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Optimizing Geopolymer Matrices for Radioactive Liquid Organic Waste Conditioning within the EURAD-2 project

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European Partnership on Radioactive Waste Management

Introduction

The EU-funded Eurad-2 project, coordinated by ANDRA across 51 mandated organizations, 69 affiliated entities, and 22 associated partners, advances safe European radioactive waste management. It aims to implement a joint Strategic Programme for research and knowledge management, aligning national programs to deliver safe, sustainable, and publicly acceptable solutions. The project comprises 18 technical work packages (WPs) dedicated to consolidating knowledge for the safe operation of geological disposal facilities for spent fuel, high-level waste, and other long-lived radioactive waste. ENEA participates through WPs 5, 7, and 11, leveraging the facilities and expertise of its Nuclear Department.

This work, carried out as part of the activities of EURAD-2 WP7 L'OPERA, investigates the encapsulation of scintillation liquids and oils used as simulants for radioactive liquid organic waste (RLOW) into a tailored geopolymer matrix optimized by blending aluminosilicate binders (fly ash, blast furnace slag, and metakaolin). Initial formulations underwent Raman, FTIR, and SEM-EDS characterizations to evaluate their microstructure, porosity, and organic phase incorporation, alongside baseline compressive strength tests. To assess durability, specimens are subjected to accelerated thermal cycling (±40°C) and Gamma irradiation at ENEA Casaccia's Calliope facility. Post-treatment physico-chemical analyses, residual mechanical stability assessments, and leaching tests are currently underway to evaluate the degradation effects and the containment efficiency.

Results and Discussion

Formulation process ➡ The geopolymer mixture of fly ash, blast furnace slag, metakaolin, and KOH as activator is milled for 15–20 min, cast into cylindrical molds, demolded, and cured in a climatic chamber for 28 days at 20°C and 95% RH.

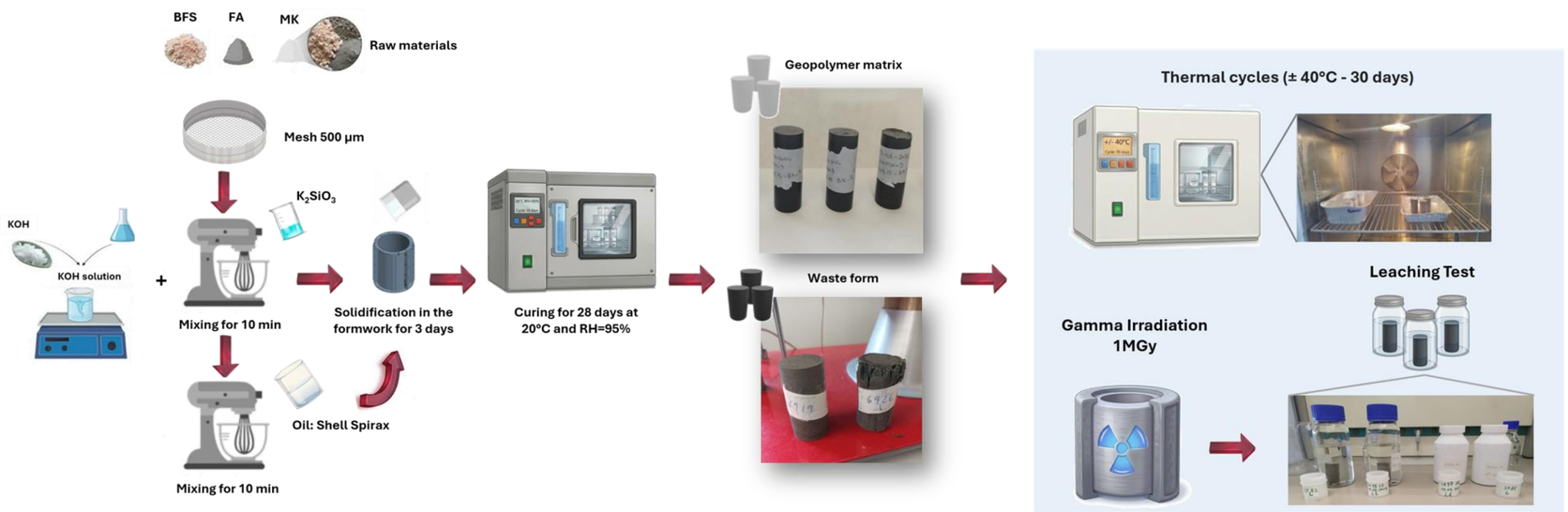
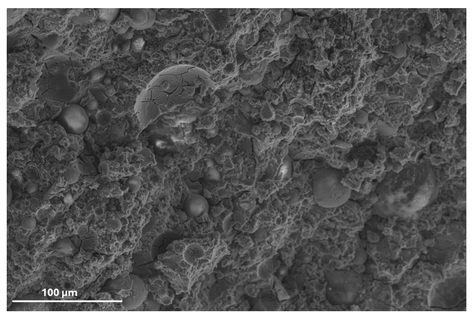


