National Aeronautics and Space Administration

Radiation -- A Cosmic Hazard to Human Habitation in Space

presentation to:

Council on
Ionizing Radiation Measurements and Standards
(CIRMS)

National Institute of Standards and Technology (NIST)
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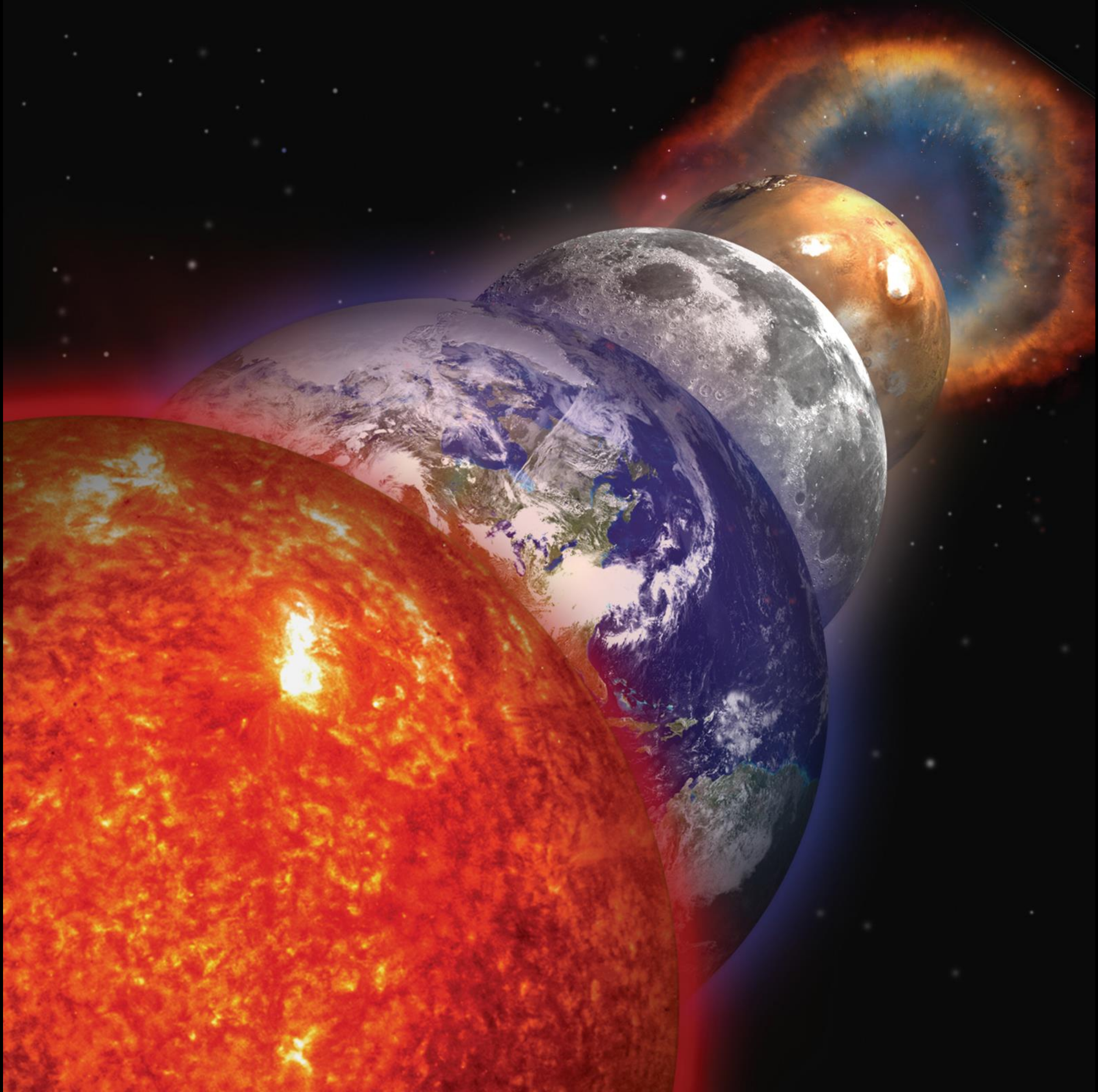
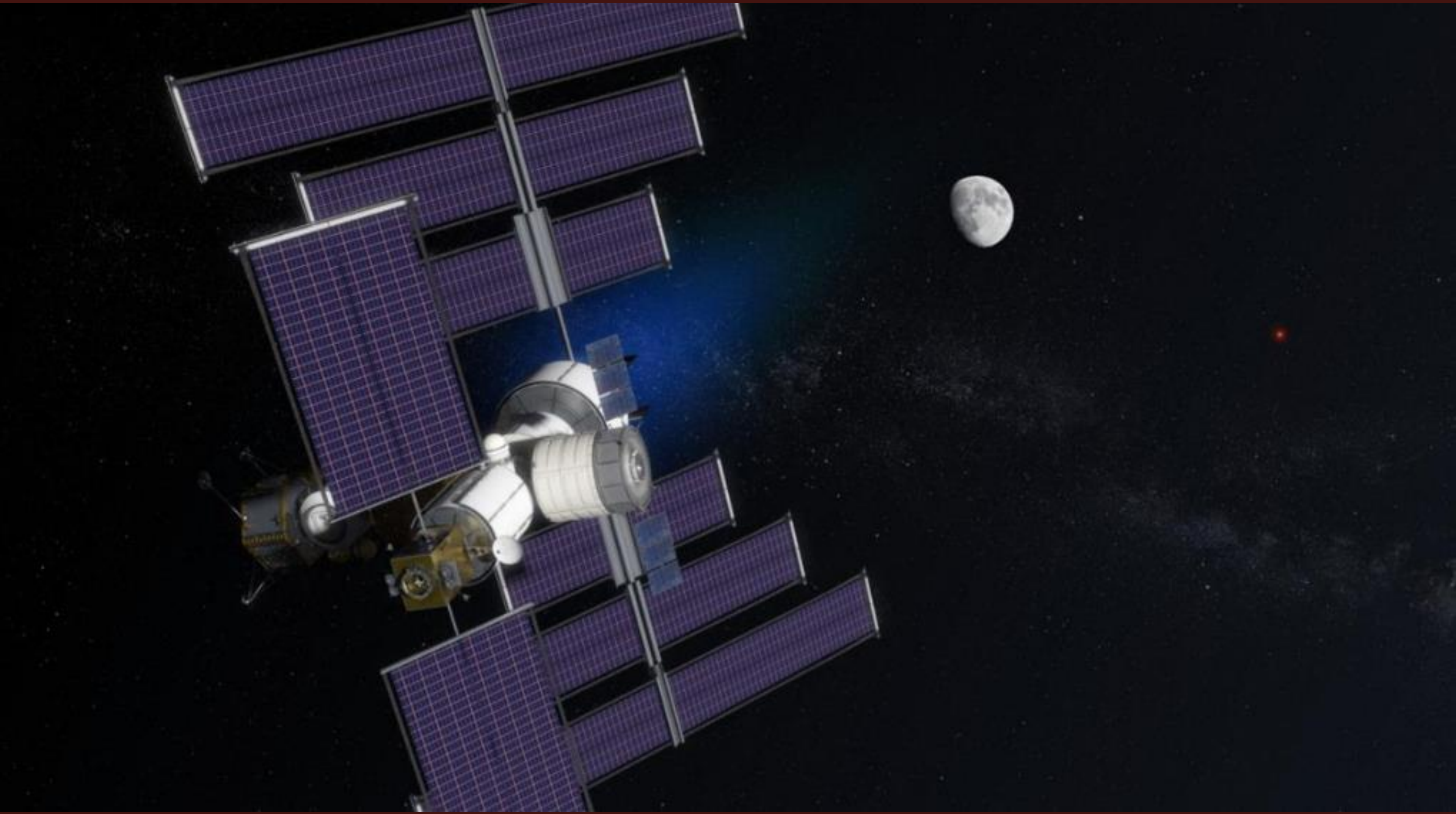
