PRECURSOR MISSIONS TO REDUCE RADIATION ENVIRONMENT AND EFFECT UNCERTAINTY.
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For long-duration crewed missions beyond low Earth orbit (LEO), the presence and effects of exposure to ionizing radiation must be considered. Current crewed Mars mission plans result in galactic cosmic radiation (GCR) becoming a non-negligible component of astronaut exposure. Current radiation exposure estimation methods suggest that the level of shielding required to meet astronaut radiation exposure requirements will add significant mass to already massive vehicles. There is a significant uncertainty to these methods however resulting from two primary sources, lack of validation data for radiation estimates outside of LEO and uncertainty of the response of cells in response to low linear energy transfer (LET) radiation.

The shortcomings of current crewed Mars architecture plans illustrate the need for further investigation into deep-space radiation. NASA's current human exploration plan for Mars, the *Human Exploration of Mars Design Reference Architecture 5.0* (DRA5.0), estimates for habitats having either 5 g/cm^2 or 20g/cm^2 of aluminum shielding the estimated effective dose on an astronaut will be 1,070-1,240 mSv for a conjunction-class mission during solar minimum [1]. Compared to the Constellation effective dose requirement of 150 mSv and DRA5.0's stated requirement of 250 mSv, the shielding anticipated by DRA5.0 is insufficient relative to the anticipated requirement resulting in an unacceptable risk to crew health. Currently, the only available solution is to add many tons of shielding mass to block the incoming particles.

Precursor missions have the opportunity to be very valuable in reducing uncertainty in radiation knowledge which in turn would relax current requirements for human exposure in space. The legal requirement for human exposure in LEO states that astronaut exposure shall not result in greater than 3% excess fatal cancer risk [2]. It is expected that crewed Mars missions will have a similar restrictions. Previous work has shown that the amount of uncertainty in estimates of cancer risk based on radiation exposure are so large as to make discerning between radiation shielding options impossible [3]. Past practice has been to use effective dose as a proxy for excess cancer risk [4]. Even then the nominal rate must be reduced by two to four times to meet a 95% confidence interval of not exceeding the requirement due to the uncertainty in the estimate [3,5].

To address the uncertainty caused by the lack if validation data in deep space radiation shielding estimates, a secondary payload approach is proposed. Such an approach would be a continuation of the work being done by the Radiation Assessment Detector (RAD) currently in transit to Mars as part of the Mars Science Laboratory mission [6]. It is proposed that subsequent missions use multiple RADs with various shielding configurations and pairings of expected spacecraft shielding materials in geometries that can be readily modeled. The data generated by such a payload would provide critical code validation, which would help to reduce current model uncertainty.

A more ambitious project that would serve as a primary research payload would be the launch and recovery of mice containing specialized human cells. The proposed mission is a repurposing of the Mars Gravity Biosatellite project [7]. Rather than test the effects of a reduced gravity environment, the mission would investigate the combined effects of the space radiation and zero-gravity on human tissue. Demonstration of the growth of various human cells, such as kidney and brain cells, in mice have already been done so relevant human physiology could be investigated without endangering crew [8]. The satellite containing the mice would be launched beyond the shielding provided by Earth's magnetosphere for an extended period of time before returning to Earth for recovery. The human cells within the mice could then be investigated for evidence of cancer and other damage. This would vastly enhance knowledge of the effects of space radiation on human cells and would help to eliminate uncertainty in estimating cancer risk based on radiation exposure.

Radiation is a known challenge for direct human exploration of Mars and remains an unretired risk. Precursor missions can directly support the eventual human exploration of Mars by allocating some resources to help reduce uncertainty in key areas of radiation effects prediction and estimation. This increased knowledge will allow requirements to be relaxed relative to their current levels without increasing risk to crew health.

References:

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