AFFORDABLE DEVELOPMENT AND OPTIMIZATION OF CERMET FUELS FOR NTP GROUND TESTING

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Introduction: CERMET fuel materials for Nuclear Thermal Propulsion (NTP) are currently being developed at NASA's Marshall Space Flight Center. The work is part of NASA's Advanced Space Exploration Systems Nuclear Cryogenic Propulsion Stage (NCPS) Project. The goal of the FY12-14 project is to address critical NTP technology challenges and programmatic issues to establish confidence in the affordability and viability of an NTP system. A key enabling technology for an NCPS system is the fabrication of a stable high temperature nuclear fuel form. Although much of the technology was demonstrated during previous programs, there are currently no qualified fuel materials or processes. The work at MSFC is focused on developing critical materials and process technologies for manufacturing robust, full-scale CERMET fuels. Prototypical samples are being fabricated and tested in flowing hot hydrogen to understand processing and performance relationships. As part of this initial demonstration task, a final full scale element test will be performed to validate robust designs. The next phase of the project will focus on continued development and optimization of the fuel materials to enable future ground testing. The purpose of this paper is to provide a detailed overview of the CERMET fuel materials development plan.

The overall CERMET fuel development path is shown in Figure 2. The activities begin prior to ATP for a ground reactor or engine system test and include materials and process optimization, hot hydrogen screening, material property testing, and irradiation testing. The goal of the development is to increase the maturity of the fuel form and reduce risk. One of the main accomplishmens of the current AES FY12-14 project was to develop dedicated laboratories at MSFC for the fabrication and testing of full length fuel elements. This capability will enable affordable, near term development and optimization of the CERMET fuels for future ground testing. Figure 2 provides a timeline of the development and optimization tasks for the AES FY15-17 follow on program.

Materials and Process Optimization: An iterative approach will be used to sequentially optimize the materials and process technologies for fabrication of CERMET fuels. The fuels will be based on the starting materials, compositions, microstructures, and forms that were demonstrated on previous programs[2]. CERMETS with mono and mixed size fuel particles will be fabricated for characterization. The list below provides a summary of the mechanisms and approaches that will be optimized to improve the performance of CERMET fuels.

Mechanisms of fuel loss from CERMETS:

- Vaporization of fuel particles
- Thermal decomposition of fuel/matrix
- Diffusion through pores and cracks
- High vapor pressures exerted by impurities
- Differences in CTE of tungsten and fuel particles

Materials and processes to minimize fuel loss:

- Size of the fuel particles and shape
- Tungsten coating of spherical UO_2 particles
- Complete surface cladding with tungsten
- Addition of fuel stabilization materials

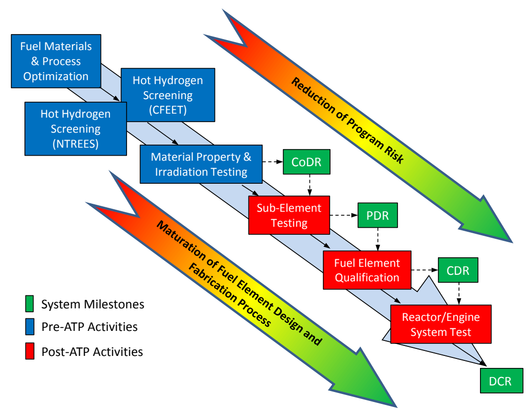

Figure 1: CERMET Fuel Development Path

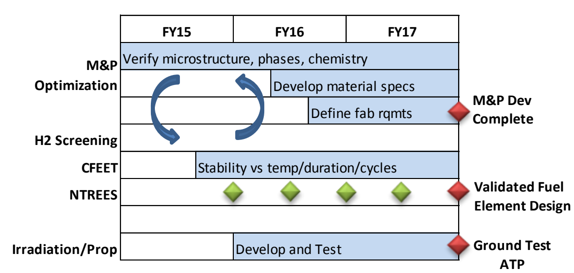

Figure 2: Development and Optimization Schedule

Hot Hydrogen Screening: A critical obstacle to the development of an NCPS engine is the high-cost and safety/security concerns associated with nuclear testing. Current efforts at MSFC under the NCPS program resulted in the development of environmental simulators that are capable of subjecting fuel material samples and full scale elements to hot hydrogen. It is well documented in literature that failure of NTP fuels is driven by the thermochemical and thermal stress evnvionment. The purpose of the testing capability is to enable low-cost non-nuclear screening.