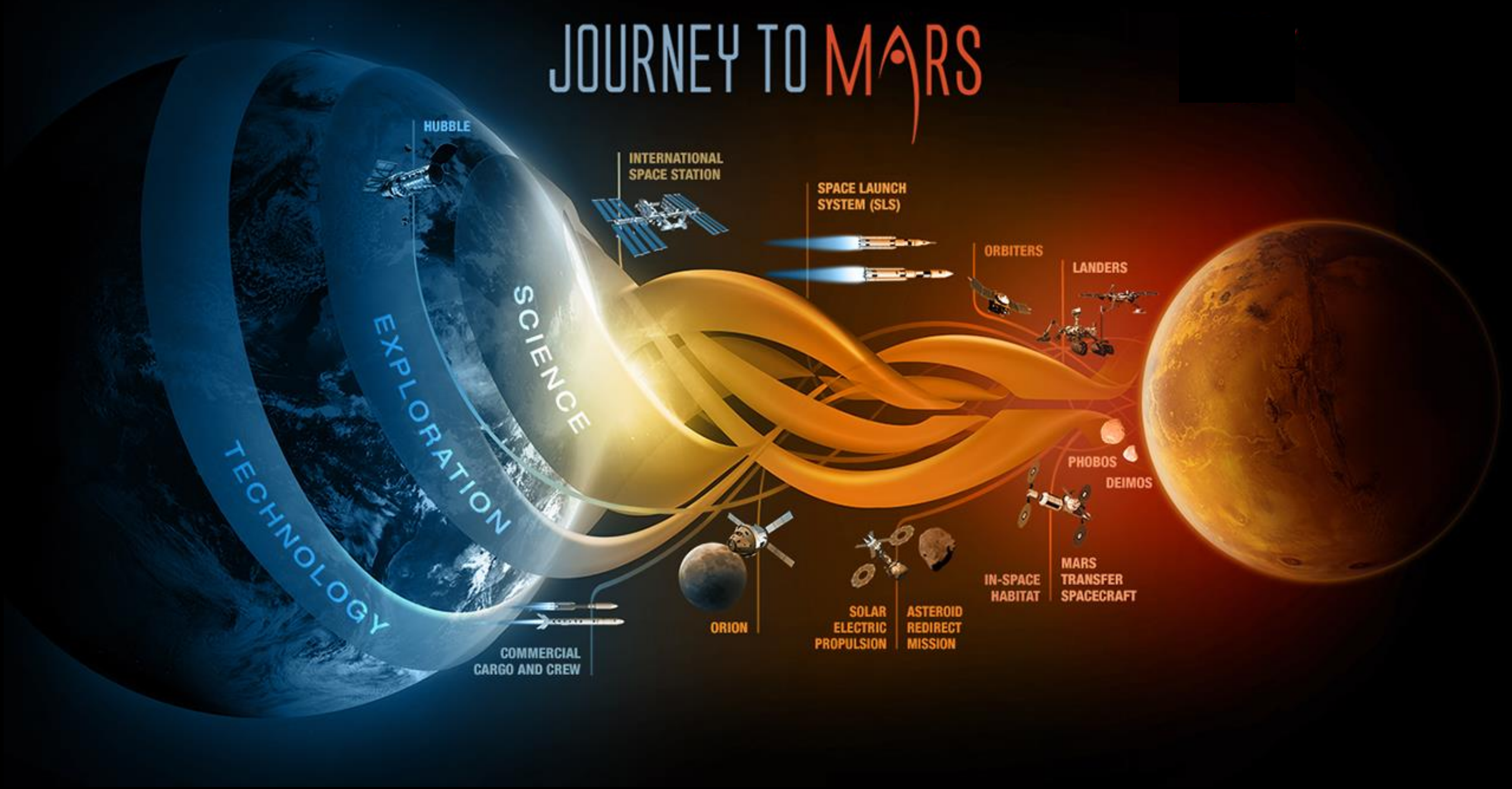
Dr. Ruthan Lewis, Ph.D., Exploration Systems and Habitation
NASA Goddard Space Flight Center
ruthan.lewis@nasa.gov, 301-442-9058 (c)

