National Aeronautics and Space Administration

Crew Health, Medical, and Safety: Human Research Program

Briefing to the National Research Council Committee on Human Spaceflight

Technical Panel

March 27, 2013

Steve Davison • NASA Headquarters

Spaceflight: Human Health History

"Extending the spatial and temporal boundaries of human space flight is an important goal for the nation and for NASA" (National Academies, IOM, 2006)

.............**Human Health and Performance Research**

Foundational Knowledge | **Discipline Based** | **Risk-based**

Human Survival | **Response Characterization** | **Physiological Bases of µg responses** | **Risk-based Applied Research**

Apollo
Gemini
Mercury | Skylab | Shuttle/Spacelab | Shuttle/*Mir* | ISS

1960 | 1970 | 1980 | 1990 | 2000

Human Adaptation | **Fundamental Research** | **Human Endurance** | **Exploration Medicine & Technology**

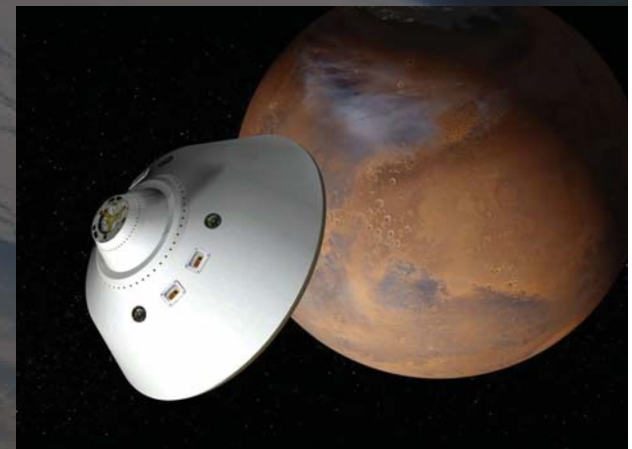
.............**Research Capacity**

ISS is Our Space Biomedical Laboratory and Gateway to Mars

Primary orbiting laboratory that enables space biomedical research involving crewmembers

Only facility capable of providing long-term exposure to the reduced-gravity environment of space

Equipped as a space biomedical research platform



ISS One-year Mission - Launch in March 2015

Scott Kelly STS-103, STS-118, ISS 25/26

Mikhail Kornienko ISS 23/24

ISS Research –*Critical to mitigating human exploration risks*

On-Orbit Research Facilities

Human Research Rack-1

Human Research Rack-2

Exercise Facilities

Biomedical Research

Nutritional Requirements

Physiological Changes and Exercise Countermeasures

Immunological Changes

Crew Sleep and Performance Research

Space Radiation Research

ISS Research –*Critical to mitigating human exploration risks*

Biomedical Capabilities Development

Lightweight Trauma Module

Portable Medical Imaging

Integrated heath care system

IV Fluid Generation

International Research Collaborations

CSA Cardiovascular Function Experiment

ESA Muscle Physiology Facility

JAXA Bone Loss Countermeasure Experiment

Russian Fluid Shift Countermeasure Experiment

Human Response to Spaceflight

Astronauts experience a spectrum of adaptations/stressors in flight and post-flight

Balance Disorders
Fluid Shifts
Cardiovascular Deconditioning
Decreased Immune Function
Muscle Atrophy
Bone Loss
Radiation Exposure
Sleep Disturbances
Isolation and Confinement

- Sensorimotor
- Cardiovascular
- Bone and Muscle
- Food/Nutrition
- Behavior/Performance
- Space Radiation
- Ocular Impairment
- Immunology

Health and Performance Risks

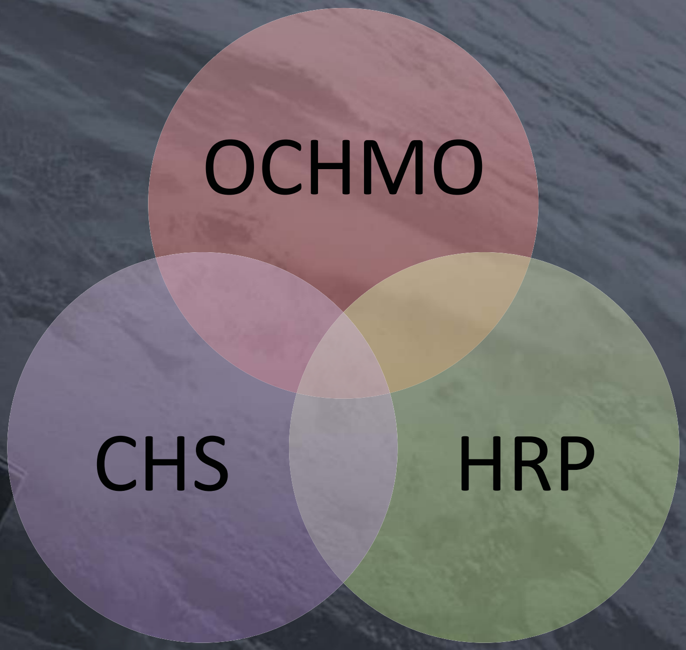
"Human space flight remains an endeavor with substantial risks, and these risks must be identified, managed, and mitigated appropriately to achieve the nation's goals in space."

(A Risk Reduction Strategy for Human Exploration of Space, National Academies, Institute of Medicine, 2006)

- **Humans have limits which drive mission and vehicle design**
  - Exposure to micro-gravity, G-tolerance, Radiation exposure, Closed environment, Psychological and Behavioral, Habitation & Life Support (air, nutrition, etc.)
- **Highest health risks associated with exploration missions have been identified, documented, reviewed, and are actively managed**
- **Health Risk Framework and Research underpinnings have been established by the National Academies**
- **Research Roadmap: http://humanresearchroadmap.nasa.gov/**

Crew Health, Medical, and Safety

- **Policy, Operations, and Research are integrated through a Human Health Risk Framework**
  - Office of the Chief Health and Medical Officer (OCHMO)
    - Medical Policy, Health and Performance Standards, and Bioethics (IRB, ACUC, Risk Threshold)
  - Crew Health and Safety (CHS)
    - Medical Operations and Occupational Health (career health care/post career monitoring)
  - NASA Human Research Program (HRP)
    - Human health & performance research in support of space exploration
      - Perform research necessary to understand & reduce health & performance risks
      - Develop and validate technologies to characterize and reduce medical risks
      - Enable development of human spaceflight medical and performance standards



Crew Health, Medical, and Safety

- **Standards are the first step in risk mitigation and acknowledging accepted risk**
  - Standards based on best available scientific/clinical evidence & expert recommendations (research findings, lessons learned from previous space missions and analogue environments, current standards of medical practice, risk management data)

- **Four sets of health and medical standards have been identified & approved by NASA**
  - Astronaut selection/retention
  - Human Factors/Environmental
  - Space Flight Health Standards
  - Levels of medical care

- **Space Flight Health Standards**
  - Fitness for Duty (FFD – e.g. cardiovascular): Minimum measurable capability or capacity for a given physiological or behavioral parameter that allows successful performance of all required duties.
  - Permissible Exposure Limits (PEL – e.g. radiation): Quantifiable limit of exposure to a space flight factor over a given length of time (e.g. life time radiation exposure).
  - Permissible Outcome Limits (POL – e.g. limit bone loss): POLs delineate an acceptable maximum decrement or change in a physiological or behavioral parameter, as the result of exposure to the space environment.

