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ADVANCED CERAMICS FOR USE AS FUEL ELEMENT MATERIALS IN NUCLEAR THERMAL PROPULSION SYSTEMS. P. G. Valentine, L. R. Allen, and A. P. Shapiro, National Aeronautics and Space Administration (Marshall Space Flight Center, EM41, AL 35812, Peter.G.Valentine@nasa.gov).

Introduction: With the recent start (October 2011) of the joint National Aeronautics and Space Administration (NASA) and Department of Energy (DOE) Advanced Exploration Systems (AES) Nuclear Cryogenic Propulsion Stage (NCPS) Program, there is renewed interest in developing advanced ceramics for use as fuel element materials in nuclear thermal propulsion (NTP) systems. Three classes of fuel element materials are being considered under the NCPS Program: (a) graphite composites – consisting of coated graphite elements containing uranium carbide (or mixed carbide), (b) cermets (ceramic/metallic composites) – consisting of refractory metal elements containing uranium oxide, and (c) advanced carbides – consisting of ceramic elements fabricated from uranium carbide and one or more refractory metal carbides [1]. The current development effort aims to advance the technology originally developed and demonstrated under Project Rover (1955-1973) for the NERVA (Nuclear Engine for Rocket Vehicle Application) [2].

Approach: A variety of ceramic materials, primarily carbides, are being considered for use in the fabrication of two of the three fuel element designs being considered under the NCPS Program – the graphite composite and the advanced carbide approaches. For the graphite composite fuel elements, both coatings (to prevent hydrogen attack and fuel element vaporization) and uranium-containing carbides (for use in fabricating the graphite/carbide composites) are being developed under the lead of Oak Ridge National Laboratory (ORNL). For the advanced carbide fuel elements, a variety of uranium-containing carbide materials are being considered. NASA Marshall Space Flight Center (MSFC) is leading the advanced carbide development work. The work presented in this paper deals primarily with the advanced carbide effort.

As significant improvement in specific impulse (up to 200 s) is considered possible by making use of advanced carbide fuel elements (see Fig. 1), there is considerable interest in developing such materials. Present carbide development efforts at the MSFC are concentrated on determining the binary and ternary carbide materials that offer the most promise as nuclear fuel element materials. Preliminary fabrication trials will begin in 2012 to assess some of the processing and performance issues associated with those refractory metal carbides considered potential candidates for combining with uranium carbide to enable the manufacturing of advanced carbide fuel elements. At present, efforts are concentrated on the carbides of the refractory transition metals of groups IVB through VIB of periods 4 through 6 of the periodic table. While hafnium carbide and tantalum carbide offer the highest melting points, their neutron absorption cross sections offer challenges to their potential use. Zirconium and niobium carbides appear to offer the greatest overall potential, but a variety of material property and fabrication issues need to be more fully addressed. Considerable work was performed in the past under Project Rover to investigate the use of such carbide materials. More recent evaluations of the refractory transition metals carbides for NTP have been performed by the Los Alamos National Laboratory (LANL) [3,4].

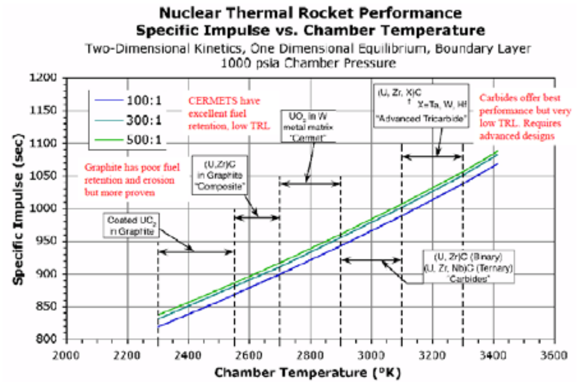

Fig. 1: Specific impulse versus chamber temperature for the three classes of fuel element materials being considered under the NCPS Program [1].

The parameters to be considered in evaluating the various refractory carbides of interest include at least the following: (a) crystallographic phase relationships, (b) melting point, (c) vaporization rate, (d) diffusion characteristics, (e) thermal conductivity, (f) cost/availability, (g) thermal expansion, (h) hydrogen compatibility/reactivity, (i) neutron absorption cross section, (j) thermal shock characteristics, and (k) potential fabrication methods. Existing literature data will be reviewed and selected experimental evaluations will be performed in order to determine the set of depleted-uranium-containing binary and ternary carbides to use in processing trials.

Additionally, both to assist assessments of potential advanced carbide compositions and to assist with the development of coatings for graphite composite fuel elements, preliminary ceramic reaction-sintered coating (CRSC) trials will be performed using graphite substrate materials (see Fig. 2). Based upon prior work by Valentine, et al. [5], the CRSC technique developed for chemical propulsion components and thermal protection systems will be modified for use without boride materials, which have high neutron absorption cross sections.

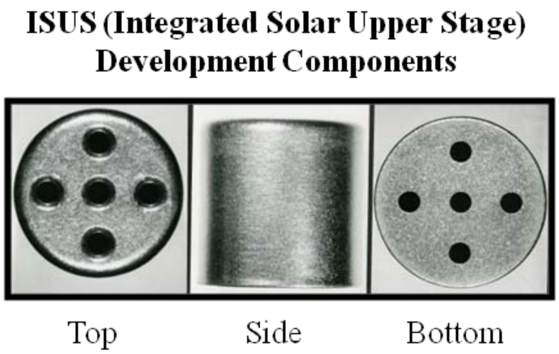

Fig. 2: HfB_2-HfC ceramic reaction-sintered coating applied to Poco graphite, grade AXF-5Q, via rapid high-temperature processing technique [5].

The ultimate goal is to develop advanced carbide materials suitable for fabricating NTP fuel elements. As such materials currently have very low technology readiness levels, the MSFC advanced ceramics efforts will also be applied to the development of coatings for the ORNL-led graphite composite fuel element efforts, which may have more near-term application.

References: [1] Houts, M.G. (2011) NASA-MSFC AES NCPS Program Kick-Off Briefing. [2] Koenig, D.R. (1986) LANL LA-10062-H. [3] Stark, Jr., W. (1993) LANL LA-CP-93-41. [4] Luther, E., et al. (2009) LANL LA-UR-09-00227. [5] Valentine, P.G., et al. (2006) NSMMS Poster.