreading in hydrosphere during the common operation of NPP and its accident with external impact including data assimilation according to the state requirements. (Present)
VI20192022142 Innovative methods for detecting ultra-low level radioactivity for water-source vulnerability evaluation after nuclear accident. (Present)
CZ.07.1.02/0.0/0.0/16_040/0000380 – Analysis of measures for mitigation of the impacts of the climate change and urbanization onto water regime in the Prague locality. (2018-2020)
CZ.07.1.02/0.0/0.0/16_040/0000382 – Recreational potential of water in Prague – presence and future. (2018-2020)
VG20122015088 - Investigation of the Temelín Power Plant accident on contamination of Vltava and Elbe Rivers up boundary profile Elbe at Hřensko (2012-2015)
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