

National Space Biomedical Research Institute
Science and Technology Program
Radiation Effects Team Strategic Plan
2007

Summary Description

The NSBRI Radiation Effects Team is focused on the development of a scientifically-based integrated approach to understanding and mitigating the risks associated with radiation exposure to astronauts. In space exploration outside the Earth's geomagnetic field, radiation exposure from solar particle events (SPEs) presents a health concern for astronauts that could impair their performance and result in the possibility of mission failure. Acute risks are therefore of particular concern during extravehicular activities (EVAs) on the lunar surface because of the rapid onset of SPEs.

The Radiation Effects Team will provide deliverables to ensure that astronauts can safely perform in the space radiation environment. These deliverables will be consistent with human health and performance standards and aligned with the Bioastronautics Roadmap, Human Research Program goals and Constellation Program milestones. Deliverables provided will include, but will not be limited to, risk assessments, methodologies and recommendations for radiation protection and mitigation in support of lunar exploration missions; these objectives will be implemented by an integrated ground-based radiation research program.

The strategies used to achieve the development of deliverables include:

1. The creation of a program project modeled after the NASA Specialized Center of Research (NSCOR). The principal aims of this program are to improve the prediction of risks to human health from space radiation (protons and heavy ions) and to provide effective countermeasures for acute exposures.
2. The development of dosimetry systems for monitoring human exposures during lunar EVA missions combined with the integration of tools and operations concepts for the utilization of these systems in operationally-relevant environments. These tasks will be accomplished in collaboration with the NSBRI Technology Development and Smart Medical Systems Teams, and the NASA Space Radiation Analysis Group and Space Radiation Project Element, as well as flight surgeons.
3. The definition of the risks of exposure to various types of space radiation on bone and cardiovascular structure and function. While this area of research is not the top priority in this strategy, the Radiation Effects Team will provide scientific and operational support (NASA Space Radiation Laboratory [NSRL] runs) to NSBRI Teams studying radiobiological responses of bone and cardiovascular tissues.

Goals

1. *Determine the risks of exposure to the types and levels of radiation encountered during a SPE, and develop countermeasures to reduce and mitigate these acute radiation risks. This area of research will be primarily focused on three areas: prodromal syndrome, radiation effects on the skin, and radiation damage to the immune and hematopoietic systems.*

This goal addresses the following risks and gaps:

Bioastronautics Roadmap Radiation Effects Discipline Area

BR31: Acute Radiation Risks.

Human Health Countermeasures Program Element Risk and Gaps:

Risk of Acute Radiation Syndromes due to Solar Particle Events

Identified Knowledge Gaps:

SR23: Dose-rate effects for prodromal risks

SR24. Countermeasure for prodromal risks and determination of their effectiveness under space conditions.

2) *To develop dosimetry systems for monitoring human exposures during lunar EVA missions as well as to integrate tools and develop concepts of operations for the utilization of these systems in operationally-relevant environments.*

This goal addresses the following risks and gaps:

Human Health Countermeasures Program Element Risk and Gaps:

Research and Technology Developments Necessary to Enable the Development of the Radiation Sections of the Spaceflight Human Systems Standard, Vol. 2.

Identified Knowledge and Technology Gaps:

SR26. Develop and integrate reliable monitors inside vehicles and EVA suits.

Risk of Compromised EVA Performance and Crew Health Due to Inadequate EVA Suit Systems

Identified Knowledge Gaps:

EPSP7. What surface ops concepts could maximize human performance of mission tasks as well as protect crew health?

EPSP8. What are the biomedical monitoring requirements of an EVA suit for each phase of Lunar or Mars missions?

EPSP9. What suit-human biomedical interactions aspects of the EVA suit design affect the protection of crew health, and what design changes or countermeasures can be implemented to protect crew health?

3) *Determine the risks of exposure to various types of space radiation on bone and cardiovascular systems. While published data suggest that space radiation adversely affects bone, if it is determined that exposure to space radiation poses an elevated risk for the development of atherosclerosis, efforts to understand cardiovascular dysfunction will be made in order to develop countermeasures for this radiation risk.*

This goal addresses the following risks and gaps:

Bioastronautics Roadmap Radiation Effects Discipline Area

BR30: Chronic and Degenerative Tissue Risks.

Human Health Countermeasures Program Element Risk and Gaps:

Risk of Degenerative Tissue or other Health Affects from Radiation Exposure

Identified Knowledge Gaps:

SR21. What degenerative risks other than cataracts need to be assessed?

SR22. Determine whether effective thresholds exist for specific degenerative risks.

Risk of Bone Fracture

Identified Knowledge Gaps:

B11. What are the effects of radiation on bone?

Risk of Cardiac Rhythm Problems

Identified Knowledge Gap:

CV1. Unknown in-flight alteration in cardiac structure and function.

