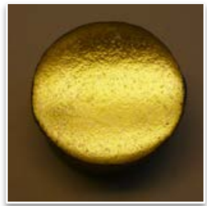
UN



$(U_{1-x},Zr_x)N$

Development of uranium nitride composite for space reactors application

FROM UN TO $(U_{1-X},Zr_X)N$ COMPOSITE: A POSSIBLE FUEL FOR SPACE REACTORS

KTH Fuel Lab

Introduction

Nuclear reactors has being considered for space application for support human life, in Moon and Mars exploration, and for propulsion purposes. Nuclear powered spacecraft will enable missions well beyond the capabilities of current chemical, radioisotope thermoelectric generator and solar technologies.

Characteristics including operating temperature, coolant, neutron flux, neutron spectrum, fuel type, and lifetime must all be considered in the space reactor design. However, while all of these factors are important, the reactor operating temperature is the primary criteria. Since the reactor size must be kept to a minimum, high operating temperatures (>1,000 K) are desirable to enable high thermal conversion efficiencies and high specific energies. This high temperature is even higher than the specified for the next generation reactors (GEN-IV). Moreover, space fission reactors may be required to operate in this temperature for 15–20 years without the benefit of maintenance.

These entire requirements turn the focus to the UN nuclear fuel. Uranium nitride is an attractive material fuel option due to the combination of its high fissile nuclide density, high thermal conductive, and a high melting point.

However under irradiation, nitrides fuel tend to swelling significantly, leading to pellet-clad mechanical interaction, which has given cause to the majority of the fuel pin failure in the past. It was observed that the nitride fuel swelling is sensitive to the fuel temperature rather than to the achieved burnup, which is quite significant for space reactor applications.

KTH Fuel Lab activities

KTH Fuel Lab has been development nitrides fuel fabrication technology for application in GEN-IV reactors and for accelerator-driven sub-critical systems (ADS), for nuclear waste transmutation.

Having established good experience in UN fabrication by the hydriding-nitriding process, KTH Fuel Lab has started a research stream of manufacturing and characterization of $(U_{1-x},Zr_X)N$ compound nitride. It has been suggested that if in solution with ZrN, the performance of nitride fuel could be improved. As the solution is more stable at high temperature this leads to reduced dissociation of the fuel, and also the increasing in thermal conductivity resulting in low thermal gradient over the fuel, which could minimize the fission gas release and swelling. All these factors make this compound of great interest for application in space reactors.

$(U_{1-x},Zr_x)N$ manufacture consists of development of three stages; manufacturing UN and ZrN (both in high purity, i.e. O and C <500 ppm), and then the processing of (U,Zr)N composite itself. Obtaining a product of high purity and ensure the achievement of homogeneous solid solution are mandatory for this composite shows the expected performance under irradiation, but this is still one major challenge.

Investigation on processing by mechanical alloying and sintering plasma sparking (SPS) has been conducted to establish parameters to produce a material that meets nuclear fuel space reactor specifications. Additionally, thermo physical test such as thermal diffusivity and specific heat are programmed to allow evaluation of different compositions of this composite as fuel, as well as to drive a phase transformation study to investigate the occurrence of a miscibility gap for some compositions.

Preliminary results of this project were presented at the workshop of Democritus (Demonstrators for Conversion Reactor, Radiator and Electric Propulsion Systems for Thrusters) conducted in Jan. 26-27 2016. DEMOCRITOS is an European consortium with the objective of investigate the necessary demonstration activities in order to mature technologies for nuclear electric propulsion (NEP) in space. KTH Fuel Lab is following this initiative to adequate the research project in progress with the fuel requirement update.