ANALYTIC SHIELDING OPTIMIZATION TO REDUCE CREW EXPOSURE TO IONIZING RADIATION INSIDE SPACE VEHICLES. Razvan Gaza[1], Tim P. Cooper[1], Arthur Hanzo[1], Hesham Hussein[1], Kandy S. Jarvis[1], Ryan Kimble[1], Kerry T. Lee[2], Chirag Patel[1], Brandon D. Reddell[1], Nicholas Stoffle[2], E. Neal Zapp[2], and Tad D. Shelfer[1]

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A sustainable lunar architecture provides capabilities for leveraging out-of-service components for alternate uses. Discarded architecture elements may be used to provide ionizing radiation shielding to the crew habitat in case of a Solar Particle Event. The specific location relative to the vehicle where the additional shielding mass is placed, as corroborated with particularities of the vehicle design, has a large influence on protection gain. This effect is caused by the exponential-like decrease of radiation exposure with shielding mass thickness, which in turn determines that the most benefit from a given amount of shielding mass is obtained by placing it so that it preferentially augments protection in under-shielded areas of the vehicle exposed to the radiation environment.

A novel analytic technique to derive an optimal shielding configuration was developed by Lockheed Martin during Design Analysis Cycle 3 (DAC-3) of the Orion Crew Exploration Vehicle (CEV). [1] Based on a detailed Computer Aided Design (CAD) model of the vehicle including a specific crew positioning scenario, a set of under-shielded vehicle regions can be identified as candidates for placement of additional shielding. Analytic tools are available to allow capturing an idealized supplemental shielding distribution in the CAD environment, which in turn is used as a reference for deriving a realistic shielding configuration from available vehicle components.

While the analysis referenced in this communication applies particularly to the Orion vehicle, the general method can be applied to a large range of space exploration vehicles, including but not limited to lunar and Mars architecture components. In addition, the method can be immediately applied for optimization of radiation shielding provided to sensitive electronic components.

References:

[1] Lockheed Martin, DRD CEV-T-045001 "Project Orion: CEV Space Radiation Analysis and Certification Report", NASA Deliverable (2009)

Analytic Shielding Optimization to Reduce Crew Exposure to Ionizing Radiation Inside Space Vehicles

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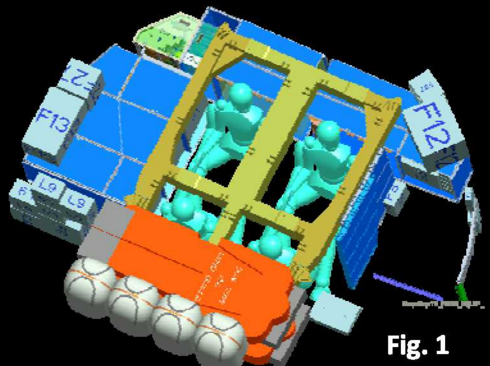
Fig. 1

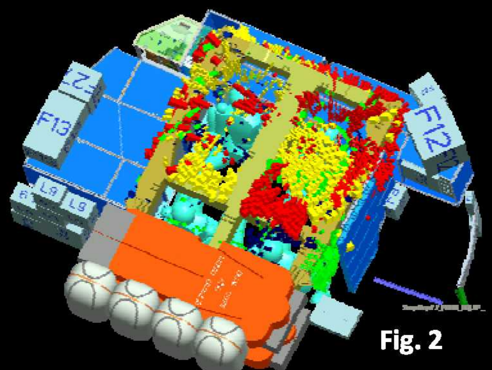
Fig. 2

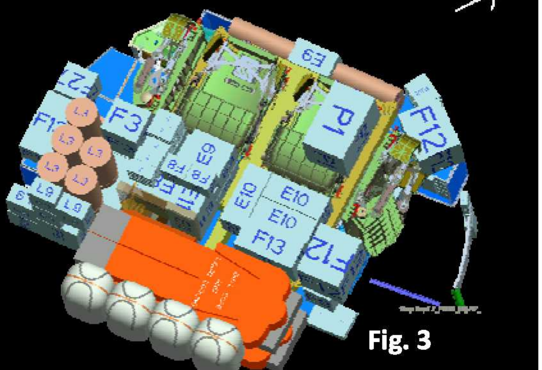
Fig. 3

1. Introduction

- Solar Particle Events (SPEs) are massive, transient emissions of ionized particles (mostly protons) from the Sun; exposure to SPE radiation is detrimental to crew health and sensitive electronic equipment
- Omni-directional environment, can be mitigated w/ passive shielding
- Characteristics of SPE energy spectra result in an exponential-like decay of radiation exposure with shielding mass thickness