Objectives

1. Space Radiation Induced Acute Effects

Acute effects such as death from collapse of the blood-forming system, together with marked decrements in the gastrointestinal system, lung, and skin, as well as prodromal syndromes are well studied for gamma-ray and x-ray exposures. There is limited knowledge of these effects for moderate dose-rate conditions and proton effects. The poor understanding of these dose-rate effects can increase shielding requirements for the mission or limit timelines for EVAs.

Consequences of poor understanding of risk estimates may therefore result in mission failure or disruption if medical treatment is not available. SPE risks are largest during EVAs with risks in deep space higher than on the lunar surface.

As part of the preparatory steps to reconstitute the Radiation Effects Team, the NSBRI Medical Radiation Countermeasures Workshop was held (October 2006) to discuss state-of-the-art medical radiation countermeasures. Speakers from academia, the military and other federal organizations reviewed available FDA-approved drugs for radiation acute effects, dietary supplements, animal and human data for acute effects, and strategies employed in radiation therapy and military operations. Workshop recommendations included therapeutic approaches and candidates for mitigation of space radiation-induced acute effects, and form the basis for the Team strategy described here.

NSBRI Radiation Effects Team will evaluate various methods in use for control of the radiation-induced prodromal syndrome, skin effects and hematological changes in humans in animal studies in which the effects of proton radiation (of various energies, doses, dose-rates, etc.) can be evaluated with and without treatments to prevent/mitigate selected system decrements.

Specific Objectives:

- **Create a NSBRI Acute Effects Program Project (NSCOR type)**
- Define the acute risks for which biological countermeasures are needed.

Top priority areas:

1. Prodromal Syndrome (nausea, vomiting, fatigue)
2. Skin Reactions (erythema and swelling; ulceration, etc.)
3. Hematological Changes (cytopenia)

Specific Tasks:

- Perform risk assessment research using appropriate animal models. Risk questions include:
 1. How do dose rate modifiers (DRM) and calculations of relative biological effectiveness (RBE) vary with acute risks?
 2. What are the dose responses and kinetics for acute risks for protons at variable energies and dose rates (during a simulated SPE)?
 3. What are the RBEs for protons and secondaries?
 4. Are there synergistic effects from other flight stressors (microgravity, stress, bone loss) or galactic cosmic radiation (GCR) on acute risks?
 5. Does long-term exposure to GCR modify acute doses from a SPE in relationship to the acute radiation syndrome?

6. What are the most effective biomedical or dietary countermeasures to mitigate acute radiation risks? By what mechanisms are the countermeasures likely to work?
 - Define appropriate experimental risk models to be used for testing of countermeasure effectiveness.
 - Potential existing and new therapies will require further assessment in animal models and *in vitro* systems.
 - FDA-approved agents used to prevent or mitigate radiation injury in humans (radiation therapy, radiological accidents, etc.) will be validated for proton exposures.
 - How can the effectiveness of acute countermeasures be evaluated and extrapolated to humans?

Expected Deliverables:

- Understanding of radiation effects on health and performance through ground-based research.
- Development of approaches to prevent acute risks and reduce chronic risks.
- Evaluation of mitigation approaches for reducing risks.
- Support for risk projection models for NASA programs.
- Support for the definition of acceptable levels of risk (acute and chronic dose limits).
- Definition of the most promising mature biological countermeasures (FDA-approved agents) for acute risks of concern.

Earth Spin-offs:

- Better understanding of the basic mechanism involved in acute effects of radiation exposure.
- Improved prevention and treatment of normal tissue adverse reactions following radiation therapy.
- Improved mitigation and treatment strategies for Homeland Security in the case of a nuclear terrorist attack and nuclear accidents.

2. EVA Dosimetry Systems for Lunar Operations

Current requirements stress the need for adequate radiation monitoring for lunar EVA operations, as well as contingency medical plans if an astronaut develops acute radiation syndrome after an SPE during a lunar sortie or outpost mission. During SPEs, conditions evolve which require advanced monitoring technologies to ensure proper operational responses to the variable dose-rate conditions presented over the time-course of an SPE. Real-time area radiation monitors are routinely utilized inflight; however, further development is needed for active crew personal dosimetry, including methods to incorporate dosimetry into extravehicular spacesuits, lunar rovers or EVA tool-boxes. Spacesuits or lunar surface radiation detectors will be constrained by mass, volume, power and data transmission requirements.

Specific Objectives (in order of priority):

1. Support research and development efforts to design dosimetry systems for EVA lunar operations based on solid state and gas-based detector (tissue equivalent proportional counter, TEPC) technologies.
2. Support the development of preliminary operational concepts for lunar surface active dosimetry and radiation health risk management during simulated EVA operations using relevant analogs (Antarctica, Devon Island, etc.).
3. Evaluate hardware for the assessment of the biologic effects of acute radiation exposure (to include leukocyte counts and differential) in operational environments.

4. Determine the operational integration between teams (SRAG, flight surgeons, NSBRI) and develop a medical checklist for the monitoring and mock treatment of the worst case scenario for prodromal syndrome, skin effects and hematological changes.

