Metatomic, Inc.
Partnered with
Savannah River National Laboratory

NE-23-32134: Metatomic Molten Salt Immersed Hydrochlorination Subsystem Characterization

YEAR AWARDED: 2023

TOTAL PROJECT VALUE: $625k

STATUS: Completed

PRINCIPAL LAB INVESTIGATORS: Ken Baer (Metatomic), Bob Pierce (SRNL)

DESCRIPTION: Metatomic, Inc., of Greenville, S.C., seeks to address the increasing inventory of used nuclear fuel (UNF) currently stored onsite at commercial nuclear power plants across the United States by using a patented process converting it into fuel for Molten Salt Fast Reactors (MSFRs). Access to a national laboratory provides bench scale demonstration and data generation for their molten salt immersed hydrohalogenation system and cover/off-gas management system. Savannah River National Laboratory (SRNL) provided the requisite expertise and handling capabilities to enable laboratory scale demonstration and assessment.

BENEFIT: In recent years, molten salt reactors (MSRs) have garnered attention for their advantages in both safety and efficiency when compared to alternative reactor designs. Within MSRs, chloride-based fuel offers benefits over the more corrosive fluoride- and the more cost-intensive bromide-based fuels. The production of chloride-based MSR fuels has also been predicted as a pathway to reuse UNF with minimal reprocessing.

IMPACT: The Phase 1 hydrochlorination experiments consisted of preparing alumina crucibles with UO_2 in a eutectic mixture of NaCl and CsCl, heating the uranium/salt mixture to various temperatures (550, 650, or 750 °C), and flowing anhydrous hydrogen chloride (HCl) gas across the surface of the uranium-bearing molten salt mixture.[1] The hydrochlorination process conditions were maintained for up to 5 hours and the percent conversion for each batch of UO_2 was determined using a suite of analytical characterization techniques (powder XRD, ICP-MS, UV-Vis and Raman spectroscopy). The degree of UO_2 conversion was found to be greatest at the highest tested temperature, ultimately achieving 32.9% conversion of UO_2 to water-soluble uranium-chloro species (e.g., UO_2Cl_2, UCl_4, etc.) after exposure to $HCl_{(g)}$ for 4.25 hours at 750 °C. Phase 2 experiments involved a custom-built Hastelloy reaction vessel designed to sparge $HCl_{(g)}$ directly through the uranium-salt mixture with up to 400 g UO_2 present.[2] Hydrochlorination was demonstrated at 650 °C using the reactor vessel; however, the degree of hydrochlorination was lower than expected and a large amount of Hastelloy corrosion products were observed. Both of these phenomena are likely attributable to the generation of water within the reaction vessel.

SIGNIFICANT CONCLUSIONS: Results from the Phase 1 experiments indicate that hydrochlorination of UO_2 to form water-soluble uranium species in molten salt media is achievable. For a NaCl-CsCl molten salt medium, elevated temperatures promoted higher conversion of UO_2 to water-soluble U species, such as $Cs_2UO_2Cl_4$ or UCl_4. Phase 2 results reinforced the Phase 1 results through observation of uranium chlorides. Observations of byproducts generated through the course of the hydrochlorination experiments seem to suggest that the water generated from hydrochlorination of UO_2 deleteriously interacts with the uranium chloride products and causes corrosion of the reaction vessel.

NEXT STEPS: Management of the generated moisture must be addressed for future UO_2 hydrochlorination in molten chloride salt media.

(1) Nguyen, V. T.; Foley, B. J.; Pierce, R. A. *Hydrochlorination of Uranium Dioxide in a Molten Salt Mixture - Phase 1: Tube Furnace Cross Flow Experiments*; SRNL-TR-2024-00718; Savannah River National Laboratory, 2025.

(2) Nguyen, V. T.; Hege, N.; Foley, B. J.; Pierce, R. A. *Hydrochlorination of Uranium Dioxide in a Molten Salt Mixture- Phase 2: Sparged Benchtop Reaction Vessel Experiment*; SRNL-STI-2025-00192; Savannah River National Laboratory, 2025.