Thorium Assay and Mining Experiment (TAME)

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Following the guidance from the President in 2017's Space Policy Directive 1, the Artemis III mission, the first U.S. human mission to the Moon in over half a century, is intended as the first step in building a sustained American presence on the lunar surface.

Unfortunately, the long lunar night means solar power is not a long term option for sustained support of human presence in the Moon. Even though there are areas in perpetual sunlight at the poles, they would provide limited power for a growing lunar settlement. Multiple NASA studies have concluded that nuclear power will be needed [1][2].

That is why NASA is developing the "Kilopower" fission reactor - with a goal of producing 1-10kWe of power - but this concept requires the launch of tens of kilograms of Highly Enriched Uranium (HEU) from the Earth's surface (the 5kW KRUSTY test reactor for Kilopower had a 28kg nuclear core, 92% of which was HEU[3]).

Putting dozens of kilograms on a launch vehicle raises serious environmental concerns, however - concerns that would likely lead to years-long environmental studies and approvals.

The current process for the launch of nuclear materials into space consists of an ad hoc Interagency Nuclear Safety Review Panel which evaluates the risks associated with the mission and prepares a Safety Evaluation Report for Presidential approval via the Office of Science and Technology Policy. This process takes an average of 4 years to complete.[4]

It might be better to launch the components of a fission reactor from Earth to the Moon without fuel and obtain it on the lunar surface. The most plentiful fissile material on the Moon is Thorium (through concentration and transmutation to U_{233}) - but in order to use it, it would be necessary to know where the fuel is located and its precise concentration.

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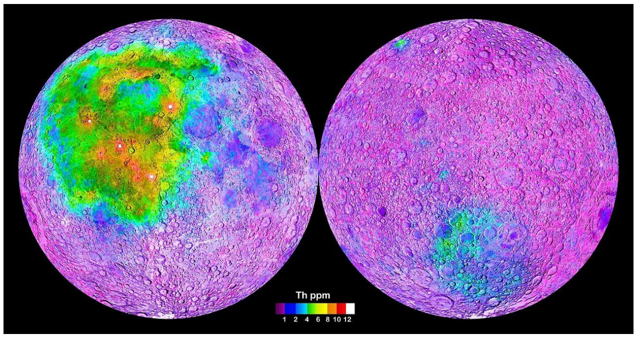
[1] Exploration Systems Architecture Study, NASA-TM-2005-214062, p. 80, Office of Exploration Case Studies, 1989: "As the power demands at the lunar outpost increase above the 100 kWe level, nuclear power offers improved specific power." https://www.nasa.gov/pdf/140649main_ESAS_full.pdf

[2] Exploration Systems Architecture Study, NASA-TM-2005-214062, p. 205, "The team concluded that a fission nuclear power system offered the best solution.." https://www.nasa.gov/pdf/140649main_ESAS_full.pdf

[3] *Why NASA thinks nuclear reactors could supply power for human colonies in space*, Chemical & Engineering News, Vol. 98, Issue 19, May 2020, https://cen.acs.org/energy/nuclear-power/NASA-thinks-nuclear-reactors-supply/98/i19

[4] Developing a launch approval process for nuclear fission reactors: lessons learned from risk mitigation and approval processes in other sectors; J. Behrens, R. Bueconsejo, B. Lal, S. Howieson, ANS NETS 2018 – Nuclear and Emerging Technologies for Space Las Vegas, NV, February 26 – March 1, 2018, https://www.ida.org/-/media/feature/publications/d/de/developing-a-launch-approval-process-for-nuclear-fission-reactors---lessons-learned/behrens-nets-2018-v3.ashx?la=en&hash=E94B9A324B64439E8360760257B83DD5

We have some idea of general concentrations from Lunar Reconnaissance Orbiter, Lunar Prospector (image below) and Chang'e 2 - but mining for actual use requires a better assay.



Since observations from the gamma ray spectrometer aboard Chang'e 2 suggest Thorium concentrations of 1.5-3.5 ppm in the South-Pole Aitken Terrane (SPAT)[5], there might be an opportunity to get a closer look at the actual on-the-ground concentrations near a landing site that is within 6 degrees of the South Pole.

For a landing in or near the SPAT, we propose the Artemis III crew conduct a three-step TAME experiment to determine the ability to detect, assay and extract Thorium Dioxide (Thoria) fission precursor material in the South Pole region, i.e.:

1) Conduct portable gamma ray spectrometer detection to determine actual concentrations of Th
2) Use hand tools to excavate a small amount of regolith with the highest relative concentration of Th
3) Conduct in situ experiments to determine the practicality of extracting Th from lunar regolith.

We suggest grinding or milling the collected material to nanometer size and then separating the Thoria out via centrifuge. Iron-nickel, which has a similar density, may have to be separated from the Thoria with an electromagnet.[6]

In order to settle and "tame" the Moon, many experiments similar to TAME, which seek to determine the presence and accessibility of resources, will have to be conducted.

We hope that this idea is useful to the SDT and to NASA as the Agency works to determine the science objectives for this historic mission.

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[5] Thorium distribution on the Moon: new insights from Chang'E-2 gamma ray spectrometer, Meng-Hua Zhu *et al* 2019 *Res. Astron. Astrophys.* 19 076 https://iopscience.iop.org/article/10.1088/1674-4527/19/6/76/pdf

[6] Nuclear Power from Lunar ISRU, P. Schubert, *Insights in Mining Science and Technology.* Vol. 1, Issue 1, May 2019, https://juniperpublishers.com/imst/pdf/IMST.MS.ID.555555.pdf