National Aeronautics and Space Administration

Radiation Countermeasures and the NASA Space Radiation Program

Janice L. Huff, Ph.D, Deputy Element Scientist
Lisa C. Simonsen, Ph.D. Chief Scientist
NASA Space Radiation Program
Human Research Program

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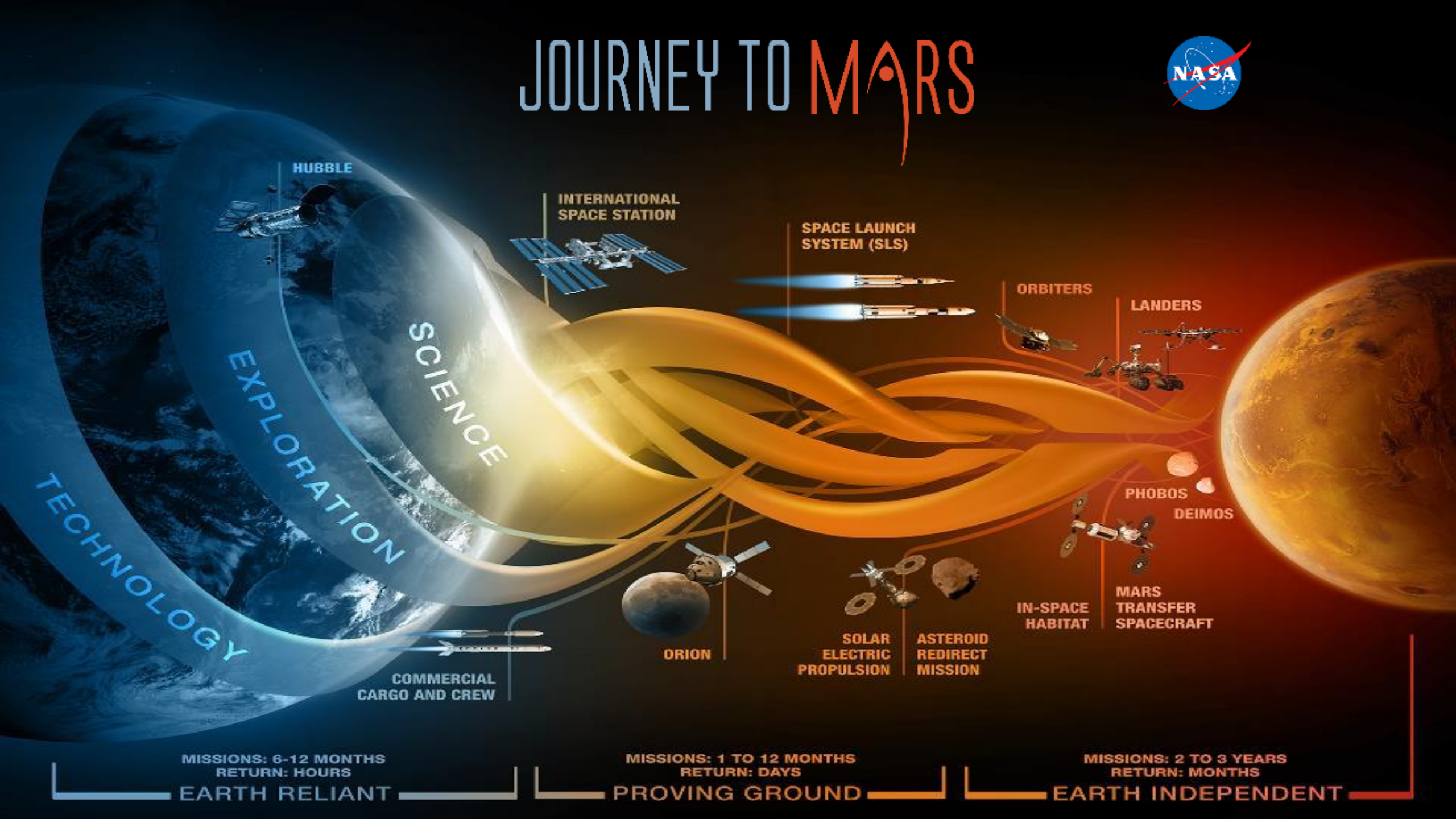
JOURNEY TO MARS