Dr. Jonny Pellish, Ph.D., Radiation Effects and Analysis
NASA Goddard Space Flight Center
jonathan.pellish@nasa.gov, 301-286-8046





Low Earth *Cis-Lunar* *Cis-Mars*



Why Humans?
Benefits and Leverage

Robust Infrastructure

INHERENT HUMAN CAPABILITY:

- Adaptability and Agility
- Recognition and Problem Solving
- Decision Making

PROVIDES:

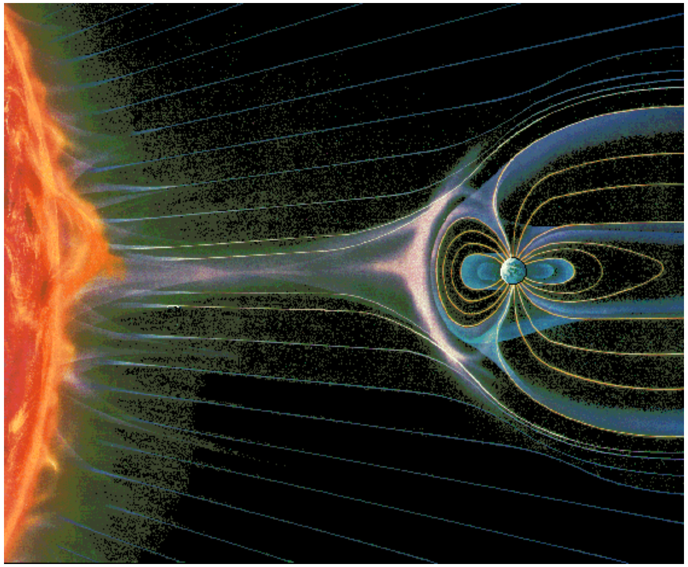
- Decreased time delays
- Greater situational awareness
- Fine control over assets

RESULTING IN:

- Greater mission range
- Greater mission duration
- Greater returned volume and mass

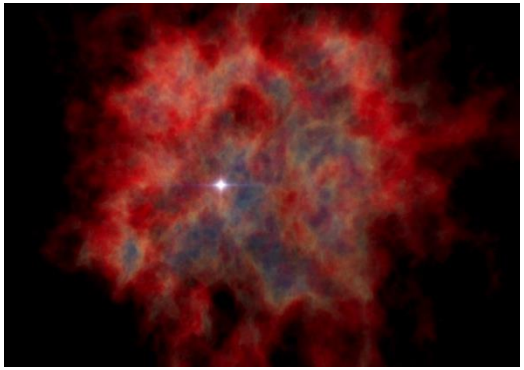
Particle Radiation: High Energy Electrons, Protons, and Heavy Ions

- Radiation exposure is one of the greatest environmental threats to the performance and success of human and robotic space missions
- Radiation “permeates” all space and aeronautical systems, challenges optimal and reliable performance, and tests survival and survivability



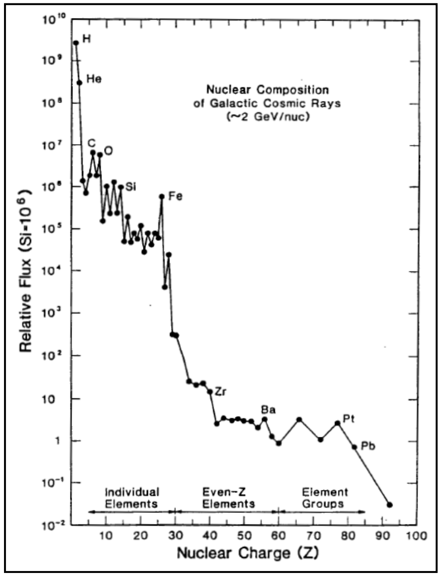
Solar Protons, Heavier Ions

- Low to medium energy protons
- Varying amounts of energetic heavy ions
- Solar Particle Events, Coronal Mass Ejections



Galactic Cosmic Rays (GCRs)