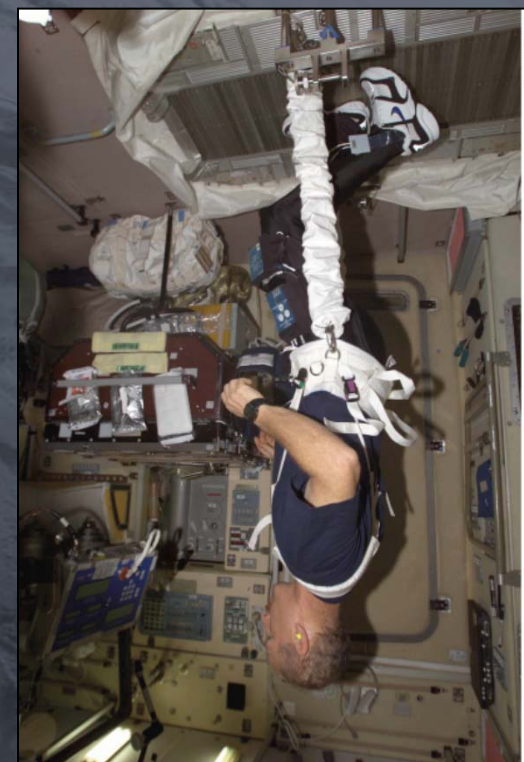
Crew Health, Medical, and Safety: Space Flight Health Standards

Standard Area	Type	Standard	Deliverables
Bone	POL	Maintain bone mass at ≥-2SD	❑ Risk assessment/ knowledge quantification ❑ Risk reduction knowledge/ mechanisms ❑ CM/ nutrition, pharmacology, exercise, A/G, other biomechanical ❑ Medical Assessment/ diagnosis/ treatment
Cardiovascular	FFD	Maintain ≥75% of baseline VO2 max	
Neurosensory	FFD	General Sensory Motor, Motion Sickness, Perception, Gaze Control	
Behavioral	FFD	Maintain nominal behaviors, cognitive test scores, adequate sleep	
Immunology	POL	WBC > 5000/ul CD4 + T > 2000/ul	
Nutrition	POL	80% of spaceflight-modified/ USDA nutrient requirements	
Muscle	FFD	Maintain 70% of baseline muscle strength	
Radiation	PEL	≤ 3% REID (Risk of Exposure Induced Death)	

Exercise: *solution for many of the space health issues*

- **Physical fitness benefits**
  - Cardiovascular system
  - Aerobic capacity
  - Muscle mass and Bone strength

- **Psychological Benefits**
  - Antidepressant, Relieves stress, Better sleep



Lack of gravity requires exercise hardware to maintain baseline physical fitness

Human Research Program

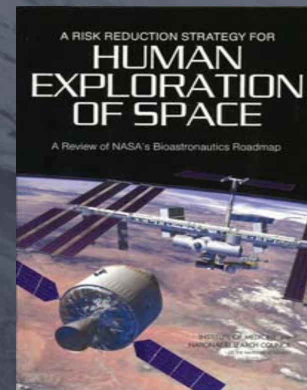
- **Science Management & Program Integration Office**
  - Peer Review, Task/Risk Management, Data Archive
  - Program planning, integration & control
- **Elements**
  - Behavioral Health and Performance
    - Individual, sleep, and interpersonal
  - Human Health and Countermeasures
    - Physiology, ocular impairment
  - ISS Medical Project
    - Infrastructure for flight experiments
  - Exploration Medical Capability
    - Medical care for missions beyond low Earth orbit
  - Space Human Factors and Habitability
    - Interfaces between humans and vehicles/habitats
  - Space Radiation
    - Radiation exposure and biological effects
- **National Space Biomedical Research Institute**
  - Cooperative agreement to pursue research that complements the HRP portfolio

External Research Community

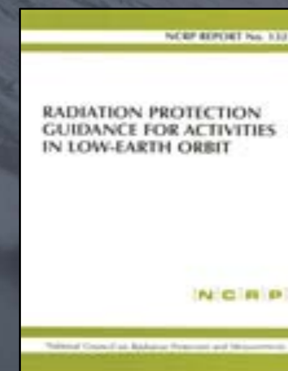
- **Strategic Planning**
  - National Academies (IOM, NRC)
    - Risk Reduction Strategy for Human Exploration of Space
    - Review of HRP Evidence Base and Merit Review Process
  - National Council on Radiation Protection (NCRP)
  - NASA Advisory Committee (NAC)
  - Annual Standing Review Panels (SRP)

- **Science Planning**
  - Research and Clinical Advisory Panel for Visual Impairment, Papilledema & VIIP Summits
  - Telemedicine Summit, Osteoporosis & Bone Summits
  - Atmospheric Dust Toxicity Assessment Group
  - Decompression Risk Review, Dental Working Group
  - Acute Risk: Radiation Workshop, CNS Research Panel,
  - Habitable Volume Workshop

- **Research Implementation**
  - National Research Solicitations
    - Crew Health and Performance NRA, Space Radiobiology NRA
  - Graduate Student and Post-Doctoral Programs

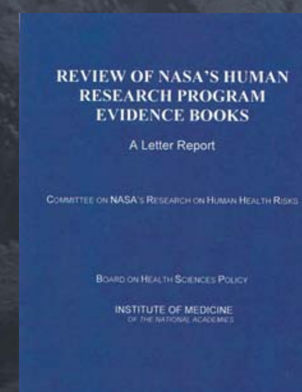


A Risk Reduction Strategy for Human Exploration of Space



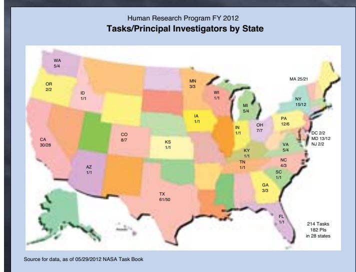
National Council on Radiation Protection & Measurement