MISSIONS: 6-12 MONTHS
RETURN: HOURS
EARTH RELIANT

MISSIONS: 1 TO 12 MONTHS
RETURN: DAYS
PROVING GROUND

MISSIONS: 2 TO 3 YEARS
RETURN: MONTHS
EARTH INDEPENDENT

Primary Hazards to Humans during Space Flight

Decreased gravity

- *musculoskeletal, cardiovascular, sensorimotor, immunology, fluid shifts, behavior/performance, human factors*

Isolation/confinement/altered light-dark cycles

- *behavior/performance, sleep, psychological stress*

Hostile/closed environment

- *behavior/performance, nutrition, toxicology, microbiology*

Distance from Earth

- *behavior/performance, autonomy, food systems, clinical medicine*

Increased radiation

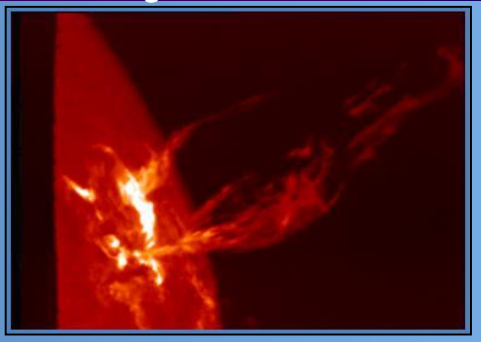
- *Cancer, CNS - inflight behavior/performance & late neurodegenerative diseases, cardiovascular, Acute Radiation Syndromes*

Space Radiation Environment

Space Radiation Program Element

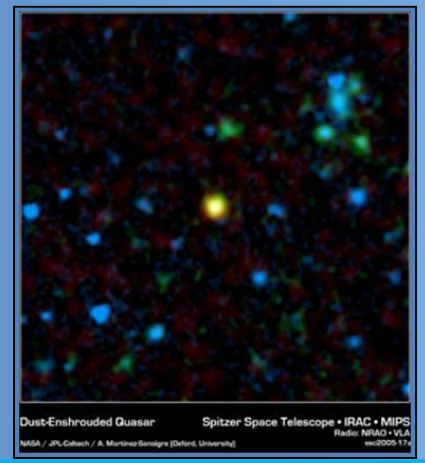
Solar Particle Events (SPE) – intermittent exposure

- Low to medium energy protons associated with coronal mass ejections and solar flares
- Shielding effective to prevent Acute Radiation Syndromes
- **Main challenge: Optimized storm shelter mass, active dosimetry, operational constraints/forecasting**



Galactic Cosmic Rays (GCR) – chronic low-dose rate exposure

- Highly charged, energetic atomic nuclei (HZE particles) and protons
- Major GCR particle types: H, He, C, O, Ne, Si, Ca, & Fe; broad energy spectra (~10 to 10,000 MeV/n)
- Not effectively shielded (fragment into lighter, penetrating species)
- **Main challenge: uncertainty about biological effects limits ability to evaluate risks and countermeasures**



Trapped Radiation (Van Allen Belts)

- Low to Medium energy protons and electrons
- Effectively shielded
- Mainly relevant to ISS and contributes ~40% of dose equivalent
- **Main challenge: develop accurate dynamic model**

Current and Future Human Space Missions

Radiation doses are mission specific:

~Destination and duration *~Vehicle and habitat design* *~Solar conditions*

International Space Station

- 2013-2024: 6-person crews for 6 months; 2-person crews for 12 months
- Typical exposures: ~50 to 100 mSv (30-60 mGy)

Lunar Missions: Sortie (30 day) and Lunar Base (1 yr.)

