DEFINING CUT-OFF GRADES FOR LUNAR HELIUM-3, A GEOLOGICAL AND ISRU ECONOMIC CASE STUDY.

Carlos D. Espejel Garcia[1], Joshua Rasera[2], and Ruby Patterson[3], [1]Space RS S.à r.l. (26 route de Luxembourg, Eisenborn, 6196, Luxembourg, carlos.espejel@space-rs.com), [2]Space RS S.à r.l. (26 route de Luxembourg, Eisenborn, 6196, Luxembourg, joshua.rasera@space-rs.com), [3]Crisium Group (ruby@crisiumgroup.com).

Introduction: Helium-3 has long been proposed as a strategic lunar resource due to its potential role in advanced fusion energy systems and as a possible driver for future cislunar economic activity [1]. However, its occurrence in lunar regolith is extremely dilute, typically measured in parts per billion, and its distribution is influenced by both solar wind implantation and the geological evolution of the lunar surface. Mature regolith deposits, particularly in lunar mare regions enriched in titanium-bearing minerals such as ilmenite, tend to exhibit relatively higher Helium-3 concentrations due to prolonged exposure to the solar wind and favorable trapping mechanisms within mineral grains [2]. Despite these geological enrichment processes, the overall abundance of Helium-3 remains extremely low, presenting significant technical and economic challenges for extraction.

An Economic Case Study for Cut-Off Grades for He-3: The development of economically viable in-situ resource utilization (ISRU) systems requires quantitative frameworks capable of linking resource characteristics, processing performance, and mission architecture. In terrestrial mining engineering, cut-off grade analysis—formalized in the work of Lane—has long been used to determine the minimum resource concentration required for economically viable extraction by integrating mining, processing, and economic constraints [3]. This study adapts Lane's cut-off grade methodology to evaluate potential Helium-3 extraction scenarios from lunar regolith under mission-driven operational conditions.

A value chain specific to Helium-3 extraction from lunar regolith is defined, including regolith excavation, material transport, high-temperature thermal processing to release implanted solar wind volatiles, gas capture and separation, storage, and eventual utilization or transport. Thermal extraction processes typically require heating regolith to temperatures of approximately 600–900°C to liberate implanted volatiles, including hydrogen, helium, and other solar wind species. This process creates strong coupling between regolith processing throughput, system energy availability, and the overall architecture of the ISRU system.

The geological characteristics of the regolith deposit play an important role in determining the economic feasibility of extraction. Regolith maturity, exposure age, and mineralogical composition influence both the concentration and retention of solar wind derived volatiles. Mare regions with elevated titanium content, particularly those containing ilmenite-rich basalts, are often considered promising targets due to their potential to host relatively higher concentrations of implanted Helium-3 compared to highland terrains.

Within this framework, cut-off grades are estimated by integrating mission-driven constraints such as available power generation, regolith handling throughput, thermal processing efficiency, and system operational losses. Unlike terrestrial mining operations, where cut-off grades are primarily determined by commodity price and processing cost, the lunar cut-off grade becomes strongly dependent on mission architecture. Energy system design, processing efficiency, and achievable operational scale therefore become dominant parameters in determining the economic feasibility of Helium-3 extraction.

A reference lunar surface scenario is evaluated to explore how variations in energy supply, regolith maturity, processing efficiency, and system throughput influence the minimum Helium-3 concentration required for economic viability. The results illustrate how cut-off grade estimation can serve as a comparative framework for evaluating different ISRU architectures, identifying dominant cost drivers, and prioritizing technology development efforts. By applying established mining economic principles to lunar resource systems, this approach contributes to moving Helium-3 resource discussions from speculative potential toward quantitative, mission-relevant evaluation.

References: [1] Lane K. F. (2015) *The Economic Definition of Ore: Cut-Off Grades in Theory and Practice.* [2] Badescu V. et al. (2023) *Handbook of Space Resources.* [3] Lucey P. G. et al. (2006) *Rev. Mineral. Geochem.*, 60, 83–219.