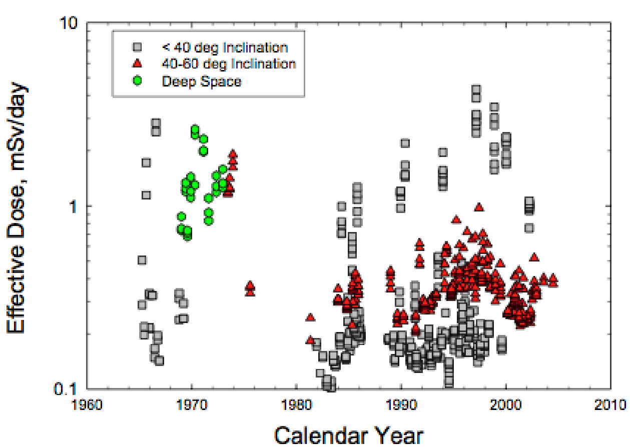
- Originates from supernovae outside the solar system
- Primarily charged particles – penetrating protons with some helium nuclei (alpha particles) and heavy nuclei
- High energy charged particles
- Most energetic of all space environment radiation



Addressing Space Radiation Issues

What are the levels of radiation in deep space; how do they change with time?	Space Weather Research, Characterization Forecasting, Prediction Modeling
How much radiation is inside the spacecraft and in the human body?	Radiation Transport and Codes Tissue and Organ Doses Modeling
What are the health risks associated with radiation exposure?	Acute Radiation Cancer Risks Non-Cancer Risks
How do we mitigate these health risks?	Shielding Bio-Countermeasures Medical Standards

Health Risks Associated with Space Radiation



- Carcinogenesis: increased cancer morbidity or mortality
- Acute radiation syndromes from solar proton events
- Degenerative tissue effects: cardiovascular disease, cataract formation
- Central nervous system damage: cognition and neurological disorders
- Digestive and respiratory disease
- Accelerated senescence leading to endocrine and immune system dysfunction

Uncertainties

- Qualitative and quantitative differences between different types of radiation
- Repair, cell, and tissue regulation in space
- Extrapolation from experimental data to humans
- Individual radiation sensitivity
- Effects of mixed radiation fields on exposure
- Prediction of solar and radiation events and conditions
- Interaction of radiation damage with other environment stressors such as microgravity
- Variances with prediction models

Data Sources

- Historical
- Nuclear power plants
- Radiation-accident related cases
- Therapy-related cases
- Animal and tissue studies
- In-space measurements

Radiation Models and Simulations

- Solar Particle Events (flares, coronal mass ejections)
  - SPENVIS (ESP, PSYCHIC, JPL-91, etc.)
  - Other packages
- Galactic Cosmic Rays
  - SPENVIS
  - CRÈME-MC
  - Other packages
- Combined
  - HZETRN
  - OLTARIS