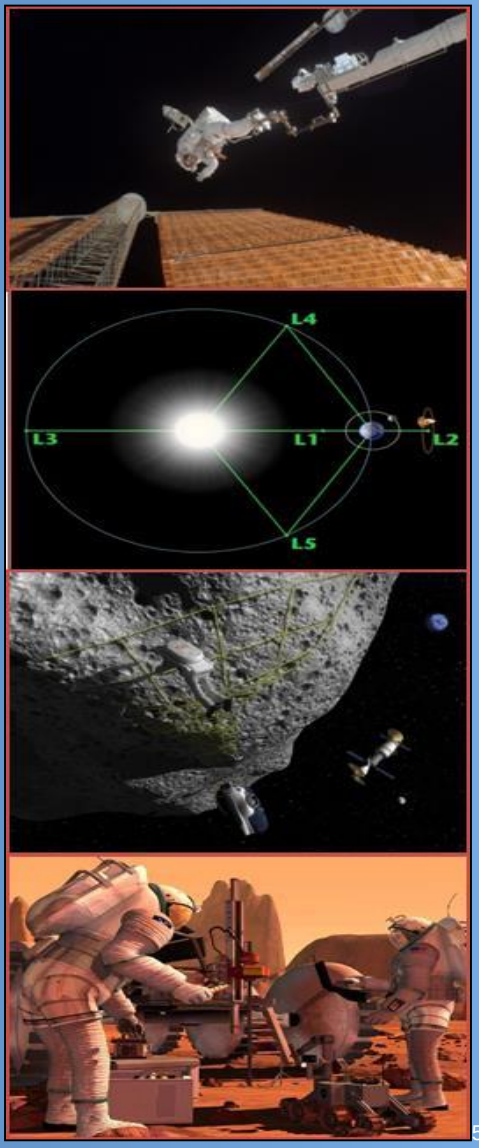
- Outside magnetosphere; Protection of planetary surface – neutron exposure increased
- One year missions: ~300 mSv to 400 mSv (100-120 mGy)

Deep Space Journey/Hab: Lagrange Points, Near Earth Objects (1 yr.)

- Outside Earth's magnetosphere in free space; No planetary protection; GCR risks major concern
- One year missions: ~500 mSv to 650 mSv (175 mGy-220 mGy)

Planetary: Mars

- 2030 and beyond: 6-person crews, up to 3 yrs.
- Long deep space transit times; mixed field environment on Mars
- Estimates for Mars missions: ~ 1000 mSv and 1300 mSv (300 to 450 mGy)

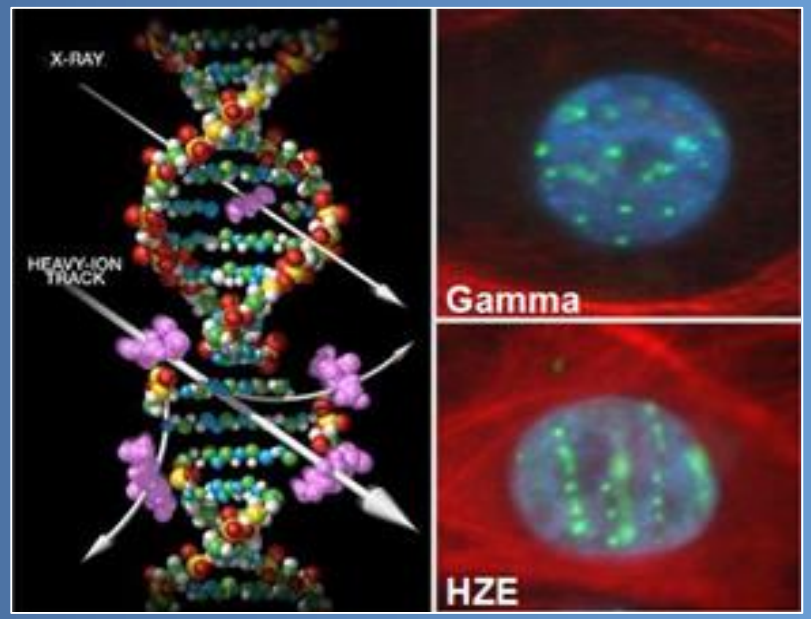


Space Radiation Challenge: Biological Perspective

Space Radiation Program Element

Heavy ions are qualitatively different from X-rays or Gamma-rays:

