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EDITED AND REVIEWED BY
Sergei Dudarev,
United Kingdom Atomic Energy Authority,
United Kingdom

*CORRESPONDENCE
Tara Beattie,
tara.beattie@mcmenvironmental.co.uk

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Editorial: EURAD: state of the art in research and development on radioactive waste management and disposal

Tara Beattie[1]* and Bernd Grambow[2]

[1]MCM Environmental Services Ltd., Science and Technology Facilities Council, Rutherford Appleton Laboratory, Didcot, United Kingdom, [2]Laboratoire de Physique Subatomique et des Technologies Associes, Nantes University, IMT Atlantique, CNRS-IN2P3, Nantes, France

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Editorial on the Research Topic
EURAD: state of the art in research and development on radioactive waste management and disposal

Introduction

For all societies that rely or have relied fully or partly on nuclear energy the long-term management of radioactive waste remains a complex challenge for generations to come. Issues are the multidisciplinary scientific understanding of key processes often coupled over time and space scales, the search of appropriate and acceptable disposal sites, the development of engineering solutions and the organization of transparency for public engagement. Deep geological repositories (DGRs) are industrial megaprojects, internationally recognised as the most robust solution, designed to isolate hazardous materials from the biosphere for more than tens of thousands of years (IAEA, 2003). First repositories have been licenced recently.

The European Joint Programme on Radioactive Waste Management (EURAD) provides a collaborative roadmap for this work, consolidating research, development and demonstration (RD&D) and Knowledge Management (KM) to strengthen the scientific basis for geological disposal (EURAD Vision, 2019). A cornerstone of EURAD is the systematic production of *State-of-the-Art* (SoTA) reports in various research fields. These documents synthesise and review current understanding, identify uncertainties, and guide future research directions.

This editorial introduces the SoTA reports published in this Research Topic and produced within EURAD-1, highlighting their contributions to the international knowledge base for geological disposal.

Primary containment

Demonstrating the ongoing innovations in radioactive waste disposal material choices, the workpackage ConCorD report on container corrosion under disposal conditions (Muñoz et al.) describe the long-term integrity of sealed containers. It covers a range of materials used to provide the long-term primary containment barrier, typical for high-level waste and spent fuel disposal containers. It surveys the current understanding of degradation processes across a range of environments, including the effects of irradiation, chemical transients, microbial activity, and extreme environmental fluctuations. It also explores the potential of novel container materials and highlights approaches to integrate experimental data into predictive models of container lifetime. Its inclusion affirms the importance of rigorous, coupled analysis of container behaviour as a keystone in safety case development.

Chemical evolution in disposal cells

The chemical environment of a disposal cell in deep geological formations is shaped by the interactions between wasteforms, engineered barriers, and surrounding host rock. Two companion SoTA reports address this complexity.

- Part I (Neeft et al.) examines processes at interfaces and the overall chemical evolution at the disposal cell scale, focusing on safety, performance, and optimisation.
- Part II (Deissmann et al.) describes the experimental and modelling tools that underpin our understanding and support the construction of coherent narratives of disposal cell evolution.

Together, these reports provide a comprehensive framework for evaluating chemical evolution in disposal systems and its significance for long-term safety. They cover disposal cells and material interfaces common to cemented intermediate level waste disposal concepts and vitrified high level waste in carbon steel overpacks with bentonite or concrete buffer materials.

Clay barriers: thermo-hydro-mechanical behaviour

Clay-based materials are integral to disposal concepts, both as engineered barriers and as host rock formations. Their thermo-hydro-mechanical (THM) behaviour at repository-relevant conditions is the focus of two SoTA reports.

- Villar et al. present the state of the art on clay buffers, with particular attention to the effects of elevated temperatures.
- A companion report by Villar et al. examines the THM behaviour of host clay formations, drawing on insights from large-scale *in situ* experiments.

Together, these studies improve understanding of how clay barriers evolve under thermal, hydraulic, and mechanical stresses, reinforcing confidence in their role towards contributing to the long-term containment of radioactive waste in DGRs.

Radionuclide retention and transport

The long-term safety of geological disposal relies on the ability of engineered and natural barriers to retain radionuclides and limit their transport. The SoTA report by Maes et al. reviews current knowledge of radionuclide retention and migration in both clay and crystalline host rocks. This synthesis clarifies the key processes that govern radionuclide mobility and highlights areas where further research is needed.

Advanced modelling of coupled processes

Repository performance assessments increasingly depend on advanced modelling of complex, coupled processes at various time and space scales. The SoTA report by Claret et al. reviews recent developments in numerical tools and high-performance computing for reactive transport, two-phase flow, and THM modelling in porous and fractured media. These advances enable more robust sensitivity analyses and uncertainty quantification, which are essential for reliable safety assessments.

Conclusion

The SoTA reports in this Research Topic demonstrate the scientific depth and collaborative effort underpinning the geological disposal of radioactive waste. By consolidating existing knowledge, identifying gaps, and providing direction for future research, they strengthen confidence in geological disposal as a safe and responsible long-term solution.

Through these contributions, EURAD continues to build a shared, internationally recognised evidence base that will support informed decision-making on radioactive waste management for decades to come.

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