2. Orion Crew Exploration Vehicle (CEV)

- Cx component; crew habitat during trans-lunar and trans-Earth transit
- Design ongoing; successfully completed the Preliminary Design Review (PDR) program milestone in September 2009
- For the first time in history, providing adequate radiation protection to the Orion crew is a requirement driving spacecraft design
- Requirement verified by analysis of the full-fidelity Orion CAD model
- Baseline radiation protection scenario during an SPE consists of:
  - → Temporarily relocating crew to preferentially shielded areas
  - → Temporarily reconfiguring vehicle to optimize radiation protection
- Shielding optimization using on-board components is preferred over use of dedicated radiation shielding due to lift-off mass constraints
- **Due to the non-linear decay of radiation dose with shielding mass thickness, net improvement in protection can be accomplished without net increase in vehicle mass by relocating cabin items to augment under-shielded vehicle regions as determined relative to crew location**

3. Derivation of the optimized shielding configuration

- Complex problem; mathematically equivalent with minimizing the multi-variable functional dependence of radiation exposure versus possible locations of individual vehicle components
- Steps of the analytic procedure as currently implemented are:

A. A subset of cabin items is identified as available for relocation

B. CAD model is configured to exclude items available for relocation and radiation analysis is performed to quantify radiation protection merit of the fixed (unmovable) vehicle components only (Fig. 1)

C. For each crew position, a value is determined to represent mass thickness threshold to which all thinly shielded directions have to be augmented to reach a desired protection endpoint

D. CAD representations are created and assembled in the vehicle CAD model to reflect distribution of radiation shielding needed to augment intrinsic vehicle shielding up to the calculated threshold (Fig. 2)

E. Excluded cabin items are reassembled in the vehicle CAD model to best reproduce the shielding configuration determined analytically in step C and visually represented in step D (Fig. 3 and Fig. 4)

F. Analysis is performed on the analytically derived Orion vehicle configuration to assess crew protection capabilities

4. CEV 606-G Orion design revision (PDR vehicle) results

- Different Orion cabin configurations were CAD modeled, using same crew positioning and cabin items available for relocation (m≈360 kg)
- Calculated tissue-averaged effective dose for the crew was compared for the analytic cabin reconfiguration (Fig. 3 and Fig. 4) versus a reference cabin reconfiguration derived qualitatively (Fig. 5)

Crew position	Effective dose E (mSv)	
	Analytic	Qualitative
C1	101	129
C2	115	139
C3	123	146
C4	99.3	140

5. Conclusions

- **A method was developed for analytic derivation of a spacecraft reconfiguration that optimizes crew protection from ionizing radiation exposure during a Solar Particle Event**
- **The method was implemented in the Orion CEV design and led to a predicted 15.8%-29.1% improvement in crew radiation protection**
- The method can be immediately applied to optimize protection of radiation-sensitive electronic equipment, in addition to crew

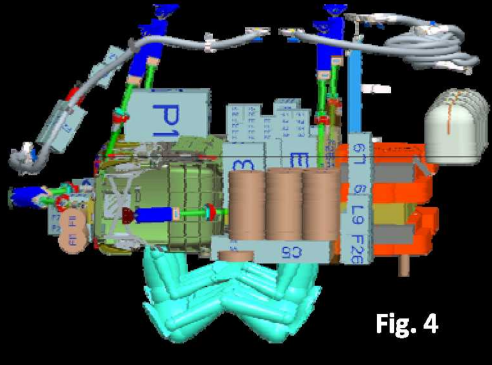
Fig. 4

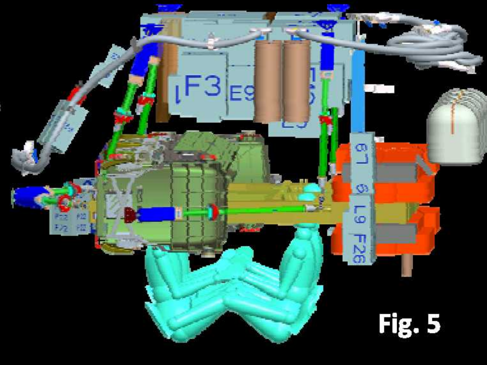
Fig. 5