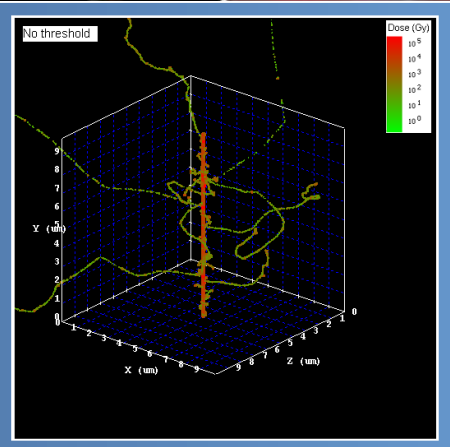
- Densely ionizing along particle track
- Cause unique damage to biomolecules, cells, and tissues
- Distinct patterns of DNA and oxidative damage
  - Produced clustered DNA damage that is difficult to repair



DNA Damage
H2AX foci (green) mark DNA double strand breaks in nuclei of human epithelial cells after radiation exposure
(Cucinotta & Saganti, Patel & Huff, NASA)

Distinct biological effects and health risks?

- No human data exist to estimate risk from heavy ions found in space
- Animal and cellular models with simulated space radiation must be used to gain new scientific knowledge

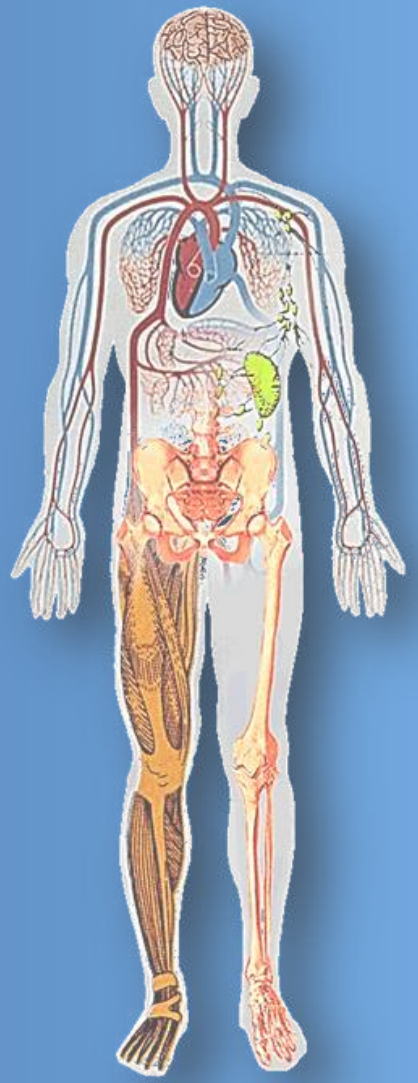


1 GeV/n ^{56}Fe nucleus
LET~150 keV/μm
Qualitative differences due to track "core" and correlated tissue damage along a particle path.

