**Volatile Extraction and *In Situ* Resource Utilization for the Moon applied to Near Earth Objects.** E. H. Cardiff, NASA GSFC, Building 11 Room E135, Greenbelt, MD 20771. Eric.H.Cardiff@nasa.gov.

**Introduction:** Most *In Situ* Resource Utilization (ISRU) development has been done with respect to either the Moon or Mars, with relatively little applicable to Near Earth Objects (NEOs). Since NASA is now pursuing a “flexible path” strategy for exploration, it behoves the community to look at the application of ISRU that can work at either the Moon or NEOs.

One technique that is applicable for resource extraction at the Moon and on an asteroid is vacuum pyrolyis. The thermal extraction of volatiles is the most promising technique for volatile extraction and scientific measurement of critical volatile species, and has been well demonstrated. Vacuum pyrolysis has also been demonstrated to produce substantial volatiles from regolith stimulants, including oxygen [1].

**Solar Heating:** A mobile platform (shown in Figure 1) has been developed at NASA GSFC to sinter and melt simulated lunar regolith. It has been demonstrated (as illustrated in Figure 2 for two samples), and the melting rates have been quantified. The vehicle consists of a chassis that supports a $1m^2$ lens used to focus the solar flux. The position of the vehicle and of the lens is determined remotely by radio control.

**Figure 1**: The NASA GSFC Fresnel lens vehicle [2].

The melting volumetric rate produced by the Fresnel lens vehicle was 2.6 $cm^3$ / min [2] (or 7.5 g/min for JSC-1A). By manipulating the lens, the focal area and intensity can be altered – thus allowing the production of volatiles with different release patterns.

**Resistive Heating:** A vacuum chamber has been used at NASA GSFC to study multiple configurations of crucibles to resitively heat regolith stimulants. A custom zirconia crucible with embedded tungsten resistive heating elements is used to pyrolyze the simulant. The resistive heating element connects to a power input from the bottom, delivering up to 160 DC volts and over 2000 W. The crucible and stands are surrounded by several layers of tungsten foil shields heat shields.

The improved crucible and shielding in this configuration required 200 W.hr to take 0.1 g of JSC1A to 1600 degrees C.

**Near Earth Objects:** The high temperature of 1600 C is not required to extract volatiles from cometary material, but cometary material is the least likely to be collected as a bulk resource. It is expected that for Near Earth Asteroids (NEAs) that may have undergone substantial heating cycles, there will be a multi-modal release pattern with low temperature volatiles or solar wind volatiles releasing at low temperatures, and residual volatiles from when the minerals were formed being released by high and prolonged temperatures. Because the density of NEAs is not well known, potential exploration targets may vary in mass by factor of 2. Typical 7 m diameter asteroids may vary from 300 T to 600 T of material.[3]

**Scaling:** At current rates, it would take a 1 $m^2$ Fresnel lens 76 years to process a 300 T asteroid. While that might meet current utilization rates on orbit, the rate could be accelerated linearly. Accordingly, a 100 $m^2$ Fresnel lens (which is within current state of the art processing capabilities for etched surfaces) could process the entire asteroid in less than a year.

Scaling the resistive process is merely a matter of power. At the current processing rates, an 83 kW power system (similar to the International Space Station) could process the same 300 T asteroid in a little over 825 years.

**Scaling:** Direct solar heating is clearly advantageous in terms of processing capability, but also imposes significant difficulties. Resistive heating is much easier to contain. Without significant precautions, direct solar heating can cause condensation of the released volatiles on cooler processing optics, leading to failure of the optics. However, resistive elements are much more susceptible to thermal shock, and thereby limit the processing rate.

It should be noted that the processing capability should be driven by the demand for the volatiles. The scaled resistive heating system would supply over 300 kg of material per year, which is a significant material stream, with a relatively high value.

**References:** [1] E. Cardiff, B. Pomeroy, I. Banks, and A. Benz, *Vacuum Pyrolysis and Related ISRU Techniques*, STAIF, 2007. [2] 5. E.H. Cardiff, and Hall, B. C., *A Dust Mitigation Vehicle Utilizing Direct Solar Heating*, Space Resources Roundtable X, October, 2008. [3] *Asteroid Retrieval Feasibility Study*, April 2012, Keck Institute for Space Studies, JPL.