Modeling the prodromal effects and performance reduction of astronauts from exposure to large solar particle events

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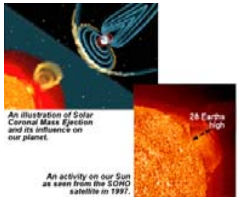
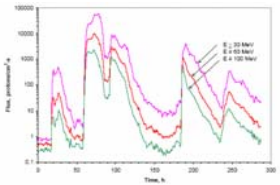
Introduction



- **Radiation exposure from solar particle events (SPE) presents a health concern for astronauts, that could impair their performance and result in possibility of failure of the mission.**
- **Assessing the potential of early radiation effects under such adverse conditions is of prime importance.**
- **A biologic based mathematical model[1] which describes the dose and time-dependent early human responses to ionizing radiation is presented.**

Exposure Calculation

Hourly-averaged proton flux of GOES (Geostationary Operational Environmental Satellites) measurements during Oct 26-Nov 6, 2003 SPE.

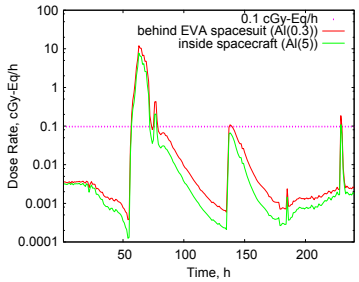


Model system:
- Baryon transport code (BRYNTRN[2])
- Spherical spacecraft in deep space
- Computerized anatomical man (CAM) model[2]

Light ions considered: n, p, ^{2}H, ^{3}H, ^{3}He, and α

Worst Historical Event

BFO dose rate during August 1972 SPE



Human Response Program (1981-1996)

- Battlefield impact of acute radiation sickness
- *illness → symptoms → performance*
- Performance degradation = task time extension

Radiation Induced Performance Deduction (RIPD) code

Symptoms of Acute Radiation Sickness (ARS):
- Upper Gastrointestinal Distress (UG)
- Lower Gastrointestinal Distress (LG)
- Fatigability and Weakness (FW)
- Fluid Loss and Electrolyte Imbalance (FL)
- Infection and Bleeding (IB)
- Hypotension (HY)

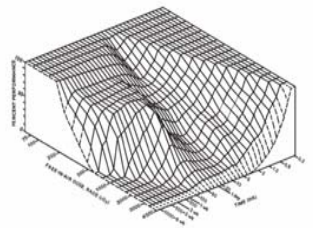
Human response quantification

Severity levels of upper gastrointestinal (UG) distress in humans

Severity level	Signs and symptoms
5	Vomiting/retching several times including the dry heaves
4	Vomiting/retching once or twice; nauseated and vomiting may recur
3	Nauseated, sweating, frequent retching and swallowing to avoid vomiting
2	Upset stomach clammy and sweaty; mild nausea
1	Normal; no noticeable effect

Model calculation: performance degradation

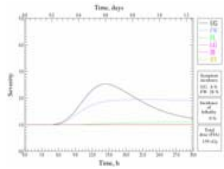
$$P = \left\{1 + \exp\left[-\left(\beta_0 + \sum_{k=1}^{k} \beta_k X_k\right)\right]\right\}^{-1},\ X_k = (1,5),\ 0 \le P \le 1$$



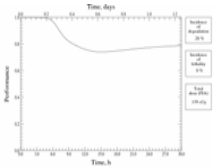
Worst Case Study

Model Calculations

30 hours stay in spacecraft during the August 1972 SPE peak



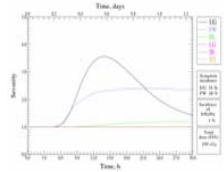
Sickness severity



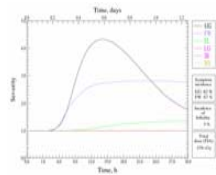
Performance degradation

- **Early illnesses of UG and FW are manifested inside a poor shelter.**
- **Performance degradation is expected but risk of death is small.**

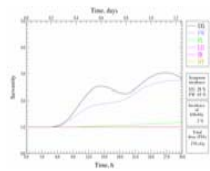
3 hours EVA during the SPE peak



Doubled in strength

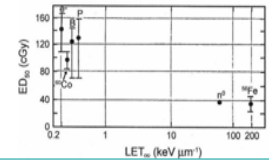


Doubled in a same period



Compatibility Issues

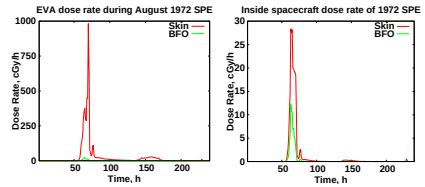
How effective are protons causing prodromal effects?[a]



LET dependence of RBE of radiation in producing emesis in ferrets; B = bremsstrahlung (X-rays), P = protons, e$^-$ = electrons, ^{60}Co = cobalt γ rays, n^0 = neutrons, ^{56}Fe = iron ions.

[a]National Council on Radiation Protection and Measurements, Information Needed to Make Radiation Protection Recommendations for Space Missions Beyond Low-Earth Orbit. NCRP Rep. No. 153, November, (2006)

Which dose to use: skin dose or bone marrow dose?[b]



- EVA protons are attenuated by the body tissue much more effectively than gamma-rays.
- For gamma-rays, the ratio of dose rate of FIA (free-in-air) to that of MLT (midline tissue) is 1.5.

[b] Parsons, J. L. and Townsend, L. W., Interplanetary Crew Dose Rates for the August 1972 Solar Particle Event, *Radiat. Res.* **153**, 729–733, (2000)

Conclusions and Future Work

- **Assuming the same prodromal effects for exposures to SPE radiation as those for the gamma rays, the worst-case historical SPEs are capable of inducing early effects to crew members and impair their performance.**
- **Events with higher flux or frequency (2 times that of August 1972) significantly increase the ARS effects but the incidence of mortality is small (3%) even without medical treatment.**
- **Bench marking of the RIPD code to space radiation environment is necessary for a precise analysis of the health risk to astronauts.**
- **Specific organ dose (e.g., stomach, intestinal) will be used in future work.**

References

1) Anno, G. H., McClellan, G. E., Dore, M. A., Protracted Radiation-Induced Performance Decrement, Volume 1—Model Development, Defense Nuclear Agency: Alexandria VA, (1996)
2) Kim, M. Y., Hu, X, and Cucinotta, F. A., Effect of Shielding Materials from SPEs on the Lunar and Mars Surface, *AIAA Space 2005*, paper number AIAA-2005-6653, Long Beach, CA, August 30-September 1, (2005)