Advances in Electrochemical and Spectroscopic Techniques for Understanding Molten Salt Environments in Nuclear Applications

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Molten salts have attracted considerable interest for a wide range of applications, including Molten Salt Reactors (MSRs), fusion blankets, pyroprocessing, concentrated solar power with thermal energy storage, and high-temperature metallurgical processes. The demanding operating environments of these systems, characterized by elevated temperatures, chemically aggressive salt media, complex salt chemistry, and, in nuclear applications, intense radiation fields, present significant challenges for in-situ monitoring and diagnostics. Reliable real-time sensing is therefore essential for maintaining process safety, controlling corrosion, understanding salt chemistry, and supporting nuclear material accountancy and safeguards in nuclear systems.

This study investigates electrochemical and laser-based sensing techniques for the characterization of molten salt systems, with particular emphasis on electrochemical measurements and laser-induced breakdown spectroscopy (LIBS). Voltammetry and potentiometry are employed to monitor redox conditions, quantify actinide species, and detect electroactive fission products, while LIBS is utilized for rapid elemental analysis of molten salts. As electrochemical and optical techniques provide complementary information on molten salt chemistry, this work also discusses the potential application of machine learning-based data fusion for integrating heterogeneous sensor data to support real-time interpretation of salt chemistry and anomaly detection. The proposed sensing strategy is expected to contribute to the development of advanced monitoring technologies for next-generation molten salt systems.

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