HIGH-POWER LASER EXPERIMENTS ON ROTATING SMALL-SCALE GPHS MODULES

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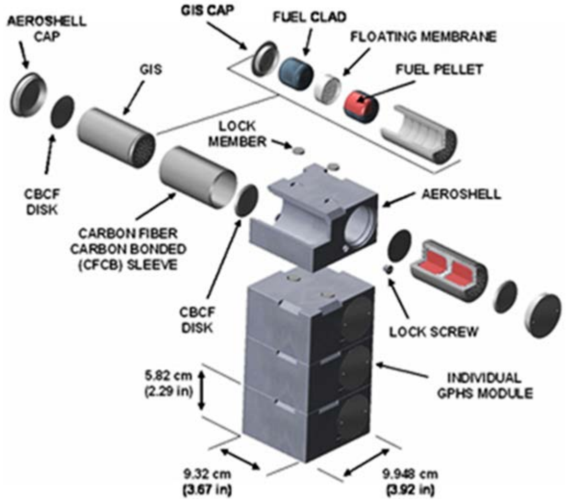
Introduction: The design of Radioisotope Power Systems (RPS) include many aspects that are directly related to the containment of the plutonium-238 dioxide ($^{238}PuO_2$) fuel in case of an inadvertent launch abort or accident scenario. As shown in Figure 1, the current U.S. design employs a multilayer approach including; the fuel pellet is encased within iridium (Ir) cladding, two Ir cladded fuel pellets are placed within a Graphite Impact Shell (GIS), and two GISs are placed within a General Purpose Heat Source (GPHS) module. Therefore, each GPHS contains four $^{238}PuO_2$ fuel pellets.

Figure 1. Schematic of a General Purpose Heat Source (GPHS) Module Stack. (DOE)



GPHS modules have been utilized in U.S. RPSs since the 1980s on a number of deep space planetary exploration missions including Galileo (Jupiter), Cassini (Saturn), and New Horizons (Pluto). The most recent planetary mission, Mars Science Laboratory, was launched in November 2011 with the rover Curiosity which landed on the surface of Mars in August 2012. Curiosity obtains all of its electrical power from the latest U.S. generation of RPS called a Multi-Mission Radioisotope Thermoelectric Generator (MMRTG). Curiosity's MMRTG contains eight GPHS modules with ~4.8 kilograms of $^{238}PuO_2$ fuel.

A close examination of Figure 1 reveals that during fabrication a small "notch" is machined into one of the top-side surfaces of each of the four GPHS modules shown in the figure. It can also be observed in the figure that the top GPHS module is also identified as an Aeroshell. This is because during an accident re-entry scenario the GPHS module stack is designed to first separate into individual modules, and the notch in each GPHS module will cause it to rotate and thermally ablate. This is another safety design aspect utilized to help protect the $^{238}PuO_2$ fuel.

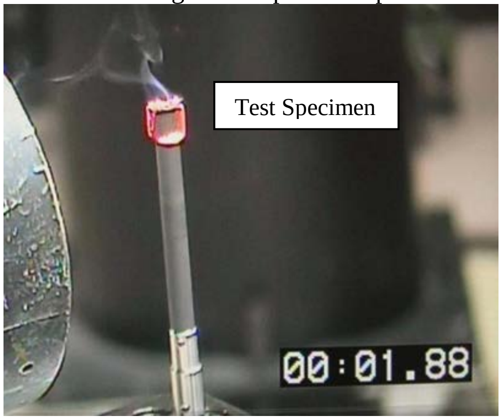
Experimental Considerations: GPHS modules are currently fabricated out of a ~3D C-C material known as Fine Weaved Pierced Fabric (FWPF). FWPF is not a true 3D material, therefore some of its properties are anisotropic. The current research was initiated, on a 1st order basis, to observe the oxidation or "ablation" characteristics of small-scale GPHS modules when subjected to a rapid time-temperature pulse which could result from potential accident scenarios.

In order to obtain the required time-temperature pulse characteristics, small-scale GPHS modules were fabricated and exposed during the experiments to high power lasers. All of the experiments were performed at the U.S. Air Force's LHMEL (Laser Hardened Materials Evaluation Laboratory) facility located at Wright-Patterson Air Force Base, Dayton, OH. The oxidation simulation experiments were performed employing either a 15kW CO_2 laser or a 10kW Ytterbium solid state laser with fluences of up to ~50,000J/cm^2.

For the experiments, small-scale GPHS test specimens were machined out of several materials including FWPF. A test rig was developed that was designed to rotate the small-scale test specimens at a known rotational rate per minute. The test rig allowed the test specimens to be rotated and simultaneously exposed to the high thermal pulse from a laser beam during the simulated oxidation experiments. After exposure to the time-temperature pulse provided by the laser, various dimensional and physical characteristics of the specimens were determined.

Discussion: An example of a **s**mall-scale GPHS module rotating laser experiment is shown in Figure 2. The three pictures in Figure 2 consist of a time sequence taken at ~1.88s, ~3.00s, and ~7.93s after initiation of the laser exposure. During the experiments the test specimens were rotated prior and during the laser exposure. Once the measured rotation rate was set to the desired value, the laser beam was turned on with typical total laser exposure times of less than 60s.

Figure 2. Pictures of a test specimen taken during the first 8s of a rotating laser exposure experiment.



Temperature measurements were obtained during the experiments which showed thermal pulses of up to >500°C/s with maximum temperatures in excess of 3000°C. After the completion of the laser exposure experiments, various physical property measurements were obtained on the specimens, such as weight loss and dimensional changes, which were determined to be a function of laser fluence, specimen material, and exposure time.