SANDWORM POLAR VOLATILE EXTRACTION AND ORE CONCENTRATION. B. Blair[1], N. Davis[2], E. Patrick[3], C. Morrison[4], and T. Zuppero[5], [1]OrbChem LLC <brad@orbchem.space>, [2]OrbChem LLC <nathan@orbchem.space>, [3]Southwest Research Institute <epatrick@swri.edu>, [4]Ultra Safe Nuclear Corporation <c.morrison@usnc-tech.com>, [5]Tionesta Applied Research Corporation, <tony@neofuel.com>

Introduction: Systems Architecture for Nuclear Distillation of Water, Ore and Regolith Mining (SANDWORM) offers a class of in-situ resource utilization (ISRU) machinery that would "ingest" raw lunar polar regolith, selectively extract a set of primary volatiles, and leave secondary volatile "ore concentrate" in its trail - a set of enriched "bricks" lying in an engineered channel for later collection, transport and refining at a nearby industrial facility. The intent is to utilize *both* the electricity *and heat* produced by isotope fission to separate and refine early lunar products (water, carbon and nitrogen compounds) while concentrating, measuring and storing byproducts including mercury, sulfur compounds, heavy volatiles, etc., for easy harvest as they are later needed.

Enabling Technology: Sandworm's patent pending technology would blend state of the art mining and nuclear heating elements into a novel, hybrid ISRU system. This approach has the potential to add significant efficiency through the 'combined heat and power' approach pioneered by terrestrial industry. Ultra-Safe Nuclear Corporation has designed a small-scale Commercial Atomic Battery (CAB) [1] for space use, and a "Pylon" lunar surface nuclear reactor [2] that can be landed on a <5 Ton lunar lander and would produce 350kW thermal and 150kW electric power. Sandworm would essentially replace the radiator with a mining, heating and condensing system for polar volatile capture. In addition, betavoltaic options for CAB offer a direct path to generating electrical current, reducing mission risk. Later systems can add complexity, for example using cold lunar regolith as a heat sink for thermoelectric conversion.

Applications: Sandworm enables both public and private benefits, including a set of early exploration missions (scientific and prospecting) using its hybrid RTG-mining approach, as well as longer-term mining operations that use full-scale reactors.

Early Science Missions: Near term lander missions could drop multiple 10-100 watt CAB powered "mini-Sandworms" into promising regions within polar permanent shadow. Rich scientific data can be gathered by disaggregating, measuring, and re-condensing a continuous trench sample of lunar polar material. This approach would augment a hop and drill or drive and drill approach by adding continuous measurements to a discrete data set, dramatically improving geostatistical data continuity for promising areas in a prospecting region. Depending on CAB radioisotope choices, it may be possible to utilize 'waste' emission spectra to conduct science measurements, identifying buried features by choosing radioisotopes that emit target frequency gamma rays or neutrons. Furthermore, science payloads could be added that leverage CAB thermal stability and power. Successful demos on the Moon could enable similar missions to other bodies including Ceres, volatile-rich asteroids and Mercury.

Commercial Operations: Long-term commercial space missions could release multiple 10kW to 1mW Sandworms into polar craters for full-scale mining operations. These units would incorporate lessons learned from early prototypes, and be driven by Pylon-scale [2] or similar nuclear reactors [3].

Infrastructure: Benefits do not need to stop after Sandworm has extracted primary and byproduct ores. Options for reuse and reclamation include leaving landing pad flow channels, roadways and tunnels. Design trade space options could also include embedding solid conductive rails or wires for areas that have high enough mercury content (noting that LCROSS measured 4 wt%). Finally, a sintering train car could use focused microwave energy to print hardened features into roadways, augmenting the potential for cementation of roadways using condensed volatiles or refined sulfur cement.

Architectural Features: Systems-level capabilities enabled by the SANDWORM architecture framework include: Separation of raw material into dynamically variable product, byproduct and waste streams; Continuous production of storable ore concentrates; Minimizing required mass transport to remote refining machinery; Measurement, delineation and marking of mineral deposits by leaving a permanent track that is visible from orbit; Gathering geologic and prospecting 3D measurements through continuous trench sampling; Severing of raw materials and conversion to private property through the addition of work; Providing a thermally stable, powered mobile platform for science payloads; Scalability from watts to megawatts of power; Modularity by adding functional train cars; And, Automated construction of roadways to facilitate collection of products, providing infrastructure and enabling transport up steep crater walls.

References: [1] Morrison, C. "Chargeable Atomic Batteries (CAB)", FISO Telecon May 26, 2021, http://fiso.spiritastro.net/telecon/Morrison_5-26-21/Morrison_5-26-21.pdf. [2] Eads, M., et. al., "The PYLON", ANS Topical Meeting, Feb, 2019, http://anstd.ans.org/NETS-2019-Papers/Track-4--Space-Reactors/abstract-129-0.pdf [3] Zuppero, T. "Lunar South Pole ice as heat sink for cryofuel", INEEL, 1994, https://www.osti.gov/servlets/purl/42524.