Plante, I., Ponomarev, A., Cucinotta, F.A., 3D Visualization of the Stochastic Patterns of the Radial Dose in Nano-Volumes by a Monte Carlo Simulation of HZE Ion Track Structure. Radiat. Prot. Dosimetry 143: 156-161, 2011

Space Radiation Risks

- Risk of Radiation Carcinogenesis
  - Morbidity and mortality risks
- Risk of Acute (In-flight) & Late Central Nervous System Effects from Radiation Exposure
  - Changes in cognition, motor function, behavior and mood, or neurological disorders
- Risk Of Cardiovascular Disease and Other Degenerative Tissue Effects From Radiation Exposure
  - Degenerative changes in the cardiovascular system and lens
  - Diseases related to aging and immune system dysfunction
- Risk of Acute Radiation Syndromes due to Solar Particle Events
  - Prodromal effects (nausea, vomiting, anorexia, and fatigue)
  - Skin injury
  - Depletion of the blood-forming organs and immune dysfunction



Foundation of Space Radiation Research Plan

Space Radiation Program Element

- The Space Radiation Integrated Research Plan
  (http://humanresearchroadmap.nasa.gov/)
- External review by NCRP, NAS, and annual NASA Standing Review Panels
- Broad program of solicited, peer-reviewed research at over 40 US Universities
- Ground based studies with space radiation simulated at the NASA Space Radiation Laboratory

NASA Space Radiation Laboratory (NSRL) at Brookhaven National Lab

- Simulates space radiation - high energy ion beams (H^+, Fe, Si, C, O, Cl, Ti, etc.)
- Beam line, target area, dosimetry, biology labs, animal care, scientific, logistic and administrative support
- 3 experimental campaigns per year

NSRL Beam Line

Images courtesy of BNL

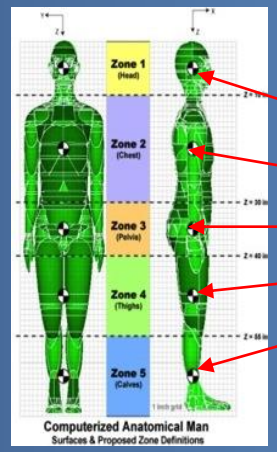
NSRL

Protection and Mitigation Approaches

Space Radiation Program Element

- Radiation Shielding: GCR & Storm Shelter
- Mission Planning: Time in Solar Cycle
- Accurate Risk Characterization
- Crew Selection
- Biomarkers predictive of radiation induced diseases
- Countermeasures

Shield Design and Optimization



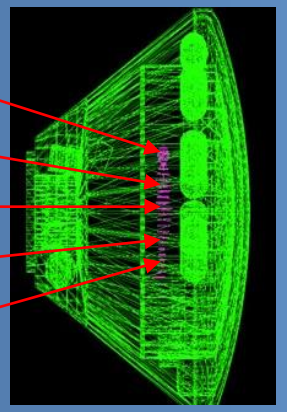
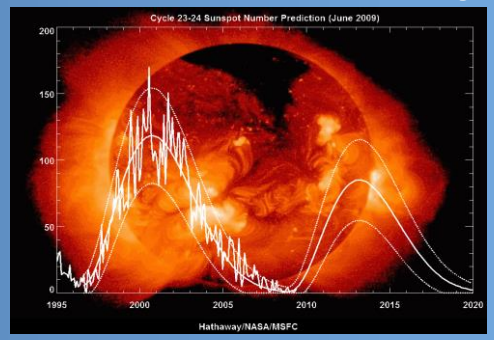