NRC Report on NASA Cancer Risk Models

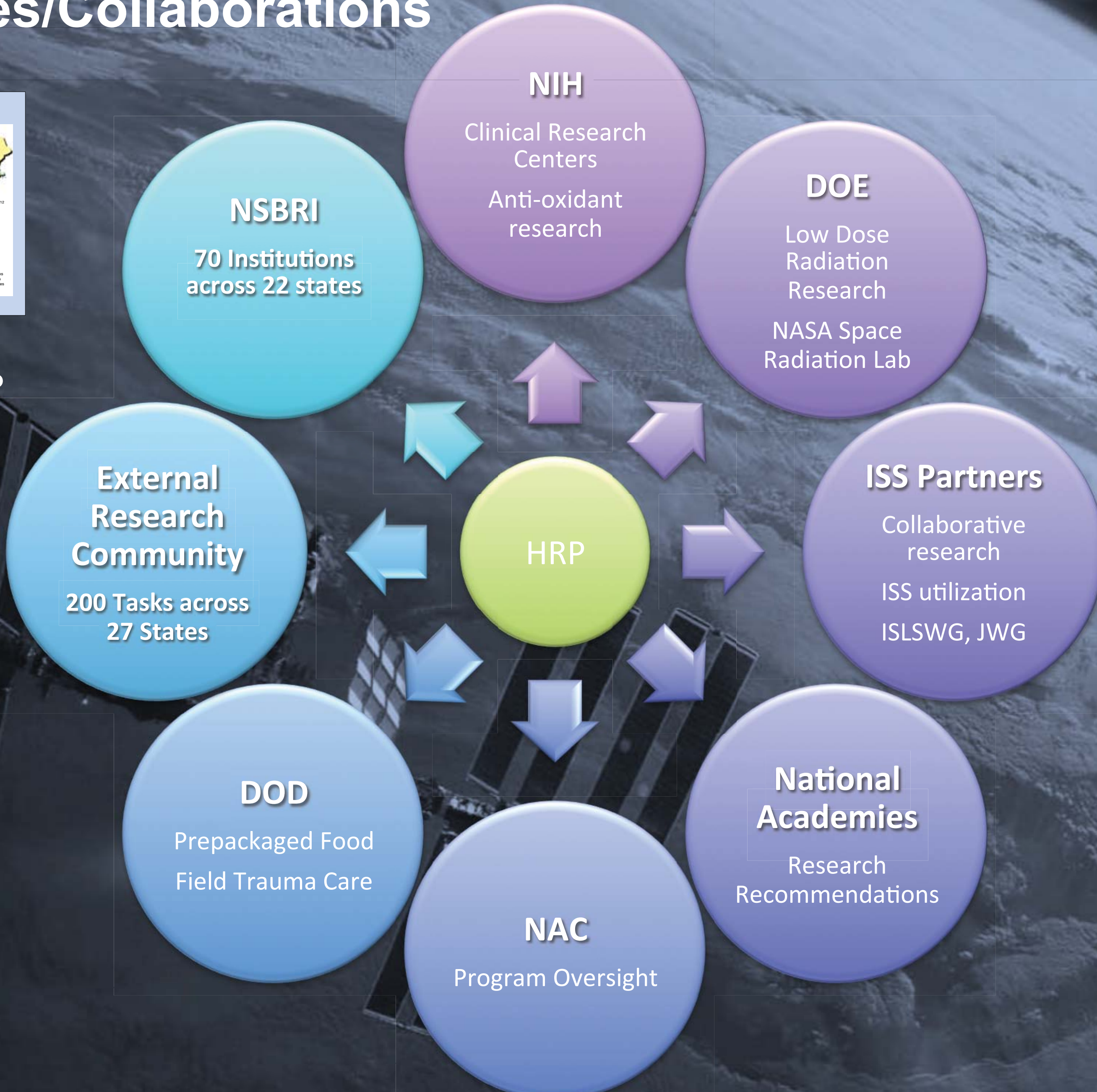


IOM Review of NASA's Human Research Program Evidence Books

Interfaces/Collaborations



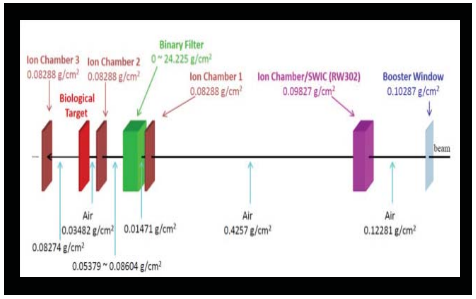
http://taskbook.nasaprs.com/Publication/welcome.cfm



