Small Scale Recycling of Irradiated Nuclear Fuel for Isotope Production and Nuclear Energy R&D

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INTRODUCTION

The USA has the largest number of nuclear power reactors, accounting for more than 30% of the generation of nuclear electricity worldwide. A primary objective for nuclear energy development is to create sustainable nuclear fuel cycles that improve uranium resource utilization, minimize waste generation, improve safety, and limit proliferation risks. One potential strategy for fuel cycle management is the use of fuel recycling or a closed-loop fuel cycle. Long-lived actinide elements can then be recycled rather than be disposed of, which will significantly reduce the overall radiotoxicity of waste and maximize uranium resource utilization.

The legal requirements to recycle fuel impede most in private industry from making significant progress in the field of both fuel cycle R&D and medical isotope production. Niowave is in the unique situation of possessing both the facilities and the NRC license to pursue the commercialization of this type of system. A commercial-scale, closed loop fuel cycle has been designed by Niowave and performed at a demonstration scale.

FACILITY DESCRIPTION

The Niowave Electron Research and Development (NERD) facility is a 14,000 ft^2 building equipped with high-tech manufacturing, testing, and processing capabilities (Fig. 1). The facility has 3 MW of electrical power available, two below-grade trenches, and two shielded tunnels for linac operations up to 40 MeV and 100 kW.

Fig. 1. View of the NERD test facility shielded tunnels.

The facility also houses a radiochemistry laboratory where irradiated uranium fuel undergoes chemical processes such as the LEU Modified Cintichem (LMC) and Uranium Redox Extraction (UREX) to extract specific radioisotopes and recycle uranium fuel, respectively. Recycled uranium oxide is presses into pellets to be reloaded into the subcritical uranium assembly for further irradiations. The radiochemistry laboratory at Niowave contains an 8’ Mott Radioisotope fume hood, a Vacuum Atmospheres glovebox, and a large volume HEPA filter.

In addition, the facility includes a gamma spectroscopy laboratory where the QA of the produced radioisotopes is performed. Also, low-power physics experiments with a subcritical assembly are performed in the spectroscopy lab to validate Monte-Carlo simulations for radioisotope production, fuel cycle development, active interrogation demonstration, and other projects.

DEMONSTRATION AND TESTING

Closed-loop fuel demonstration

Niowave had successfully operated a closed-loop fuel cycle scheme at a demonstration scale. The NRC License possessed by Niowave allows for the operation of this full-recycling system via the irradiation of a subcritical uranium assembly, radiochemical recycling and purification of irradiated fuel, fabrication of new uranium fuel targets, and reloading of the uranium assembly for further irradiation.

Irradiated uranium and transuranic discharge

The recovery of the fuel, low-enriched uranium (LEU), needs to be high to demonstrate that the closed-loop is self-sustainable, thus minimizing the demand for new fuel. Niowave’s Radioisotope Production Facility includes a subcritical assembly that consists of both low enriched uranium and natural uranium submerged in a light water pool. It is designed to operate at 210 kW of fission power with a multiplication factor of k=0.95. The amounts of Np-237 and Pu-239 discharge after one-week irradiations of 10-kg LEU batches are estimated to be 1 mg and 0.2 g, respectively. The discharged fuel average fractional burnup is 0.015%. Np and Pu should be recovered along with U with minimal fission product contamination. High purity of the recycled uranium fuel is necessary to ensure efficient operation of the subcritical uranium assembly. The estimated transuranic discharge was computed using Monte Carlo based neutral particle transport code MCNP6 [1].

Scaling to a commercial-scale recycling facility

Niowave's commercial scale radioisotope production is a rather small-scale facility from the nuclear energy community standpoint. However, this facility will enable nuclear energy based R&D for a full-recycling scheme, to develop advanced separation techniques to lower proliferation risk, and to prototype new disposal forms to capture and immobilize nuclear waste.

The ongoing development of the commercial-scale reprocessing facility for radioisotope production is currently focusing on the actinide separation technique. First, Niowave's existing liquid-liquid extraction method to extract uranium, neptunium, and plutonium together from a dissolved, irradiated uranium target will be optimized. This modified UREX process uses tri-butyl phosphate (TBP) as a uranium-binding ligand in a hydrocarbon solvent [2]. An oxidizing agent will be introduced in the nitric acid solution to oxidize pentavalent $Np(V)O_2^{+}$ to the extractable $Np(VI)O_2^{2+}$. Plutonium(IV) will partition along with uranium and neptunium. The actinides are then stripped back into the aqueous phase, now devoid of all fission fragments whereupon it will enter the target fabrication process.

Second, this liquid-liquid extraction will be automated by implementing centrifugal contactors as the separation technique. To develop the flowsheet for a complete recovery of U, Np and Pu, the Argonne Model for Universal Solvent Extraction (AMUSE) will be used. The process will be tested on the small scale using 3D-printed centrifugal contactors designed and fabricated at Argonne National Laboratory (ANL).

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