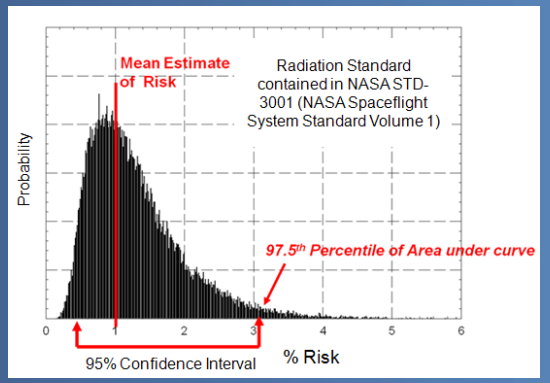
Image courtesy of OLTARIS.nasa.gov

Variations in solar activity

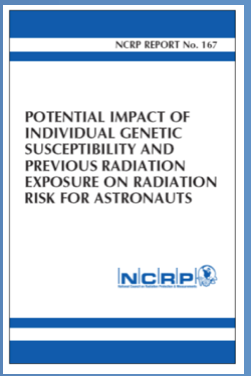


Exercise and Conditioning

Accurate Risk Characterization

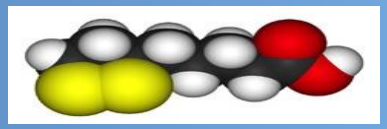


Individual Susceptibility



(NCRP 2011)

Medical Countermeasures



α-lipoic acid

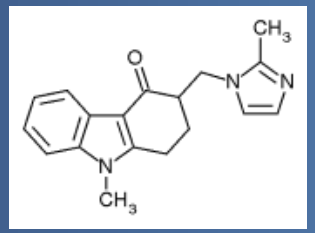
Approaches to Medical Countermeasures Supporting Deep Space Exploration

- Multiple effects to consider
- Current research provides evidence base and mechanistic understanding
- Developing strategies for implementation of testing within NASA & FDA guidelines
- Leverage shared interest in countermeasures with external agencies
- Developing advanced analytics tools (ex. IBM Watson) to link large body of biomedical data to NASA problem

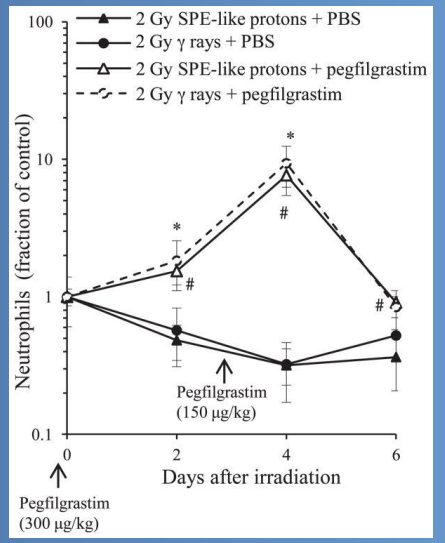
NASA Unique Problem: Understanding efficacy in low dose, mixed field radiation environment – validation requires GCR Simulator

SPE Countermeasures

- Shielding – Storm Shelter
- Operational – Active Crew Dosimetry; Ops Scheduling
- Neulasta for early Design Reference Missions outside Earth's Magnetosphere –cislunar habitat
  - Similar efficacy protons vs gamma rays in animal models
  - Special cryo-packaging required to keep cold and minimize space
  - Need minimal doses (1-2 per crew member) since return to earth feasible within days
  - Blood analyzer underdevelopment to allow determination of absolute neutrophil counts on flight
- Ondansetron for prodromal symptoms
  - Nausea and vomiting

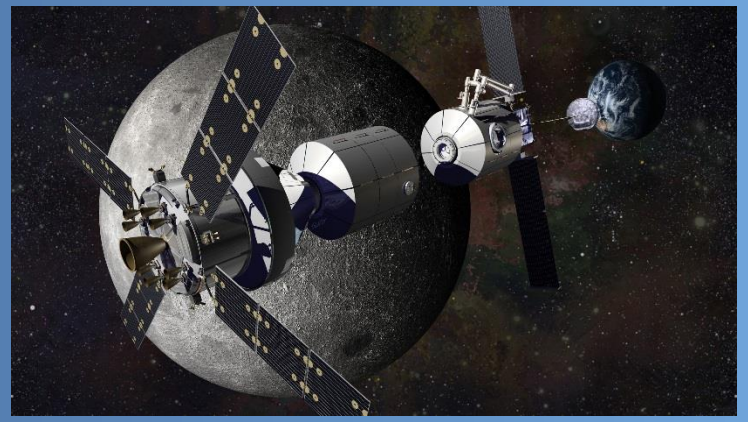


- **Future: Technology Watch on new BCMs coming out of Acute Radiation Research community**



Pegfilgrastim has comparable effects on neutrophil counts following SPE-like or gamma-ray irradiation in mice

Romero-Weaver et al., Radiat Res. 2013 180(2): 177–188.