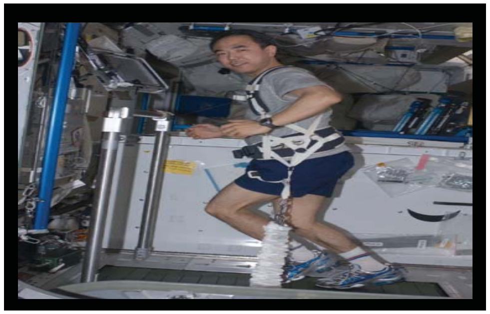
Research & Technology Deliverables

Portable Medical Imaging

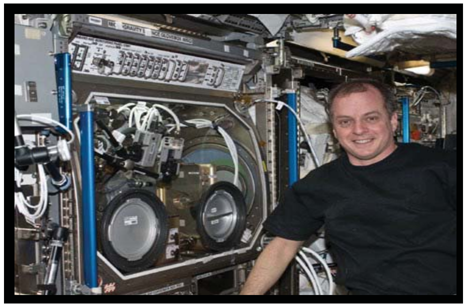
Physiological Monitoring Systems



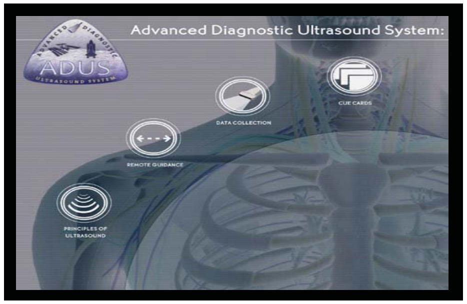
Updated Space Radiation Codes



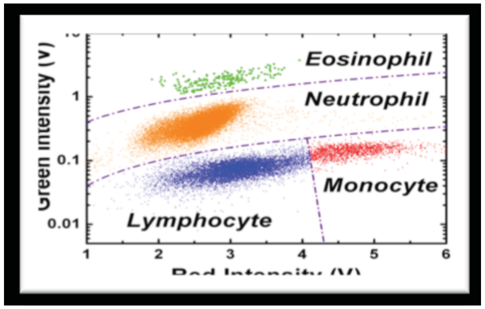
ISS instrumented harness study



In-situ-Intravenous (IV) Fluid Generation technology



Remote Medical Capability: Diagnostic guide to assist with ultrasound imaging



Technology for astronaut health monitoring

Spinal Elongation Study

Dust Permissible Exposure Limit

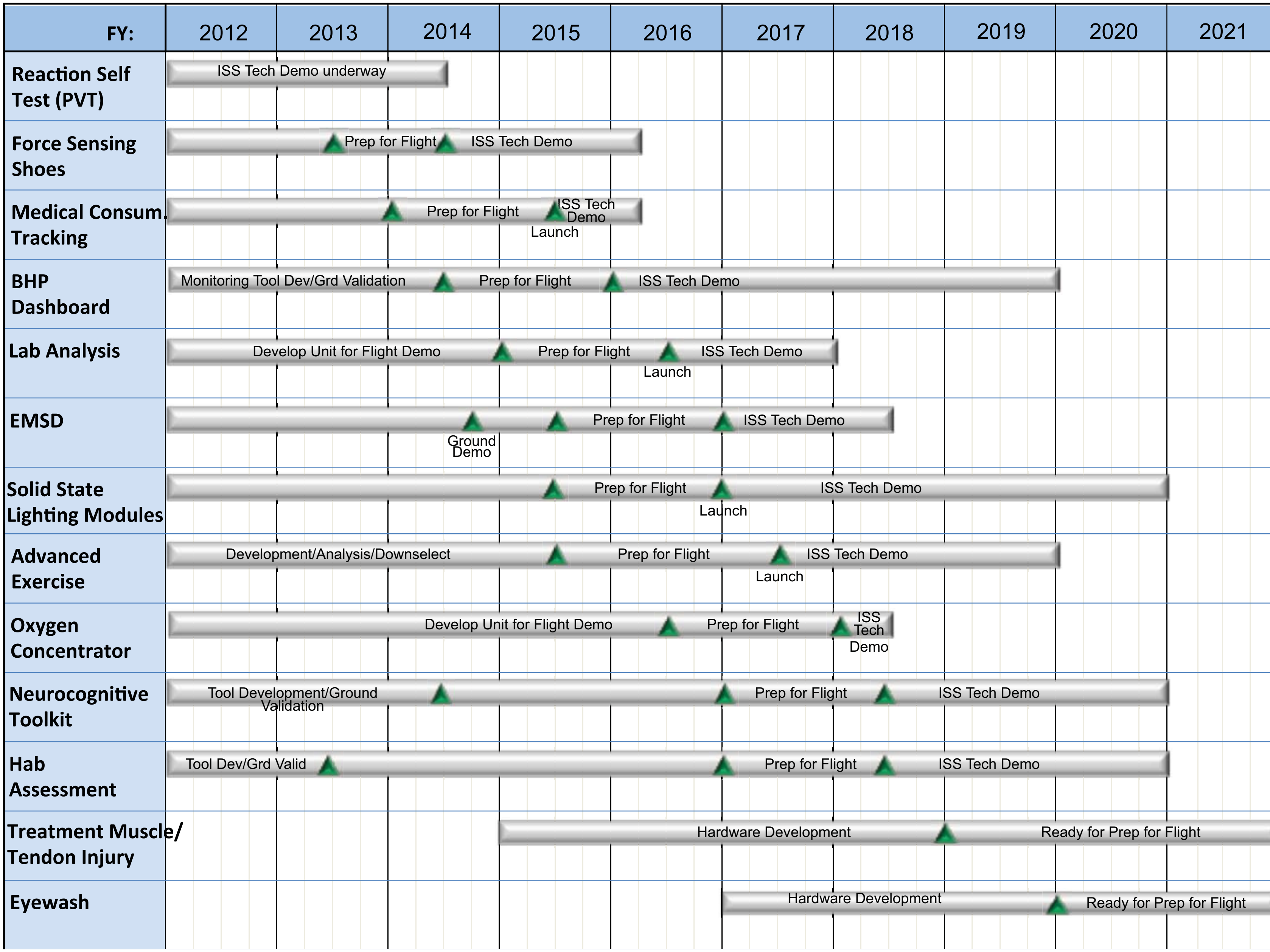
Flight and Ground Facilities

- **International Space Station**
  - Critical to understanding and mitigating a majority of the exploration human risks
  - Important test bed for space biomedical technology

- **NASA Space Radiation Laboratory (NSRL)**
  - Brookhaven National Laboratory (DOE)
  - Critical to Space Radiation Research

- **Ground-based Analogs**
  - Bed Rest Capability for Human Health Countermeasures Research (NIH)
  - Isolation Studies
    - Antarctica (NSF, International)
    - Chamber studies (e.g. Mars 500)

ISS Technology Demonstrations
Strategic Plan FY 2012 through FY 2021



Human Health and Performance Risks

- **47 Human Space Flight Health and Performance Risks**
  - Crew Health and Safety Risks (Medical Operations): current crew and space mission
  - Human Research Program Risks: require active research program to mitigate the risk for future long-duration missions
  - All human health and performance risks are managed and assessed by the NASA Human System Risk Board (Mission Operations and Research)

Crew Health and Safety Risks (Medical Operations)

Risk of Toxic Exposure
Risk of Common Medical Events
Risk of Hearing Loss Related to Spaceflight
Risk of Injury from Sunlight Exposure
Risk of Urinary Retention
Risk of Space Adaptation Back Pain
Risk of Probability of mild Acute Mountain Sickness (AMS) in astronauts resulting in reduced crew performance prior to adaptation to a mild hypoxia.
Risk of Inability to Certify Environment for Flight
Risk of Acute and Chronic Carbon Dioxide Exposure
Risk of Adverse Behavioral Conditions
Risk of Psychiatric Disorders
Risk of Compromised EVA Performance & Health Due to Inadequate EVA Suit Systems (MOD)
Risk of Compromised EVA Performance & Crew Health Due to Inadequate EVA Suit Systems
Risk of Exceeding Career Radiation Exposure Limits
Risk of Limited Crew Selection Due to Radiation Exposure Limits

Human Research Program Risks By Element: Reviewed by the National Academies' Institute of Medicine

Space Human Factors & Habitability Risks

Risk of Performance Decrement and Crew Illness Due to an Inadequate Food System

Risk of Inadequate Human-Computer Interaction

Risk of Performance Errors Due to Training Deficiencies

Risk of Inadequate Design of Human and Automation/Robotic Integration

Risk of Inadequate Critical Task Design

Risk of Adverse Health Effects of Exposure to Dust and Volatiles During Exploration of Celestial Bodies

Risk of an Incompatible Vehicle/Habitat Design

Risk of Adverse Health Effects Due to Alterations in Host-Microorganism Interactions

Behavior Health & Performance Risks

Risk of Adverse Behavioral Conditions and Psychiatric Disorders

Risk of Performance Errors Due to Fatigue Resulting from Sleep Loss, Circadian Desynchronization, Extended Wakefulness, and Work Overload

Risk of Performance Decrements due to Inadequate Cooperation, Coordination, Communication, and Psychosocial Adaptation within a Team

Space Radiation Risks

Risk of Radiation Carcinogenesis

Risk of Acute Radiation Syndromes Due to Solar Particle Events

Risk of Acute or Late Central Nervous System Effects from Radiation Exposure

Risk of Degenerative Tissue or other Health Effects from Radiation Exposure

Exploration Medical Capability Risks

Risk of Unacceptable Health and Mission Outcomes Due to Limitations of In-flight Medical Capabilities

Human Health Countermeasures Risks

Risk of Orthostatic Intolerance During Re-Exposure to Gravity

Risk of Early Onset Osteoporosis Due to Spaceflight

Risk Factor of Inadequate Nutrition

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

Risk of Impaired Performance Due to Reduced Muscle Mass, Strength and Endurance

Risk of Renal Stone Formation

Risk of Bone Fracture

Risk of Intervertebral Disc Damage

Risk of Cardiac Rhythm Problems

Risk of Reduced Physical Performance Capabilities Due to Reduced Aerobic Capacity

Risk of Crew Adverse Health Event Due to Altered Immune Response

Risk of Impaired Control of Spacecraft, Associated Systems and Immediate Vehicle Egress due to Vestibular / Sensorimotor Alterations Associated with Space Flight

