NEUP Nuclear Energy University Program
U.S. Department of Energy

Plasma-Bubble Spectroscopy: A Method for Real-Time Material Quantification in Molten Salts

PI: Alexander Bataller, NCSU
Co-PI: Katharina Stapelmann, NCSU
Collaborators: Ammon Williams, INL
Program: FC-3
Fiscal Year 2021 Consolidated Innovative Nuclear Research

ABSTRACT:

Our increasing need for safe, abundant, reliable, and carbon-free energy sources is stimulating renewed interest for employing nuclear energy to power our world. Among the new concepts being explored is the utilization of molten salts in advanced fuel cycles and next generation nuclear reactors. Establishing a real-time measurement of the salt composition in a harsh radiative environment is a necessary research task for the successful operation and safeguarding of the aforementioned nuclear applications. The demand for greater material identification and quantification is even stricter for molten salt reactors due to the vast number of fission products present within the fuel salt after reactor operation. Although the leading candidate method for real-time material accounting (laser-induced breakdown spectroscopy) has shown steady progress in recent years, its inherent technical challenges may limit widespread commercialization.

The overarching goal of the proposed research is to investigate an alternative method for quantifying nuclear materials in molten salts using a technique we call "plasma-bubble spectroscopy" (PBS). The strategy of our proposed technique is to transform small quantities of bulk molten salt into a low-density gaseous bubble using high voltage discharges in converging geometries. This molten salt bubble is then converted into a dilute plasma by means of a glow discharge, whose sharp atomic emission lines can be spectrally analyzed with sub-angstrom resolution. The proposed technique addresses several critical challenges facing materials accounting, e.g., online monitoring capability, shot-to-shot stability, optical clarity, and the possibility of uranium isotopic differentiation. Our long-term vision is to enable a low-cost, high throughput device that can operate in the extreme conditions found in MSRs and advanced fuel reprocessing.

The proposed research is comprised of three objectives that are designed to achieve the overall goal of developing a new experimental method for material quantification in molten salts by creating glow discharge plasma within a low-density gas bubble. The objectives will test the validity of our stated hypothesis, specifically, that the PBS technique will create a stable plasma condition that features extremely narrow spectral linewidths. The proposed research will first apply the PBS technique in room temperature saline solutions for rapid bubble characterization and discharge optimization. This stage of the proposed research will explore two different electrode configurations featuring a fixed "flow-through" device and a translatable fiber-coupled probe. The proposed research will develop an optical furnace that will enable molten salt experiments in a glovebox environment. Once established, a proof-of-concept demonstration of the proposed PBS device will be conducted using molten chloride salts in the presence of a uranium surrogate of varying percentage.