Cislunar Habitat Concept
Credit: Lockheed Martin

GCR Biomedical Countermeasures

Requirements driven by mission operations:

- Conservative prophylactic use; must demonstrate proven long term use, minimal side effects
- No Designer Drugs, FDA approved, FDA Off-label, FDA IND Status drugs
- Dietary supplements

Biological countermeasure criteria:

- Mechanism of action well known; independent of sex
- Chronic administration (potentially up to 3 years)
- Easily self administered (e.g. Oral, inhaled)
- No contraindications with other drugs
- Long shelf-life

Categories of Potential Agents:

- Cross-risk agents targeting common pathways (ex. anti-inflammatory agents)
- Radioprotective/mitigating agents targeting early damage and acute effects; potential for cross-over to late effects

Evaluate countermeasures developed for ARS or protection during radiotherapy under SBIR (to be released Fall 2016) using mixed field (high LET + low LET)

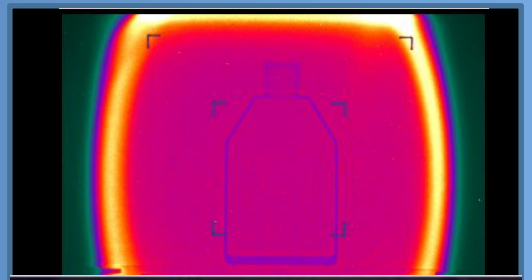
SBIR/STTR
Small Business Innovation Research / Small Business Technology Transfer

Physics & Biological Challenge:
Simulating the Galactic Cosmic Ray Environment

Challenge: Define GCR reference environment in terms of NSRL operational and delivery parameters

Current Status- Design & Validation

1. **What? Define reference tissue environment(s) during exploration missions**
   - ✓ Time in solar cycle, shielding, body models
   - ✓ What quantities? LET, dose eq, Z^2/B^2; energy binning
2. **How? Best approach to deliver that environment at NSRL. Identify facility, hardware, and software constraints.**
   - ✓ Beam energies, controls, spill rates, absorbers, low doses & dose rates, operations
3. **Define animal/cell requirements and constraints.**
   - ✓ IACUC, cages, sedation, feeding, bedding, lighting, incubators