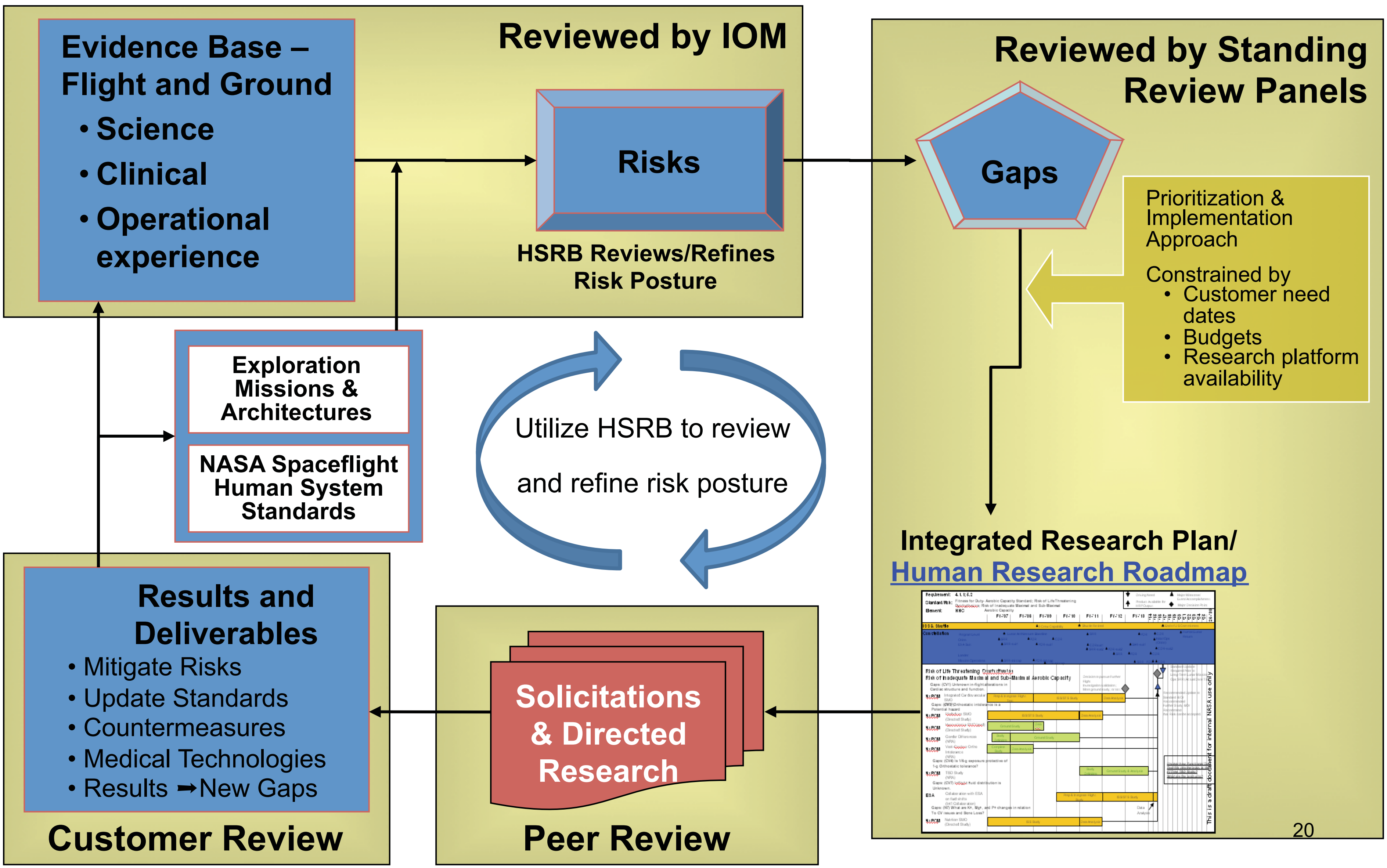
Risk of Clinically Relevant Unpredicted Effects of Medication

Risk of Spaceflight-Induced Intracranial Hypertension/Vision Alterations

Risk of Decompression Sickness

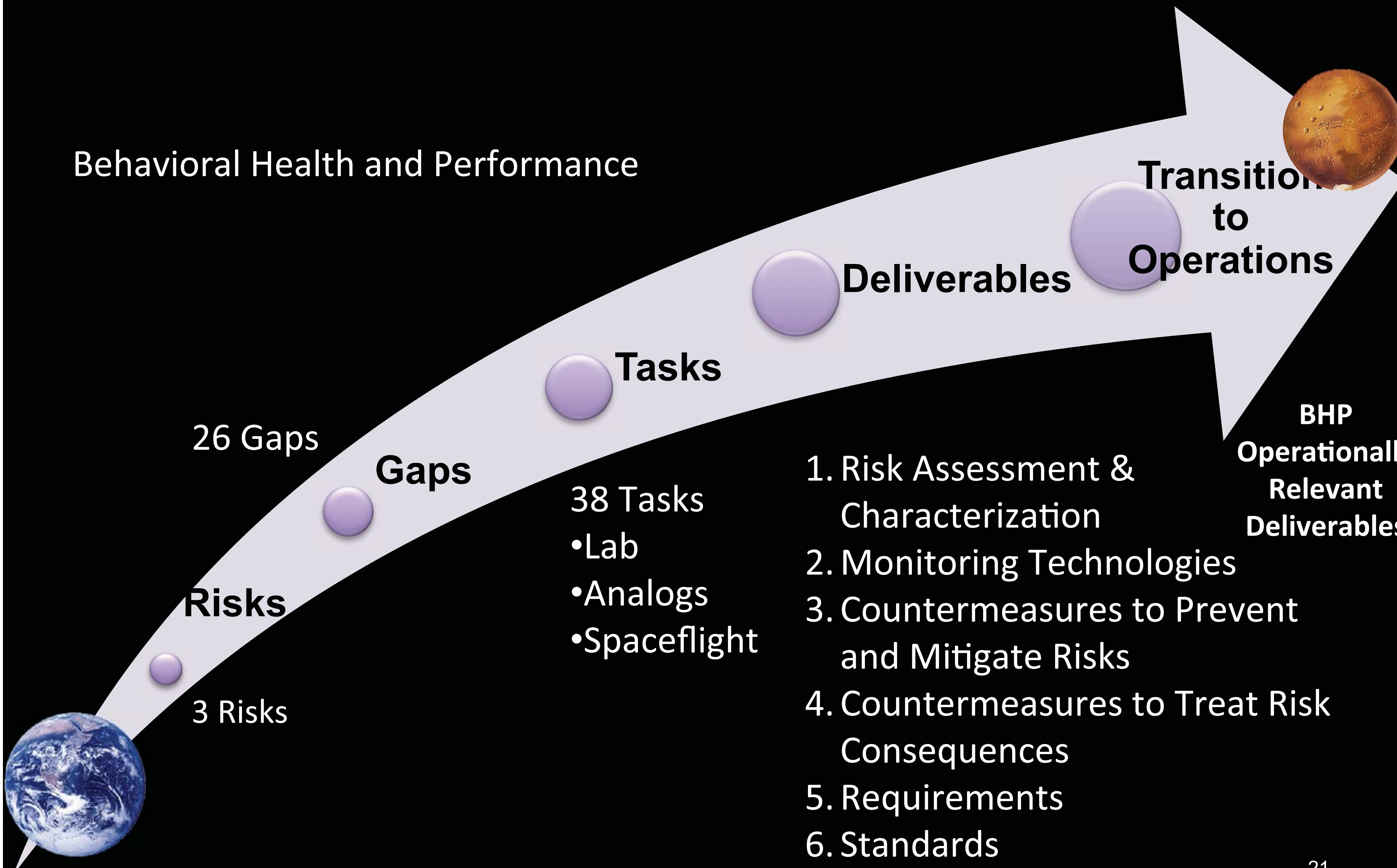
Risk of Injury from Dynamic Loads

Architecture: Evidence ➠ Risks ➠ Gaps ➠ Tasks ➠ Deliverables



Risk to Mitigation Framework

Behavioral Health and Performance



3 Risks

26 Gaps

38 Tasks
•Lab
•Analogs
•Spaceflight

1. Risk Assessment & Characterization
2. Monitoring Technologies
3. Countermeasures to Prevent and Mitigate Risks
4. Countermeasures to Treat Risk Consequences
5. Requirements
6. Standards