Figure.1 Schematic diagram of the geopolymer matrix and waste form formulation process

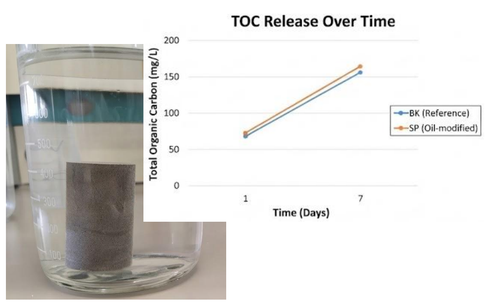
Durability and Stability testing

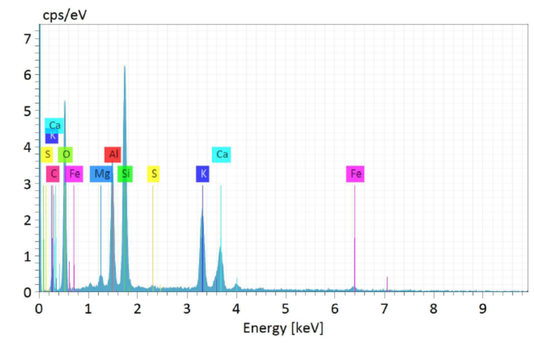
To assess degradation effects and containment efficiency, specimens are currently undergoing:

- **Thermal Cycling**: Accelerated thermal cycles (-40°C to + 40°C) for 30 days.
- **Gamma Irradiation:** 1 MGy, dose rate of ~ 1.7–1.9 kGy/h at ENEA Casaccia's Calliope facility.
- **Leaching Tests:** Ongoing evaluations for 6 months after Gamma Irradiation ➡ **TOC**



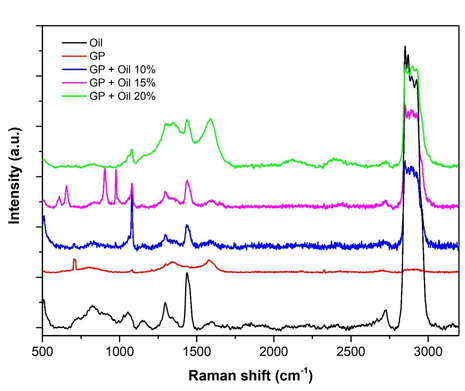
SEM: Granular + fine matrix with spherical particles and porous regions.



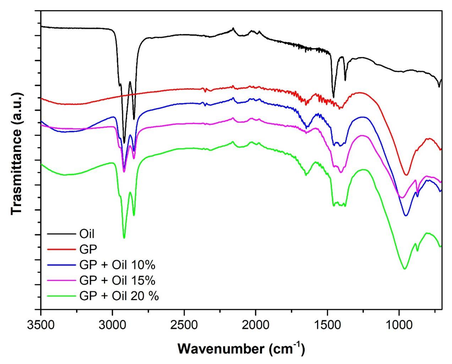


EDS: Heterogeneous aluminosilicate system (Si–Al–O) with minor Ca, K, Fe. Local Ca/Al variations reflect microstructural heterogeneity.

TOC: Data show similar carbon release in BK and SP, indicating good encapsulation efficiency; however, initial cracks and fractures are becoming visible. Findings remain provisional pending long-term tests.



Raman: The lack of organic signals in the control sample contrasts with the progressive growth of oil characteristic bands at 2850–2925 cm^{-1} and 1440 cm^{-1}. Stable peak positions indicate the physical entrapment of the oil phase within the inorganic matrix pores.



FTIR: Confirms the physical encapsulation of oil inside the geopolymer matrix through the proportional growth of C-H stretching bands without forming new covalent bonds. The primary geopolymer framework remains stable.

Project Duration

October 2024 – September 2029

Contact

Coordinator: **AGENCE NATIONALE POUR LA GESTION DES DECHETS RADIOACTIFS (ANDRA)**

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For more information