National Aeronautics and Space Administration

TECHNOLOGY SOLUTION

Materials and Coatings

Advanced Protective Coatings for Graphite-Based Nuclear Propulsion Fuel Elements

Protects crucial components from hot hydrogen attack and corrosion

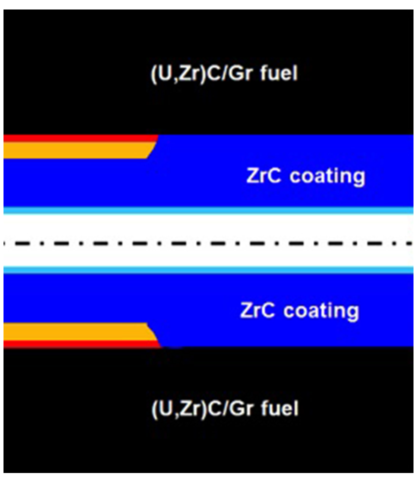
Scientists at NASA's Glenn Research Center have developed novel ways to protect fuel elements used in hot hydrogen gas-propelled nuclear thermal propulsion (NTP) engines. These fuel elements often feature a graphite (Gr)-based substrate, which can react with the hydrogen to form methane and other hydrocarbons, leading to a hot hydrogen corrosive attack. As a result, the Gr-based substrate erodes with time, thus affecting reactor neutronics and performance and leading to a premature shut-down of the NTP engine. Glenn's researchers have conceptualized a technique to create and layer protective coatings that act as a diffusion barrier between the hydrogen and the substrate. These innovations will potentially have a broad impact, as fuel elements for nuclear reactors increasingly have applications in the commercial nuclear power industry, nuclear powered submarines and ships, and outer space systems.

BENEFITS

- Increased efficiency: Prevents damage within fuel rods and thus keeps nuclear systems running without generating problems leading to a shutdown
- Decreased cost: Lessens the need to replace corroded or damaged components in nuclear systems
- Improved durability: Reduces debonding between the coating and the substrate, thus keeping out destructive hydrogen

THE TECHNOLOGY

To protect the graphite (Gr)-based substrates in a nuclear systems fuel elements from hot hydrogen attacks, earlier researchers developed a method to deposit (via chemical vapor deposition) a protective niobium carbide (NbC) or zirconium carbide (ZrC) coating in the inner cooling channels of the fuel elements through which the hydrogen propellant flows. Unfortunately, the significant difference in the coefficients of thermal expansion (CTE) between the Gr-based substrate and the ZrC coating leads to debonding at intermediate temperatures, thereby exposing the substrate to hot hydrogen attack despite the NbC or ZrC coating. Innovators at Glenn have proposed a solution to this problem by introducing additional layers of compliant metallic coatings to accommodate the differences in CTE between the ZrC and the Gr-substrate,thereby potentially increasing life and durability. In this configuration,the innermost layer is composed of molybdenum carbide (Mo_2C), and additional outer layers are made of molybdenum (Mo) and niobium (Nb) layers. The MoC acts as a diffusion barrier to minimize the diffusion of carbon into the refractory metal layers and the diffusion of Mo or Nb into the Gr-based substrate. The Mo layer is deposited on top of the Mo_2C layer. A Nb layer is deposited on the Mo layer with the ZrC forming the outside layer of the coating. A thin Mo layer on the ZrC helps to seal the cracks on the ZrC and acts a diffusion barrier to hydrogen diffusion into the coating.The Mo and Nb layers are compliant so that differences in the thermal expansion of ZrC and other layers can be accommodated without significant debonding or cracking. They also act as additional diffusion barriers to hydrogen diffusion towards the Gr-substrate. Overall, Glenn's pioneering use of layered coatings for these components will potentially increase the durability and performance of nuclear propulsion rockets.



Schematic of the multilayer coating. Hydrogen passes through a central channel, with an outer layer of molybdenum (lighter blue) deposited on top of the zirconium carbide.

Nuclear powered submarines and ships can benefit from this new low-cost approach to protective coatings for fuel elements in NTP engines.

APPLICATIONS

The technology has several potential applications:

- Aerospace (e.g., outer space systems)
- Commercial nuclear power generation
- Military transport (e.g., nuclear-powered submarines and ships)

PUBLICATIONS

Patent No: 10,068,675

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