BHP Operationally Relevant Deliverables

International Coordination: Exploration Biomedical Challenges

Green	Yellow	Red
Not mission limiting	Not mission limiting, but increased risk	Potentially Mission limiting

Human Health and Performance Risks Coordinated with all International Partners

		Mission		
		ISS 6 mo	NEA (1yr)	Mars (3yr)
Musculoskeletal	Long-term health risk of Early Onset Osteoporosis; Mission risk of reduced muscle strength and aerobic capacity	Green	Yellow	Red
Sensorimotor	Mission risk of sensory changes/dysfunctions	Green	Green	Yellow
Ocular Impairment	Mission and long-term health risk of Microgravity-Induced Visual Impairment and/or elevated Intracranial Pressure (VIIP)	Yellow	Red U	Red U
Nutrition	Mission risk of behavioral and nutritional health due to inability to provide appropriate quantity, quality and variety of food	Green	Yellow	Red
Autonomous Medical Care	Mission health risk due to inability to provide adequate medical care throughout the mission (Includes onboard training, diagnosis, treatment, and presence/absence of onboard physician)	Green	Red	Red
Behavioral Health and Performance	Mission and long-term behavioral health risk.	Green	Red	Red
Space Radiation	Long-term risk of carcinogenesis and degenerative tissue disease due to radiation exposure	Green	Red	Red
Toxicity	Mission risk of exposure to a toxic environment without adequate monitoring, warning systems or understanding of potential toxicity (dust, chemicals, infectious agents)	Yellow	Red	Red
Autonomous Emergency Response	Medical risks due to life support system failure and other emergencies (fire, depressurization, toxic atmosphere, etc.), crew rescue scenarios	Yellow	Red	Red
Hypogravity	Long-term risk associated with adaptation during IVA and EVA on asteroids and Mars (vestibular and performance dysfunctions) and post-flight rehabilitation	Green	Yellow	Red U

HRP Well-aligned with the NASA Exploration Mission

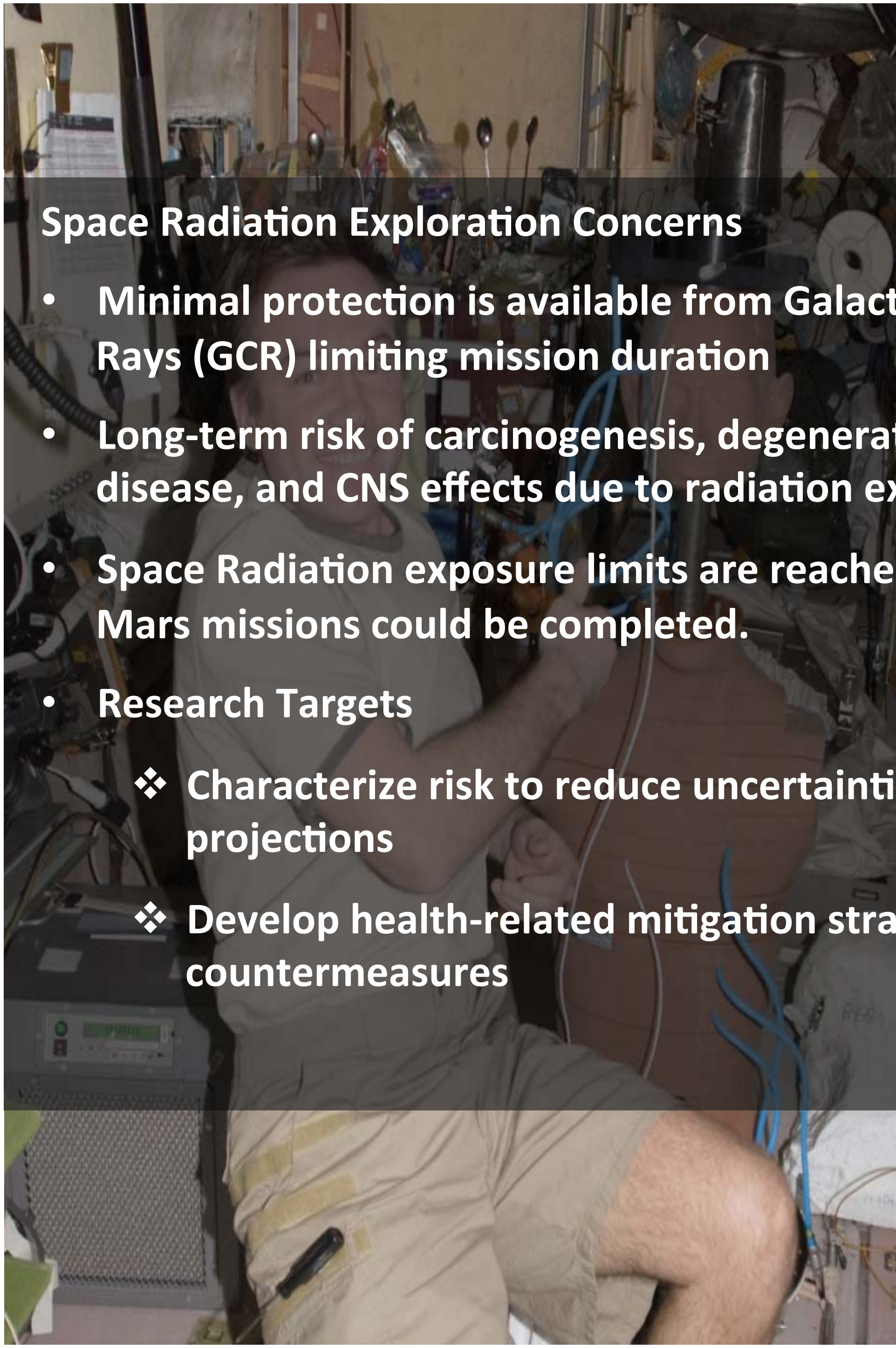
- Enhance crew health and safety by using a systematic approach to reduce the exploration mission risks
- Fully utilize ISS as a space biomedical research platform
- Ensure content/approach are vetted by National Academies and independent review boards
- Engage the U.S. research communities using open, peer reviewed research announcements to produce innovative solutions
- Collaborate with the National and International agencies to leverage funding, unique capabilities, and enhance scientific exchange
- Coordinate research with other NASA programs to gain efficiencies
- Contribute NASA innovation to broader national needs by capitalizing on R&T advancements that return benefits to the economy, health care, & STEM education
- Revitalize excitement for space exploration in young people across the nation through education and outreach projects like Mission-X

