Space Radiation Protection Status and Challenges

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The radiation environment in space has virtually nothing to do with the radiation environment on the ground. Three main factors create the space radiation environment: (1) the galactic cosmic background, a slowly varying omnidirectional field that is as many as 60 ions of the periodic table in measurable abundances at over 12 orders of energy magnitude; (2) solar particle radiation, the transient or event source; and (3) objects trapped in the geomagnetosphere, mainly protons and electrons.

NASA organizes its space radiation protection activities into three main areas: (1) fundamental human-related research in radiation and radiobiology; (2) space medicine radiation health recordkeeping (translating "physicist" to "physician") and working in risk estimation and crew selection (how NASA conducts itself related to human health: what is wrong, and how do we fix it); and (3) the space radiation analysis that provides radiological console support, extravehicular activity (EVA) crew exposure projections, comprehensive crew exposure modeling capability, and radiation characterization of the environment inside and outside of the vehicle.

Vehicle location, as opposed to the environmental state, is the primary driver for radiation in low-Earth orbit (LEO). This is counterintuitive, and results from the protection provided to LEO missions by the Earth's magnetic field. In considering operational issues, vehicle phase and ground track are essential concerns. As we consider Constellation and other long-term missions, the question of "how long until they phase in" is eliminated; the answer is always "right now."

Our radiation approach in low-Earth orbit

The point of greatest vulnerability for our crew occurs during EVA activity, so we select the right people and preplan EVA very carefully. If an event does occur based on situational awareness, we can "manipulate the timeline" to appropriately minimize the mission impact.

The primary limitations of this approach include our limited descriptions of the geomagnetic field, a highly dynamic and nonlinear system. The best tools available today are static in nature. We want to preplan activities, so we have to project tomorrow's exposure, not just account for yesterday's exposure. We are also limited by the models of trapped particles in the Earth's magnetic field.

Current passive crew and area monitoring tools include thermoluminescent dosimetry(TLD)100, 300, 600-700, and CR-39® (Columbia Resin) to measure bulk dose. Number designations here denote materials changes that produce slightly differing sensitivities. TLD 100 is the overall industry standard of lithium fluoride (LiF), which gives a relatively high efficiency for low-linear energy transfer (LET) radiation fields (i.e., photons, beta/electron sources). TLD 300 is calcium fluoride doped with thulium; it represents a measurement from which semiquantitative information can be extracted with respect to contributions of low- vs. high-LET sources. TLD 600 or 700 material is again LiF, in which abundances of fluorine isotopes are weighted to either Li_6 or Li_7 respectively. Li_6 has a very high absorption cross section for thermal neutrons, while Li_7 has a correspondingly very low cross section. As a pair then, information can be extracted concerning the contribution to total measured radiation dose resulting from thermal neutron exposure. CR-39® is a moniker for the use of allyl diglycol carbonate plastic, commonly used in the production of eyeglass lenses as a measurement device. Ionizing radiation with LET values greater than approximately 10 keV/μm cause molecular deformations in the plastic polymer. These deformations are then exacerbated with a chemical etch and individually scored. Each visible track is evaluated, geometrically relating the size and shape of the visible track to the LET of the producing particle through careful calibration. In this way we obtain a passive measurement of LET spectrum for derivation of personal regulatory quantities of interest. We will continue with passive monitoring because this form of monitoring is absolutely reliable and "unkillable," and is relatively low cost because of its low mass and volume.

Our active monitoring practices are shaped by two essential technologies leading our approach to autonomous exploration of the moon and Mars. The tissue-equivalent proportional counter (TEPC) gives real-time dose information and radiation field quality. These data are provided 24 hours a day in 1-minute cadences. The charged particle directional spectrometer (CPDS) is a stack of silicon wafers. As ionizing

radiation passes through the CPDS, the signature left on the wafer indicates the nature of the radiation.

We are starting to build next-generation hardware for the International Space Station (ISS), and are involved with the exploration Constellation Program. The next-generation TEPC is approximately the size of a deck of playing cards and weighs less than 2 lbs. The next-generation CPDS, a product of a NASA-industry-academia collaboration, is already in place for the Mars 09 mission.

Constellation: The future

In designing the next generation of U.S. space vehicles, we are driven by the inherently mass-contained nature of the physics of a lunar mission. Therefore, management of radiation exposure is achieved through vehicle reconfigurations rather than with parasitic shielding. Experience gained through the Space Shuttle and ISS Programs permits us to focus on providing multifunctional spacecraft components, allowing us to minimize crew risk at a concurrent minimum risk of vehicle additional mass and overall system impact. Minimization is particularly important in this case, as the magnitude of possible exposures outside the confines of LEO increases dramatically.