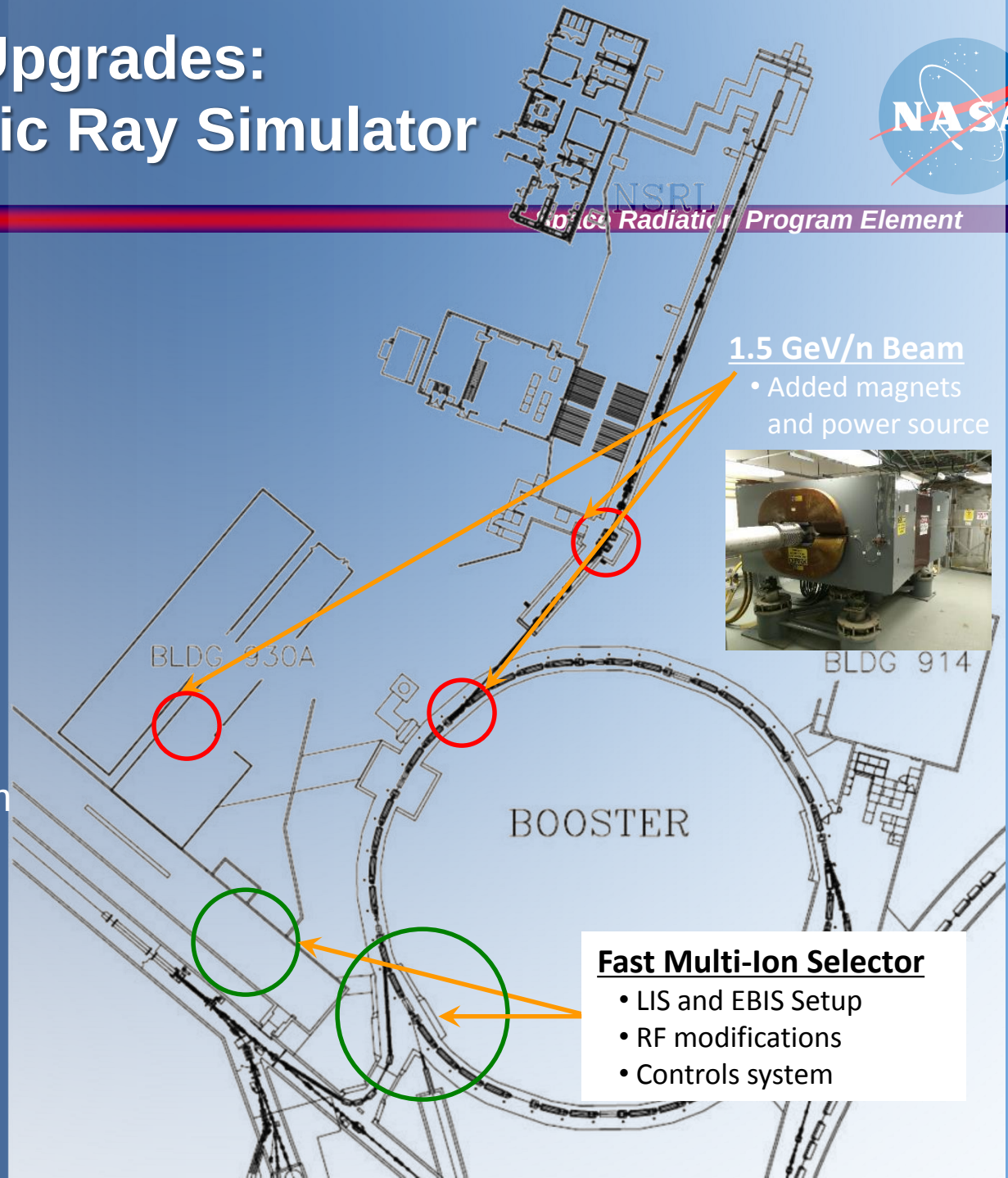
NSRL Upgrades: Galactic Cosmic Ray Simulator

Simulation of the GCR primary and secondary environment with a mixed field, high-energy capability:

- Magnet upgrades for delivery of beams at 1.5 GeV/n
- Rapidly switchable ion source
- Automated controls
- GCR species will be simulated with high precision in major LET bins ranging between 0.25 - 1,000 keV/µm

– Completion in late 2016

– Strategies for chronic exposures



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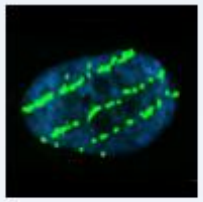
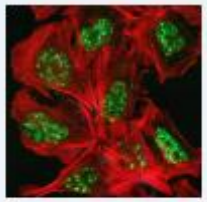


About Space Radiation

Calendar of Events, Workshops and Conferences



Space Radiation Research

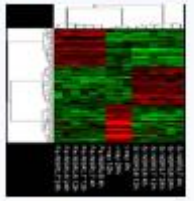
NASA Space Radiation Laboratory

The Health Risks of Extraterrestrial Environments

NASA Space Radiation Summer School

References

Integrative Risk Models Toolkit



Publications

https://spaceradiation.jsc.nasa.gov/

A cluster of massive stars NGC 3603 seen with the Hubble Space Telescope.
Credits: NASA/U. Virginia/INAF, Bologna, Italy/USRA/Ames/STScI/AURA