

Conservative Radiation Countermeasures in Response to Space Radiation Effects on the Lunar South Pole.G.A. van der Sanden¹ and B.H. Foing², ¹European Space Agency ESTEC, Noordwijk, The Netherlands²International Lunar Exploration Working Group 3 Vrije Universiteit Amsterdam, The Netherlands

Introduction: During spaceflight endeavors beyond Low Earth Orbit (LEO) human subjects are exposed to varying degrees of ionizing and non-ionizing radiation. In the framework of human-health, the primary concern is ionizing radiation, the number one health risk in space environments. The Space radiation environment for a manned Space Station beyond LEO will be exposed to this type of radiation derived from three different natural sources: terrestrial, solar events and galactic cosmic rays. This research was conducted to present conservative radiation countermeasures for a conceptual mission design of a manned operation to the lunar South Pole, Aitken Basin, named the DIANA Programme (2030-2045).

With the integrated radiation on-line tool OLTARIS for radiation assessment in space environments we analyzed the effects of space radiation on shielding, electronics and biological systems. In compliance with the architects we defined trade-offs to establish successful radiation limits for mission success. Our definitions comply with the radiation standard limits set to a 3% risk of exposure induced death at the 95% Confidence Interval. We present a quantitative estimation of the ionizing radiation environment during the DIANA Programme, as well as the defined counter measurements based on trade-offs in response of the quantified radiation risk based on the thickness distributions and materials.

1. Sunspot frequency alternation and GCR Modulation

A future prediction of the sunspot fluctuation and Solar Particle Event occurrence is the first step towards obtaining a quantitative understanding of the expected ionizing radiation and high-risk periods within the DIANA programme. Based on historic data (1954-2008) we derived an oscillation in compliance with an annual timeframe. The extrapolation of data enabled an understanding on the time of the solar maximums and solar minimums during the lunar surface exploration. The results indicate a Solar Minimum and Solar Maximum period. These results can be used to effectively mitigate the irregular and unpredictable effects of ionizing radiation on the crew, in terms of time for the DIANA mission.

2. Effective Countermeasures

Thickness and material formatting through XML resulted in different thickness distributions for the three

chosen materials: water, aluminum and regolith. The trade-off between these materials was based on indigenous presence of reservoirs (reservoirs can become resources), mass, cost, volume and most important shielding effectiveness. The regolith, which is inherently present on the lunar surface and in particular on the rim of the Shackleton crater offered the best solution in the framework of In-Situ Resource Utilization. We shall present the trade-off between the maximum radiation dose (dose equivalent) and regolith thickness for total mission duration.

3. Complimentary Countermeasures

With the help of integrated space station hardware and detectors we aim to establish real-time on-site quantifiable data to determine the absolute and accumulated dose. Instruments range from personal dosimetry, e.g. EuCPAD to on-board mapping devices e.g. DOSE or DOSE 3 to understand the dose distribution throughout the modules. In addition neutron detection devices are installed to understand the ratio of neutron particle participation. Complementary to instrumentation, we rely upon state-of-the art research conducted in terrestrial radiobiology laboratories and bio-countermeasures to combat the effects of space radiation on our biological systems, including well-known antioxidant agents e.g. vitame C/E/B1.

Additional Information: This research was conducted in the framework of the 2019 Space Station Design Workshop, organized and held at the Institute of Space Systems. An intensive 1-week workshop focusing on the development of a Space Station. Through concurrent design methods two competing teams of 20 selected young professionals were presented the challenge to design a conceptual lunar base required to be operational by 2030.

References:

- [1] Chancellor J.F., Scott G.B.I and Sutton J.P. (2014) *Life*, 4, 491-510 [2] Globus A.L. NSS Space Settlement Journal, 1-36. [3] NASA OLTARIS tool (<https://oltaris.larc.nasa.gov/>). [4] Nukala U. (2018) Antioxidants 7(2), 33.