Expected Deliverables:

- Compact and rugged dosimetry system for lunar EVA operations (spacesuit and/or rover integrated systems).
- Preliminary operational concepts to support dosimetry architecture and radiation risk management.
- Tested relevant hardware to support medical operations for acute radiation effects.
- NASA-NSBRI multidisciplinary team integration.

Earth Spin-offs:

- Compact dosimetry systems with potential applications for the nuclear power industry, nuclear medicine, national security, and commercial and military aviation needs.

3. Bone and Cardiovascular Radiation Risks

Determine the risks of exposure to various types of space radiation on bone and cardiovascular structure and function. The results of this line of investigation should indicate whether or not astronauts will have an elevated risk of developing cardiovascular disease or decreased bone healing from exposure to the types and levels of radiation encountered during space travel. The Radiation Team will support, scientifically and operationally, the NSBRI Teams studying radiobiological responses from bone and cardiovascular tissues.

Specific Objectives (in order of priority):

Top priority areas:

1. Bone structure and physiology as well as healing capacity following space radiation exposure.
2. Cardiovascular system structure and function following space radiation exposure.

Specific tasks:

- Perform risk assessment research using appropriate animal models. Risk questions include:
 1. What are the probabilities for bone and cardiovascular degenerative tissue risks from protons and HZE ions as a function age of at exposure, time after exposure, gender, tissue, mission, radiation quality, dose-rate?
 2. What are the mechanisms of degenerative tissue risks in the heart, circulatory system, and bone?
 3. What are the most effective biomedical or dietary countermeasures to degenerative tissue risks? By what mechanisms are the countermeasures likely to work?

Expected Deliverables:

- Understand radiation effects on health and performance through ground-based research.
- Develop approaches to prevent acute risks and reduce chronic risks.
- Evaluate mitigation approaches for reducing risks.
- Support risk projection models for NASA programs.

Earth Spin-offs:

- Better understanding of the basic mechanisms involved in acute radiation effects.
- Improved prevention and treatment of normal tissue adverse reactions after radiation therapy.

Strategies for Achieving Team Goals and Objectives

- 1) Initial joint NASA(SRPE)-NSBRI strategic discussions and decisions.

- 2) New and enhanced periodic communication mechanisms between NASA SRPE and NSBRI.
- 3) Gap analysis and recommendations: NSBRI Workshop 2006.
- 4) NSBRI radiation efforts will be reorganized around a dedicated and integrated program project (NSBRI-SCOR).
- 5) Joint or independent research solicitations.
- 6) Synergistic integration with Technology Development and Smart Medical Systems Teams.
- 7) New approaches to integrate basic and translational research with the operational community at NASA (SRAG and flight surgeons).
- 8) Full utilization of ground-based facilities such as NSRL (SPE simulations) and analogs for operational-related tasks (Antarctica, Devon Island, Desert-RATS, etc.).
- 9) The Radiation Effects Team will leverage Homeland Defense Department efforts, NIAID (National Institute for Allergy and Infectious Disease) for medical radiation countermeasures, and NASA SRPE program for risk assessment and mitigation approaches.
- 10) Research investigations related to the estimating the risk of decrements to bone and to the cardiovascular system from exposure to space radiation are funded and will continue.

Examples

1-5 Year Timeframe

Year 1:

- Inception of NSBRI NSCOR for Acute Effects.
- New and continuing grants in bone, cardiovascular studies and dosimetry R&D.
- Integration of efforts complementary to SRPE, SRAG and other NSBRI Teams.
- Commence NSRL studies (conventional proton exposures).

Year 2:

- NSRL studies using SPE simulator.
- Dosimetry concepts defined and ready for prototype construction and testing.
- Concept of operations defined for radiation risk management for lunar EVA.
- Use of analogs for operational testing and integration.

Year 3:

- Risk identification and definition completed for acute effects, bone and cardiovascular systems.
- Risk disposition developed (retire, transfer, avoid, watch, accept or mitigate).
- Initial testing of medical countermeasures for risk mitigation.
- Dosimetry hardware testing at NSRL.

Year 4:

- Continued testing of medical countermeasures for risk mitigation.
- Initial strategies for integration of dosimetry hardware to mission requirements and architecture.

Year 5:

- Definition of best candidates for risk mitigation completed.
- Final report and recommendations.
- Dosimetry system prototype fully tested and ready for flight operation validation opportunities.

6-10 Year Timeframe

- Definition of best mitigation strategies to be validated in relevant operational environments (ISS, analogs, etc.).

- Definition of flight rules of operations for SPE management during lunar missions.
- Definition of medical requirements for management of acute effects during lunar operations.
- Definition of medical countermeasures for flight testing (specific agents, protocols, etc.).
- Flight testing of dosimetry hardware.
- Integration of dosimetry hardware to flight equipment and system integration.