Hot hydrogen testing of CERMET fuels will range from small subscale samples to near-prototypic full length fuel elements. Several iterations of subscale testing will be performed in the Compact Fuel Element Environmental Test (CFEET) system to evaluate fuel mass loss. Post test analysis will include weight percent fuel loss, microscopy (SEM, EBSD, and EDS), and dimensional tolerance and cracking. After subscale verification in CFEET, full scale elements will be tested in the Nuclear Thermal Rocket Element Environmental Simulator (NTREES) to verify full scale thermal cycling. A primary goal of the testing is to demonstrate adequate fuel performance and to increase confidence in fuel designs prior to expensive material property and irradiation testing.

Material Property Teseting: A critical need for the development and design of an NCPS system is the verification of material properties. The properties of interest include thermal expansion, thermal conductivity, tensile strength, young's modulus, bend ductility, and creep. Properties of refractory metals and cermaics are known to be very sensitive to consolidation technique, fabrication history, and thermal treatment. For this reason, it is imperative to complete as much process optimization and hot hydrogen screening as possible prior to expensive testing of depleted uranium materials. Critical material properties will be developed to support the reactor design.

Irradiation Testing: In-pile irradiation testing of W-UO_2 CERMETS is required to verify dimensional stability and containment of fission products under prototypical conditions. Significant irradiation testing was performed during the GE710 program[3]. However, the majority of samples were tested at the lower temperatures (1500 C) and longer durations (1000's of hours) for space power systems. The testing concluded that fission gas containment was achieved in all experiments to burn-up levels exceeding $9x10^{19}$ fissions/cm^3. The primary failure mechanism was blister formation, cladding rupture, and fission gas leaks. Average burn-up levels expected in a single mission, propulsion-only NTR are almost negligible, on the order of 10^{18} fissions/cm3. Depending on the final engine power density, burn-up levels for the GE710 testing are equivalent to dozens of Mars missions. Cermet fuels show strong potential, but the integrated effects of high power density, low burnup, high operating temperature, short operating time, and thermal cycling remain to be assessed.

After demonstrating hydrogen compatibility, the CERMET fuel materials will be screened to evaluate behavior in a typical radiation environment. The testing will be performed at a DOE and/or University facility. Post-irradiation examinations (PIEs) of the test specimens will be performed to evaluate the effects on microstructure and fuel particle stability. If necessary, testing can be performed to determine material properties of irradiated samples, but this will likely not be required for fuel material qualification due to the low burn-ups. A critical issue with extensive irradiation testing is the limitations of current reactors to simulate the high temperature and pressure of an NTP system. Simulating the NTP environment may require a custom nuclear furnace or engine/reactor test bed, which could be cost prohibitive. Thus, the subscale irradiation testing will mostly be a separate effects, low level screening step to verify material behavior.

Summary: CERMET fuel materials for NTP are currently being developed at MSFC. A significant accomplishment of the project is the development of critical materials and process technologies and full scale fuel element fabrication capabilities. The capability enables affordable near term development and optimization of the CEMET fuels for future ground testing. The development approach is to mature the process through iterative fabrication and subscale testing in CFEET with periodic full scale element testing in NTREES to benchmark performance. After optimization, material properties and irradiation testing will be performed to verify the basis for design. The results will be a complete materials and process specification, validated fuel element design, and clear definition of the facility requirements and needs for fabrication of a ground test article.

References:

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[3] General Electric, "710 High Temperaure Gas Reactor Program Summary Report", Volume 1-Summary, GEMP=600, 1968.