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Radionuclide transport in shallow groundwater

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A B S T R A C T

Radioactive waste management is a strategic activity that is adopted in the nuclear field to safeguard the operating staff, the population and the environment from radiological risks. Studies that support the environmental assessment of a nuclear site offer insight into the understanding of the transport of radionuclides in environmental matrices (e.g. soil, groundwater, surface water, etc.). These studies, that involve the migration of a radiological source in the environment, are conducted to identify how to approach the safety assessment of current or future nuclear facilities. This work analyzes the source term as the key point in the modeling of the transport of radionuclides in groundwater and soil. A methodological approach, which focuses on the dynamic of the source term in space and time, was applied to model the transport of radionuclides. This approach can be used to plan reliable environmental monitoring networks. The analysis was performed at the nuclear site of Saluggia, Vercelli (Italy).

1. Introduction

In the nuclear area, radioactive waste management is a strategic activity that is adopted for public and environmental radiological protection that should be considered during design and the construction of a permanent repository. Each nuclear facility is characterized by a specific inventory, in which the type of radionuclides and their radioactivity must be known in detail, and by several containment barriers, which prevent the release of radioactive material or delay the transport of radionuclides outside the facility (Yim and Simonson, 2000).

In accidental situations, these radionuclides, or some of them, can be released into the environment. In this case, they are identified as source terms. The aim of this work was to analyze the transport of radioactive pollutants through soil and groundwater. The evaluation of the transport of radionuclides is a useful tool to design a reliable environmental monitoring network or to plan adequate mitigation works or other interventions in the case of accidental events, as well as to create a background of knowledge for accidental leakages from nuclear facilities (e.g. Levenson and Rahn, 1981; Lee and Jeong, 2011).

International Atomic Energy Agency (IAEA) defines source term as the magnitude, composition, form (physical and chemical) and mode of release (puff, intermittent or continuous) of radioactive elements (fission and/or activation products) released during a confinement loss from nuclear facilities (IAEA, 2008). The study of the source concerns the quantities and rates of release in groundwater, surface water, soil, etc. The type, the time and the location of the release must also be identified. The radiological consequences can be grouped into three categories, to facilitate their assessment (IAEA, 2008): consequences inside the reactor building with the operating staff or personnel within the building being subject to doses; on-site consequences within the area of the nuclear site (outside the reactor building); off-site consequences (on population). This work examines the consequences outside the facilities and focuses on the source term and on transport mechanisms in order to evaluate the behavior of radionuclides in soil and groundwater.

Jakimavičiūtė-Maselienė and Cidzikienė (2015) have studied the modeling of tritium in underground water at the new NPP site in Lithuania by means of the FEFLOW code. Aquino et al. (2008, 2010) presented an overview of the progress achieved in the development of Eulerian-Lagrangian schemes, to approximate the transport of radionuclides in unsaturated porous media, and developed a new algorithm for the numerical simulation of radionuclide transport problems in saturated heterogeneous porous media.

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Lamego Simões Filho et al. (2013) modeled tritium dynamics in surface waters in order to evaluate the radiological impact of its potential release from nuclear power plants into the environment.

A methodological approach, which couples on-site measurement data and the use of suitable software, Modflow (Harbaugh, 2005) and MT3DMS (Chunmiao and Wang, 1999), was applied in this work. The results are useful to identify the main critical points in which radionuclides could accumulate and, consequently, to plan a suitable environmental monitoring of the area under investigation. All these aspects were applied and validated at the Saluggia nuclear site, Vercelli (Italy). The on-site measurements were periodically carried out by national authorities in the field of environmental monitoring of nuclear sites, Regional Agency for the Protection of the Environment (Agenzia Regionale per la Protezione ambientale, ARPA) and Institute for Environmental Protection and Research (Istituto Superiore per la Protezione e la Ricerca Ambientale, ISPRA) (e.g. ARPA, 2013a). Two different transport analyses were carried out: the first in the Sogin area of the site, where four test cases were developed with a hypothetical Cs-137 as the source term; the second in the Avogadro area of the site, considering a hypothetical source of Sr-90. The choice of Cs-137 and Sr-90 was made on the basis of an accurate analysis of data published by ARPA in the 2009–2013 period.