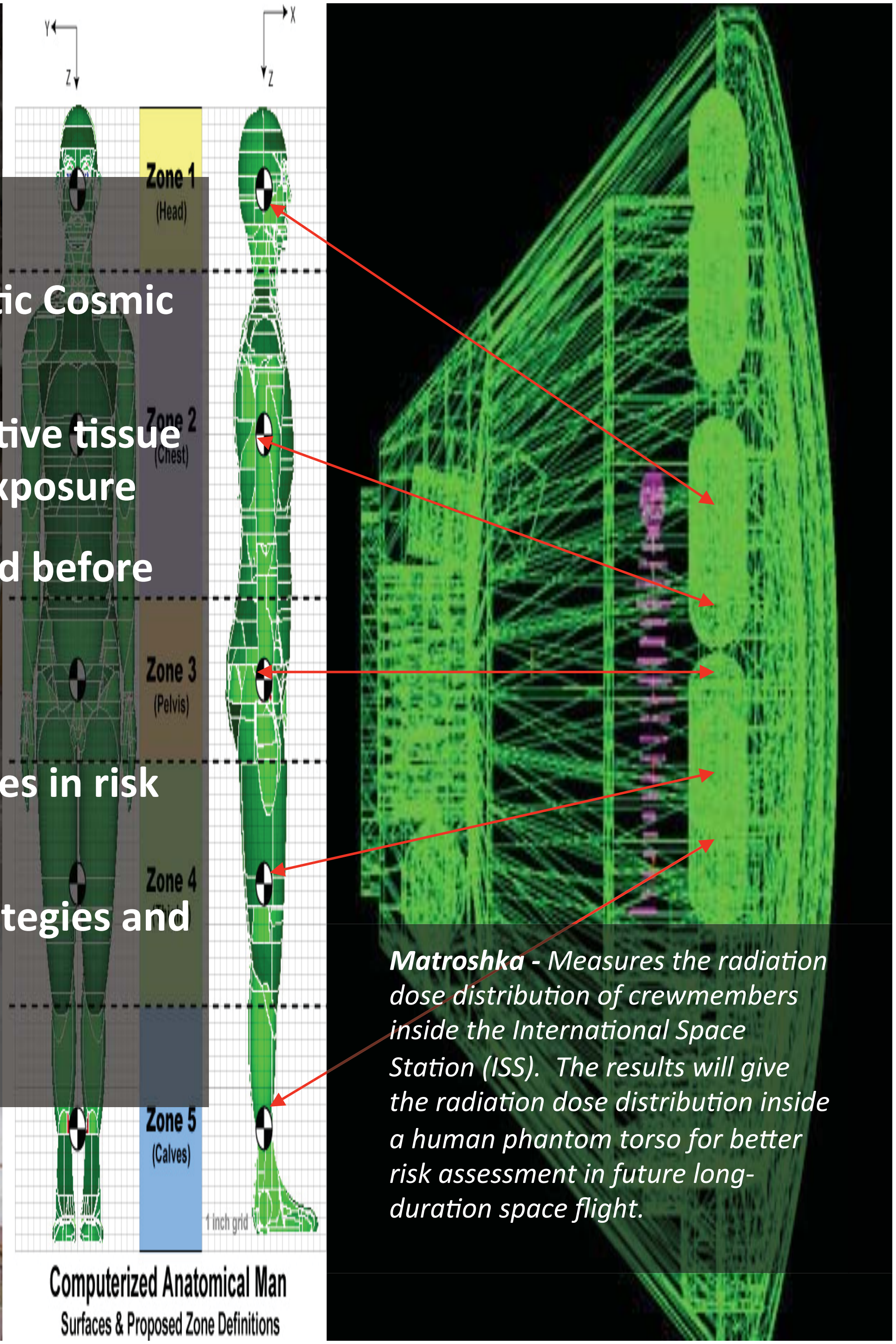
Astronauts and Education- *NASA's Mission X: Train Like An Astronaut fitness challenge built off the natural admiration toward astronauts to challenge young students to get in shape and eat right. In partnership with the White House's Let's Move Initiative, over 20 countries and thousands of students focused on addressing the urgent issue of childhood obesity while getting students excited about space, exploration, and a healthy lifestyle.*

Backup Charts

Space Radiation Exploration Concerns

- **Minimal protection is available from Galactic Cosmic Rays (GCR) limiting mission duration**
- **Long-term risk of carcinogenesis, degenerative tissue disease, and CNS effects due to radiation exposure**
- **Space Radiation exposure limits are reached before Mars missions could be completed.**
- Research Targets
  - ❖ Characterize risk to reduce uncertainties in risk projections
  - ❖ Develop health-related mitigation strategies and countermeasures

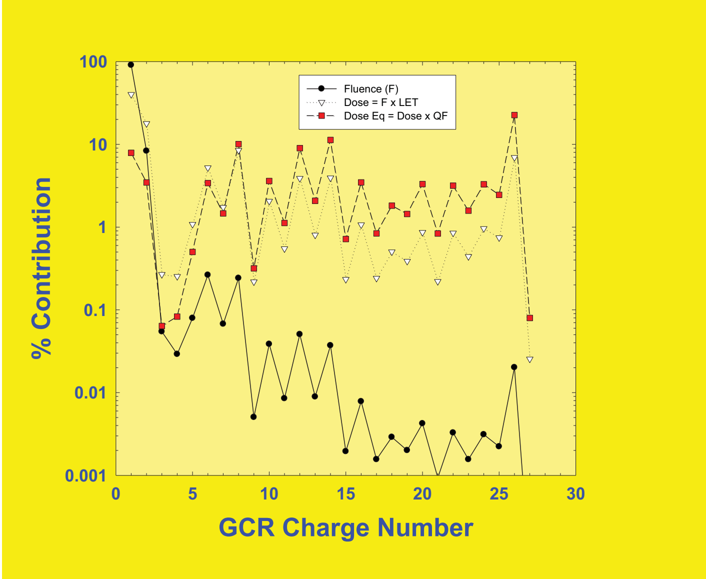




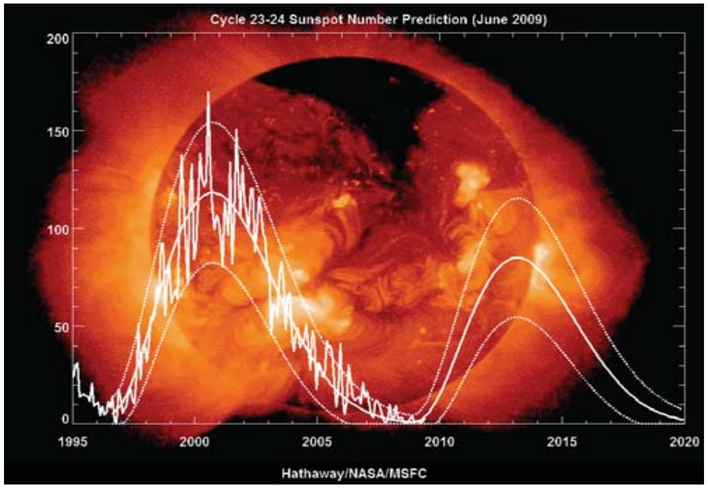
Matroshka *- Measures the radiation dose distribution of crewmembers inside the International Space Station (ISS). The results will give the radiation dose distribution inside a human phantom torso for better risk assessment in future long-duration space flight.*