First gap: Orion from a radiation perspective

In figure 1, the parts of Orion (i.e., the crew compartment for ISS and the moon) that are blue are cool/good; the red parts are hot/bad. We have taken inventory of the items already on the vehicle and reconfigured them and the crew geometrically to increase the radiation protection by a factor of 3 without adding anything to the vehicle. The same kind of approach is being investigated with respect to notional habitat and rover designs. The price paid for this is computational power – a gap where we would like to see improvement.

Second gap: Program planning and probability

The biggest problem we have is that we cannot predict what will happen next. When dealing with most environmental concerns, one is interested in environments that were brought with the crew on the vehicle – that is to say, that have engineering solutions. The natural radiation environment is, of course, not under control, and no vehicle can be designed to simply exclude it as one would approach an air contaminant. The three normal tenets of radiation protection (time, in which you minimize a person's exposure to the source; distance, in which you get the person farther away from the source of exposure;

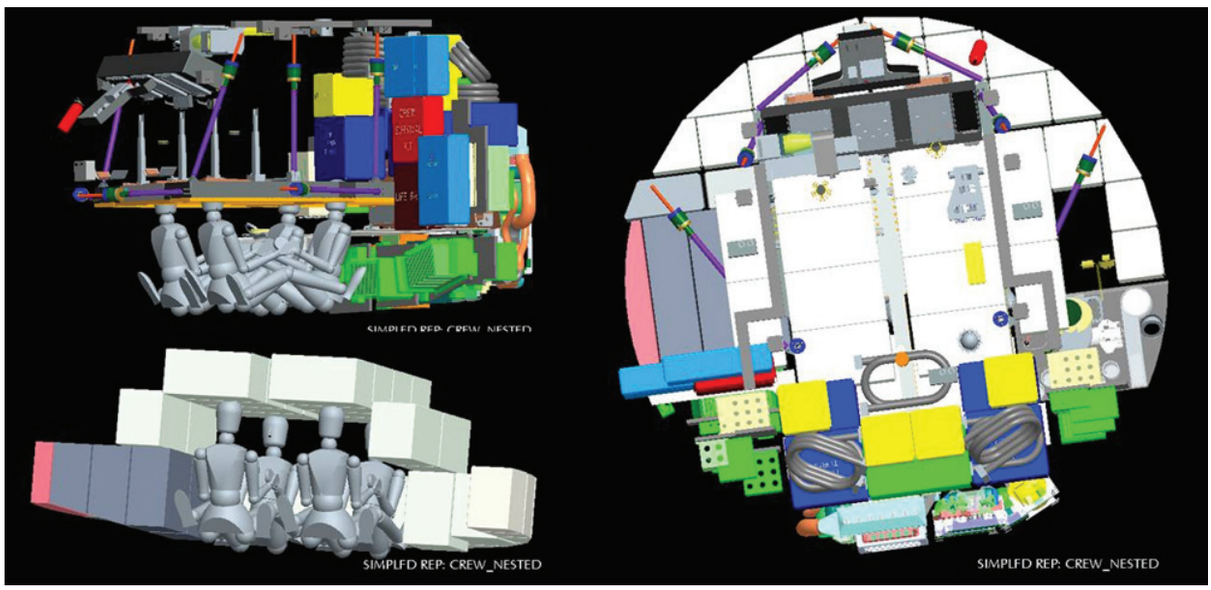

Fig. 1. *Orion from a radiation perspective.*

and shielding, in which you put something between the person and the exposure) are not effective for dealing with the space flight problem. The question is not whether radiation will impact an Exploration mission; the question is when, and what the available mitigations will be.

Third gap: Space weather monitoring

How are we going to get there? As we embark on Exploration missions, our radiation monitoring requirements must necessarily expand. We therefore need alternative data sources to those in place today. We must work together to develop accurate forecasting tools that will give us anywhere from 30 minutes to 24 hours of lead time for events. We are often asked: "How much time is needed?" The answer is: "As much as is possible." There are very real applications for a 2-hour look-ahead, as there are in a longer time frame.

Fourth gap: Transition from research to operations

It is difficult to turn fundamental scientific research into operations, but we must have the perspective to work together.

Radiation represents a significant risk to humans venturing beyond the confines of LEO that we do not yet know how to solve. There is a driving uncertainty in the environment; we simply cannot predict the future behavior of the sun as a physical system. Additionally, there is a driving uncertainty in radiobiology: understanding what it means when you are exposed. Operationally, we are working with three primary mitigations: vehicle design, crew selection, and situational awareness – all of which play a major role in space radiation protection for our crews (figure 2).

Fig. 2. *Concept for individual shielding during predicted solar event.*

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