2. Methodological approach

In the context of the environmental and safety assessment carried out in a nuclear site, the transport of radionuclides in environmental matrices (e.g. groundwater, soil, air, etc.) has to be investigated in a precise and detailed way in order to support the environmental monitoring of the nuclear site and the surrounding areas. A methodological approach is a useful tool to reach this goal. In this work, the analysis has focused on groundwater and soil, but the approach can be extended to any environmental matrix. The main steps of the methodological approach used to investigate the concentration in space and time, are:

- site description: the hydrogeological framework and the possible source terms that characterize the reference area;
- hydrogeological framework: evaluation of the hydrological features with identification of the flow lines as preferential radionuclide pathways;
- source study: the type of radionuclides and their characteristics;
- transport model: integration of hydrogeological data with transport phenomenon modeling in order to study the behavior of radionuclides in space and time;
- analysis of the results: to identify any critical points in the area and to plan the management of any possible contamination.

As far as the site description is concerned, it is necessary to collect the data which characterize the hydrogeological framework: the type of aquifers, the stratigraphy of the soil profile, the topography, and the presence of rivers or canals. Human activities and the presence of potential radiological sources must be also identified.

In the second step, the collected hydrogeological data must be qualitatively analyzed to identify the phenomena (e.g. recharge, discharge, loss of water from streams, etc.) which characterize the investigated site. In this phase, the lack or the shortage of data must be considered in order to estimate the possible errors that could be made concerning the transport of radionuclides and also to establish how to direct further investigations or sensitivity analysis.

The study of the source term determines the types of radionuclides in each nuclear facility and their quantities, which represent the possible radiological risk for the site and the surrounding areas. After identification of the main hazardous radionuclides (IAEA, 2002, 2003), their different types of behavior (e.g. radioactive half-life, interaction between radionuclide and solid matrix) are evaluated.

As far as the transport evaluation is concerned, a suitable transport model has to be developed by means of appropriate software. Several realistic and possible scenarios can be considered to analyze possible critical situations, in order to evaluate the potential migration of radionuclides in the environment, to identify radioactivity accumulation areas and to evaluate the concentration of radionuclides in space and time.

The final step concerns checking the results, and analyzing the concentration of the radionuclides in space and time. This step makes it possible to identify the main migration pathways, the accumulation points of contaminants and the risky areas for the diffusion of the radioactivity. All the information about artificial radionuclides in the environment must be managed, not only to try to restore the previous environmental conditions, but also to manage the contamination by means of removal and fixation, or environmental monitoring in the case of negligible contamination (IAEA, 2004).

The described approach can also be applied to plan a suitable and specific environmental monitoring network, according to the criteria imposed by national and international laws on nuclear monitoring activities.

3. Site description

The investigated area is the Saluggia nuclear site, Vercelli (Piemonte region, Italy). The nuclear site, which is shown in Fig. 1, can be divided in two main areas: the Sogin area, in which the Eurex plant is located, and the Avogadro area, in which the temporary Avogadro repository is located (Porzio, 2009). Eurex is a nuclear fuel reprocessing plant which is currently being decommissioned. Some temporary new radioactive waste storage facilities and waste ponds, which collect the liquid effluents from the Eurex plant, are also located in the Sogin area. These facilities are owned by Sogin, the Italian company responsible for the national nuclear site decommissioning and the management of radioactive waste. Instead, the Avogadro repository was originally a nuclear research

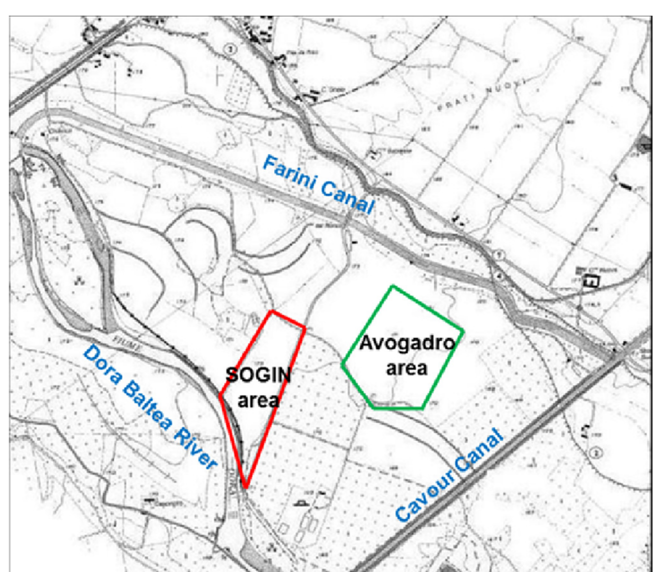

Fig. 1. Saluggia nuclear site: Sogin area and Avogadro area.