Studies of In Situ Fissile Fuel from Lunar Resources

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Abstract: A nuclear reactor to power lunar habitats, science, and ISRU operations will dramatically increase productivity. Launching radioactive materials is controversial, so a new approach is called for. By using materials already extant on the lunar surface, it may be possible to produce the fissile fuel in situ. The key operations, to concentrate thorium, and then to transmute thorium into uranium, will become process steps having multiple additional scientific and engineering applications.

Two interesting natural phenomenon underpin the studies proposed herein. First, the surface concentration of thorium on the Mon is much higher than on Earth. Around certain craters, thorium has been excavated by meteorite bombardment, and may be 3-4 times more concentrated. Thorium is still a trace mineral, and will require further concentration. But Th is also very dense, so the means of density sorting of regolith can be used to concentrate other dense fractions, such as free iron.

The second phenomenon is the gamma ray fog, arriving isotropically from the deep sky. Although the origin of these gamma rays remains a mystery, they have been characterized by energy and flux. Beryllium exposed to these gamma rays becomes a neutron source. After passing through a graphite moderator, these neutrons will be captured by Th, which transmutes into U after a couple months as Pa. Such a neutron source on the moon can be used for several scientific purposes.

Hardware for testing density sorting and transmutation can be made very lightweight, just 10s of kg, and operated with modest tending (hours) by an astronaut or robot. Analytical equipment is minimal, such as a lab scale and a neutron scintillator and a few sample containers.

Density sorting methods adaptable to lunar gravity include momentum transfer and a hydrocyclone. Momentum transfer is simplest and easiest, and can use ferrous bullet particles to pass perpendicularly through a cascade of size-sorted regolith. Light fractions will be deflected further than dense fractions. Bins to capture outfall will be slightly concentrated on each pass, but can be readily fed back into the apparatus for another pass. Each pass concentrates by 2-5 percent, requiring 200-300 passes in order to achieve 95% purity. The first experiments on the moon need only run 20-30 times to demonstrate technical feasibility. With bullet particles collected from the bins by electromagnet, free iron, and Fe^0-bearing agglomerates, can also be harvested at the same time.

Transmutation has no moving parts. Although it would be most satisfying to use concentrated lunar thorium, for the proof of concept, terrestrial Th will likely be used as the fertile source. The test apparatus can be self-contained, with no moving parts, and can operate without tending on the lunar surface. One embedded sensor would test for neutrons (scintillator with PMT, or microstructured semiconductor neutron detector) to characterize the n^0 flux produced by gamma ray fog impinging on beryllium. A second sensor will test for the presence of uranium using X-ray fluorescence. Hand-held XRF sensors are readily available, and can test, over time, how the concentration of U increases as the following nuclear chemistry reaction runs to its completion:

$$^{232}_{90}Th + n^0 \rightarrow {}^{233}_{90}Th + \beta^- \rightarrow {}^{233}_{91}Pa + \beta^- \xrightarrow{27\ days} {}^{233}_{92}U$$

Detailed experimental plans are developed in this paper, and used to produce estimates of mass, volume, bandwidth, and operator attention for density sorting and transmutation. Results from such a test, on the Moon, could generate considerable interest in the development of a fission reactor for lunar operations where no radioactive materials are launched by rocket.

Future operations include the excavation needed to gather many tons of regolith in order to obtain meaningful quantities of Th, and chemical separation of uranium from protactinium and unchanged thorium (THOREX). Factors unique to the lunar surface are important to characterize, such as the influence of charged particles from the solar wind, which may require ionizers to prevent sticking or deflection. This work could lead to an ultra-safe baseload lunar reactor which now makes possible a very wide range of scientific, engineering, and human habitation endeavors on the Moon. As a further future development, such fissile fuel could be used to power nuclear thermal rockets, making it much easier and faster to reach Mars or main belt asteroid.