Closure of regenerative life support systems: results of the Lunar-Mars Life Support Test Project

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Future long duration human exploration missions away from Earth will require closed-loop regenerative life support systems to reduce launch mass, reduce dependency on resupply and increase the level of mission self sufficiency. Such systems may be based on the integration of biological and physiocochemical processes to produce potable water, breathable atmosphere and nutritious food from metabolic and other mission wastes. Over the period 1995 to 1998 a series of ground-based tests were conducted at the National Aeronautics and Space Administration, Johnson Space Center, to evaluate the performance of advanced closed-loop life support technologies with real human metabolic and hygiene loads. Named the Lunar-Mars Life Support Test Project (LMLSTP), four integrated human tests were conducted with increasing duration, complexity and closure. The first test, LMLSTP Phase I, was designed to demonstrate the ability of higher plants to revitalize cabin atmosphere. A single crew member spent 15 days within an atmospherically closed chamber containing 11.2 square meters of actively growing wheat. Atmospheric carbon dioxide and oxygen levels were maintained by control of the rate of photosynthesis through manipulation of light intensity or the availability of carbon dioxide and included integrated physicochemical systems. During the second and third tests, LMLSTP Phases II & IIa, four crew members spent 30 days and 60 days, respectively, in a larger sealed chamber. Advanced physicochemical life support hardware was used to regenerate the atmosphere and produce potable water from wastewater. Air revitalization was accomplished by using a molecular sieve and a Sabatier processor for carbon dioxide absorption and reduction, respectively, with oxygen generation performed by water hydrolysis. Production of potable water from wastewater included urine treatment (vapor compression distillation), primary treatment (ultrafiltration/reverse osmosis and multi-filtration) and post processing. For the Phase II test the water recovery rate ranged from 95 to 98%, depending on the processor. LMLSTP Phase III, the fourth test of the series, had a duration of 91 days and included four crew members. The test demonstrated an integration of physicochemical and biological technologies for air revitalization, water recovery and waste processing. Wheat supplemented the physicochemical air revitalization systems by providing approximately 25% of the oxygen required for the 4-person crew. The water recovery system included immobilized cell and trickling filter bioreactors for primary water treatment, reverse osmosis and air evaporation systems for secondary water treatment, followed by post processing. The 8 day initial supply of water was recycled through

the chamber and crew 10 times over the course of the test. Grain from the wheat together with fresh lettuce from a small growth chamber within the crew chamber provided supplementation to the stored food system, but at a level less than 5% of the crew's caloric requirement. An incinerator was used to demonstrate mineralization of the crew's solid waste, with the combustion products (mainly carbon dioxide) returned to the wheat for conversion to oxygen.