Guidelines, Standards

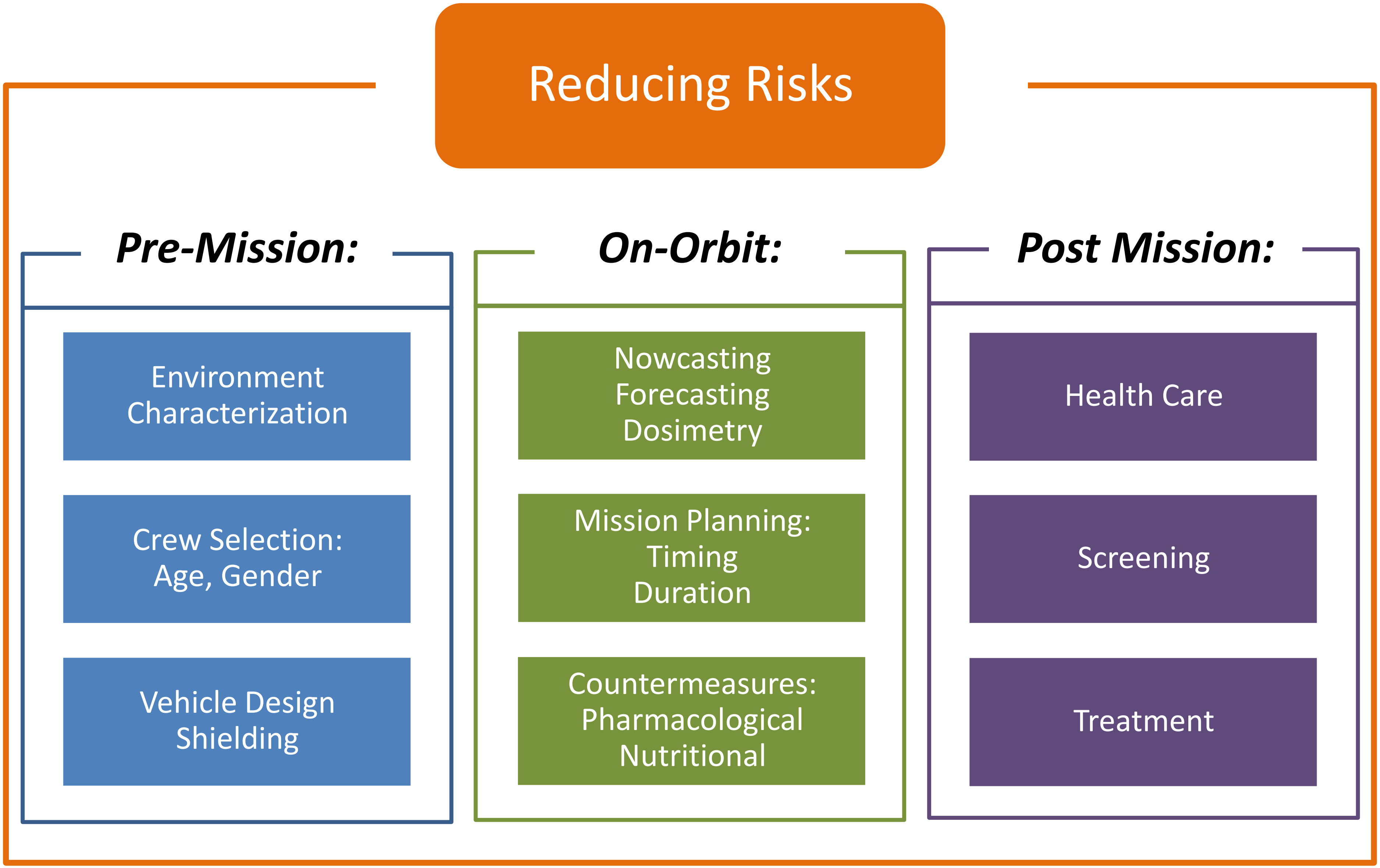
- External advisory panels guidance: National Council on Radiation Protection (NCRP) and National Academy of Medicine (Institute of Medicine)
- As Low As Reasonably Achievable (ALARA)
- Current dose career limit of 3% increased Risk of Exposure Induced Death (REID) for fatal cancer (95% confidence interval), but Mars missions may exceed these limits
  - NASA standards limit the *additional* risk of cancer death by radiation exposure, not the total lifetime risk of dying from cancer
  - "If 100 astronauts were exposed to the Mars mission space radiation, in a worst case (95% confidence) 5 to 7 would die of cancer, later in life, attributable to their radiation exposure and their life expectancy would be reduced by an average on the order of 15 years"
  - Confidence level depends on exposure type (GCR, SPE, etc.)
- Ethics: informed decision making

