Space Radiation Risks for Long Duration Missions

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Space Radiation Environments

Galactic cosmic rays (GCR) penetrating protons and heavy nuclei—a biological science challenge

- shielding is not effective
- large biological uncertainties limits ability to evaluate risks and effectiveness of mitigations

Solar Particle Events (SPE) largely medium energy protons—a shielding, operations, and risk assessment challenge

- shielding is effective; optimization needed to reduce weight
- improved understanding of radiobiology needed to perform optimization
- accurate event alert/dosimetry and responses is essential
Solar Cycle Effects on Risks

- The solar cycle is approximately 11-years in length, however variations in length of ±2 y can occur
  - Doses from SPEs are highest at solar maximum when solar activity is highest
  - Doses from GCR are highest at solar minimum
- Each cycle will have varying modulation conditions and number and sizes of SPE
- The prediction of solar condition temporal patterns are uncertain for future solar cycles
Solar Particle Events

Solar Flares & Coronal Mass Ejections

- Onset, magnitude, time course currently not predictable
- Intensity and the energy spectrum of a SPE vary throughout the course of the event
- Events last from a few hours to several days
- Many events can be relatively harmless to human health with minimal shielding protection
- Dose rates are low in general for many events
  - Large events - ????
- SPEs with large fluences of particles with energies above 30 MeV are a concern
- Protons with energies above 10 MeV have sufficient range to penetrate an EVA spacesuit
Categories of Radiation Risk

Four categories of risk of concern to NASA:

- **Carcinogenesis (morbidity and mortality risk)**

- **Acute and Late Central Nervous System (CNS) risks to the Brain**

- **Chronic & Degenerative Tissue Risks**
  
  ✔ cataracts, heart-disease, etc.

- **Acute Radiation Risks**

Differences in biological damage of heavy nuclei in space compared to x-rays, limits Earth-based radiation data on health effects for space applications

- **New knowledge on risks must be obtained**
Radiation and Non-Cancer Effects

• Early Acute risks are very unlikely:
  – Low or modest dose-rates for SPE’s insufficient for risk of early death
  – SPE doses are greatly reduced by tissue or vehicle shielding

• Radiation induced Late Non-Cancer risks are well known at high doses and recently a concern at doses below 1 Sv (100 rem)
  – Significant Heart disease in Japanese Survivors and several patient and Reactor Worker Studies
  – Dose threshold is possible making risk unlikely for ISS Missions(<0.2 Sv) but possibly a concern for Mars or lunar missions due to higher GCR and SPE dose
  – Qualitative differences between GCR and gamma-rays are a major concern
Space Radiation Safety Requirements

- Congress has chartered the National Council on Radiation Protection (NCRP) to guide Federal agencies on radiation limits and procedures.
- Crew safety
  - Career limit of 3% fatal cancer risk
  - NASA limits the 3% risk at a 95% confidence level to protect against uncertainties in risk projections
  - Prevent radiation sickness during mission
  - Requirements to limit Central nervous system (CNS) and heart disease risks from space radiation

- Mission and Vehicle Requirements
  - Shielding analysis, dosimetry, and operational countermeasures
- NASA programs must follow the ALARA principle to ensure astronauts do not approach dose limits.
Age and Gender Specific Dose Limits

• NCRP Recommendations in 1989 and 2000 were well below the 4 Sv limit used by NASA since 1970, however placed no real limitation on STS or ISS missions


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*Differences reflect changes from DS65 to DS86, longer follow-up of A-bomb survivors, and other changes to data analysis

**NCRP 98 used ICRP 26 Q_f(LET), NCRP 132 used ICRP 60 Q_f(LET)*
Revised standard applies a 95% confidence level (CL) to the career limit of 3% REID

95% confidence is conservative
- Takes specific risk probabilities of individuals into account
- Narrows range of increased risk
- Epidemiology, DDREF, quality (QF) and dosimetry uncertainties

Uncertainty analysis NCRP Report 126 methods amended for Q(L) and F(L) uncertainties

Broad confidence interval leads to potential mission restrictions and most ISS crew limited to 3 to 4 missions
Sources of Uncertainty

• Radiation quality effects on biological damage
  – Qualitative and quantitative differences of Space Radiation compared to x-rays
• Dependence of risk on dose-rates in space
  – Biology of DNA repair, cell regulation
• Space dosimetry and organ doses
• Predicting solar particle events
  – Temporal and size predictions
• Extrapolation from experimental data to humans
• Individual radiation-sensitivity
  – Genetic, dietary and “healthy worker” effects

ISS Mission Nominal Fatal Cancer Risk

95% Confidence Interval: 1 in 20 Chance True Answer falls outside this interval from 2.5th to 97.5th Percentiles (95% Area under Curve)
External Advisory Groups
Standards, Policy, Best Practices, Risk Modeling
Components of Recommended Updates (2010)

• Revision of Low LET models
  – NAS (BEIR VII), UN (UNSCEAR) and Radiation Effects Research Foundation (RERF) in Hiroshima analysis of Human data

• Baseline for astronauts
  – Radiation risks for Never smokers

• Dose- and Dose-Rate Effectiveness factor (DDREF) changes

• Quality Factors
  – Distinct Q for Solid cancers and leukemia
  – Replace LET dependence with Charge and Energy dependence

• Revised Uncertainties:
  – Low LET human data
  – Space Environments and Organ Exposures
  – Radiation Quality factors
Executive Summary

• Space radiation presents significant health risks including mortality for long duration space missions
  – Galactic cosmic ray (GCR) heavy ions are distinct from radiation that occurs on Earth leading to different biological impacts
  – Large uncertainties in GCR risk projections impact ability to design and assess mitigation approaches and select crew
  – Solar Proton Events (SPEs) require new operational and shielding approaches and new biological data on risks

• Risk estimates are changing as new scientific knowledge is gained:
  – Research on biological effects of space radiation show qualitative and quantitative differences with X- or gamma-rays
  – Expert recommendations and regulatory policy are changing
  – New knowledge leads to changes in estimates for the number of days in space to stay below Permissible Exposure Limits (PELs)
Executive Summary - continued

• NASA limits acceptable levels of risks of astronauts to a 3% Risk of Exposure Induced Death (REID) from cancer
  – PEL requirement to be below 95% Confidence Interval (C.I.) for cancer risk protects against uncertainties in risk projection models

• New scientific findings will modify NASA’s Risk Projection Models:
  – New research results and findings from NASA, DoE and NIH scientists
  – Findings of international bodies such as the National Academy of Sciences and the United Nations, or regulatory bodies (NCRP or ICRP)
  – Potential for late Non-cancer mortality risks (Heart and Brain) on long-term exploration missions complicates assessments of career risk, which includes only cancer at this time
Backup
Past Radiation Limits at NASA

- Limits prior to 1989 were from National Research Council (NRC) reports published in 1967 and 1970.
  - Career limit of 400 rem (4 Sv) based on estimated doubling dose for cancer fatality over a 20-y period for 35-year Males (dose to double fatal cancer risk over ages 35 to 55 y)
  - Appropriate dose limits to prevent deterministic effects of the skin, lens, testis and blood forming organs (BFO)
- The shuttle program led to a more larger range of astronaut ages and the addition of female astronauts. NASA asked the NCRP to advise on radiation protection for the shuttle program resulting in NCRP Report No. 98 (1989)
  - Age and gender dependent career exposure limits recommended and implemented by NASA
GCR and SPE Doses: Materials & Tissue

No Tissue Shielding

With Tissue Shielding

August 1972 SPE and GCR Solar Min