Organ Specific Exposure Limits for Astronauts

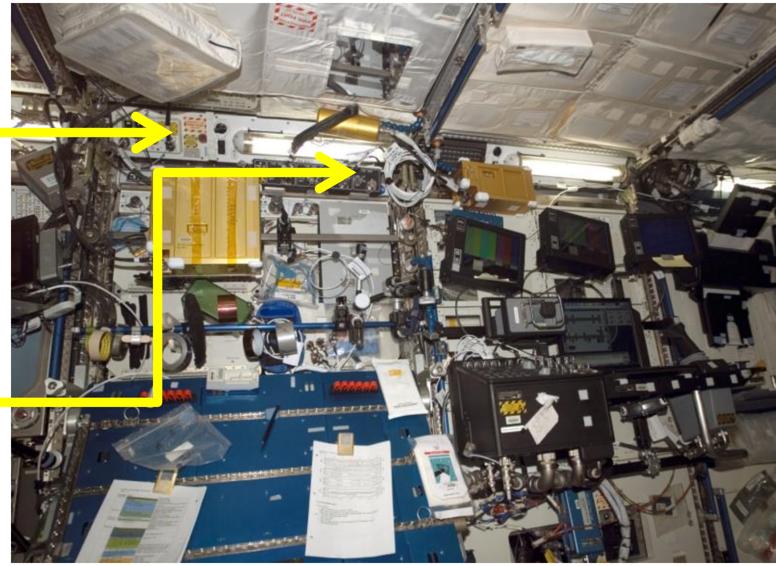
Exposure Interval	Blood Forming Organs	Eye	Skin
30 Days	25 rem	100 rem	150 rem
Annual	50 rem	200 rem	300 rem
Career	150 - 400 rem [200 + 7.5(age - 30) for men] 100 - 300 rem [200 + 7.5(age - 38) for women]	400 rem	600 rem

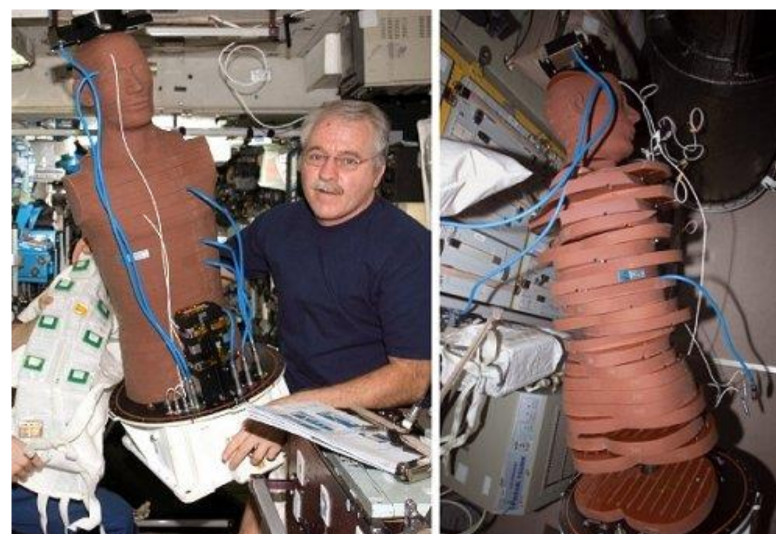
Average International Space Station hourly crew dose rates are on the order of 20 µSv/hr – comparable to commercial aircraft rates

(1 Sievert = 100 rem, 1 micro = 0.0010 milli)


Reducing Risks
Pre-Mission:
Environment Characterization
Crew Selection: Age, Gender
Vehicle Design Shielding
On-Orbit:
Nowcasting Forecasting Dosimetry
Mission Planning: Timing Duration
Countermeasures: Pharmacological Nutritional
Post Mission:
Health Care
Screening
Treatment

Mitigation Technologies: Dosimetry



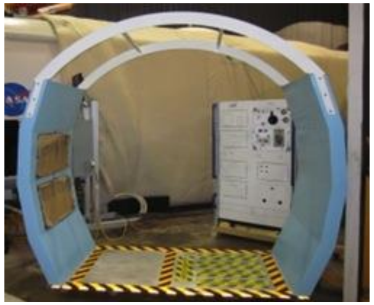


Mitigation Technologies: Shielding, Shelter

- Exposure to ionizing radiation can be reduced by
  - increasing the distance from the source
  - reducing the exposure time
  - using active or passive shielding

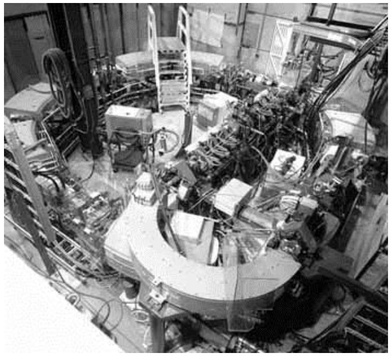
- Unlike for low-LET gamma or X rays, the shielding of energetic charged particles may increase risk -- secondary radiation, composed of projectile and target fragments (including neutrons) from the interaction with the shields, may deliver a higher dose than what would have been absorbed from the primary radiation

- Shielding material with low mean atomic mass (high hydrogen content) provides an efficient reduction of the radiation risk
  - Reconfigurable logistics
  - Water walls
  - Polyethylene-like
  - Wearable vests
  - Augmented sleep restraints



Testing and Facilities

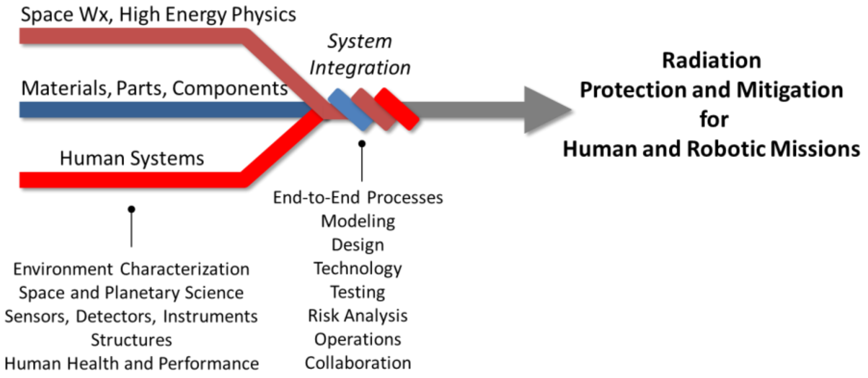
- NASA with U.S. Department of Energy (DOE)
  - NASA Space Radiation Laboratory (NSRL) at DOE's Brookhaven National Laboratory
  - Brookhaven Electron Beam Ion Source
  - Brookhaven Relativistic Heavy Ion Collider
  - Lawrence Berkeley National Laboratory
  - Large Hadron Collider (Geneva)
- Non-NASA Laboratories
  - Loma Linda
  - Texas A&M
  - Others
- International Space Station



A System of Systems Approach

A System of Systems approach will meet NASA's critical need to enable an integrated, multidisciplinary, multi-scaled, end-to-end, systematic strategy to radiation mitigation for deep space human missions

- Currently, there is an apparent tension between statistical treatment, observation, forecasts, and design conceptualization and requirements with dramatically…
  - diminished accuracy and precision of our models
  - significant risk and uncertainty



- Create a collaborative emergence process that will breed unique capabilities and solutions from the integration of and collaboration within and across traditionally "independent" human and robotic domains
  - Facilitate crosscutting radiation mitigation solutions
  - Derive tools, technologies, and solutions
  - Understand the impact of contributing systems on the entire system, and the measure(s) of impact
- Produce a whole that is greater than its parts with a unified goal to improve performance measures, e.g. risk, cost, robustness, reliability, etc.

Methodology

- Apply a treatment that has physics-based and evidence-based variables, statistical variables, theories, and ethical terms to understand and sufficiently solve a very complex problem
- Identify and characterize contributing multi-discipline, multi-scale factors that play a role in radiation mitigation
  - explore “fraction”/depth/magnitude of their contributions
  - characterize the strength of their interactions
  - Identify investments and divestments to be made at what time
- Clarify high level technical objectives
- Identify systems key to System of Systems (SoS) objectives
- Define current performance of the SoS
- Identify performance objectives of subsystems
- Develop architecture overlay for the SoS
  - Addresses concept of operation for the SoS
  - Encompasses functions, relationships, and dependencies of constituent systems
  - Includes end-to-end functionality and data flow and communications
  - Options and trades

Bounding the System Variables

$$M = E \cdot R \cdot H \cdot P \cdot L \cdot T \cdot U \cdot D \cdot S$$

M	Radiation Mitigation
E	Ethics
R	Radiation types and magnitudes
H	Effect of radiation on human performance and health
P	Effect of radiation on materials, parts, components
L	Target Location
T	Exposure time and point in time of Solar Cycle
U	Uncertainty and Error of forecasts, models, research
D	Design, Development, Test, and Evaluation
S	Success Criteria