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

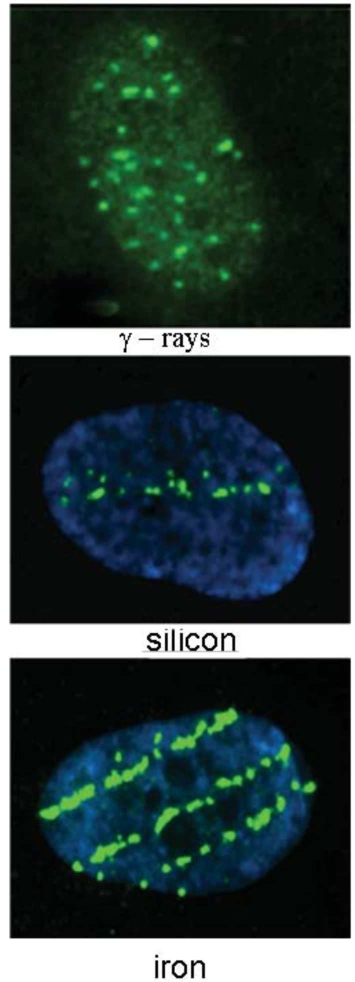


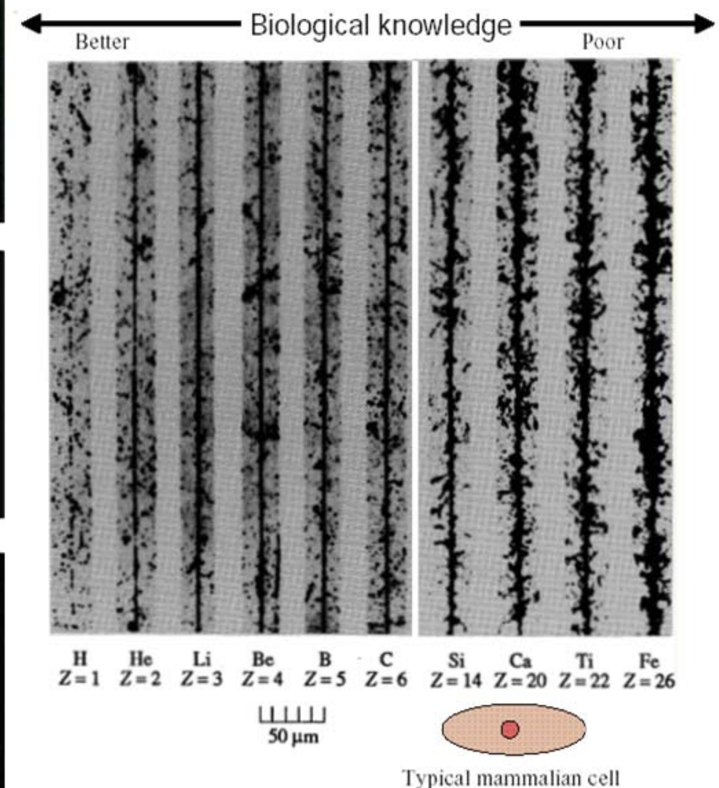
- **Solar Particle Events (SPE) largely medium energy protons – a shielding, operational, and risk assessment challenge**
  - shielding is effective; optimization needed to reduce weight
  - improved understanding of radiobiology needed to perform optimization
  - accurate event alert and responses is essential for crew safety



The Space Radiation Problem

- **Space radiation is comprised of high-energy protons and heavy ions (HZE's) and secondary protons, neutrons, and heavy ions produced in shielding**
- **Unique damage to biomolecules, cells, and tissues occurs from HZE ions that is qualitatively distinct from X-rays and gamma-rays on Earth**
- **No human data to estimate risk from heavy ions**
- **Animal models must be applied or developed to estimate cancer, CNS risks, and other risks**
- **Shielding has excessive costs and will not eliminate galactic cosmic rays (GCR)**



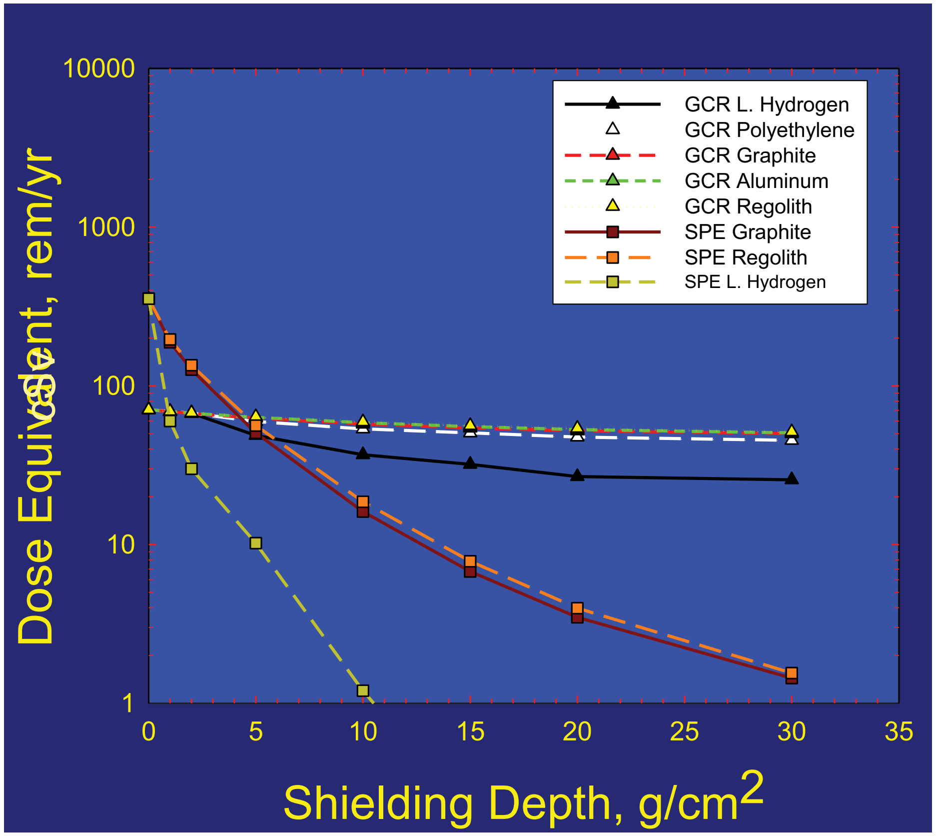


Cucinotta and Durante, Lancet Oncology (2006)

Space Radiation Shielding is Well Understood

- **NASA has invested in shielding technologies for many years and understanding is nearly complete**
  - **Over 1,000 research publications since 1980**
  - **Solar events can be shielded**
  - **GCR requires enormous mass to shield because of high energies and secondary radiation**
- **Highly accurate predictive codes exist with +15% errors for organ exposure projections**
  - Transport codes
  - Environmental models
  - Optimal materials
  - Topology Design methods
- **Knowledge missing is accurate understanding of radiobiology for Exposure to Risk conversion**

Radiation Shielding Materials are not effective against GCR's



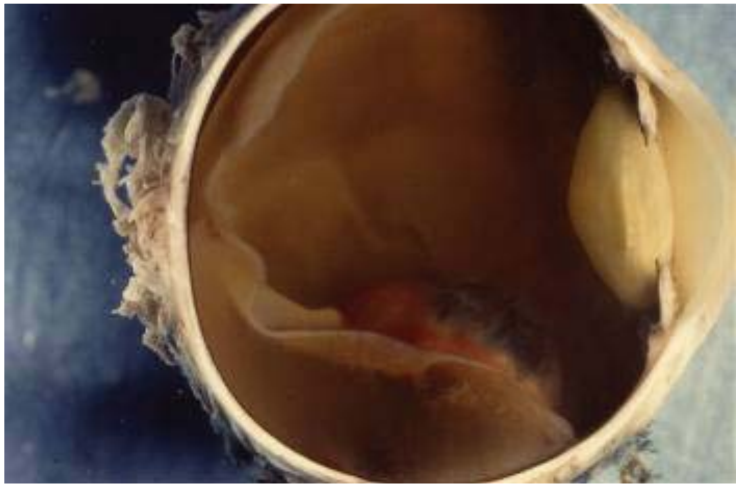
August 1972 SPE and GCR Solar Min

Categories of Radiation Risk

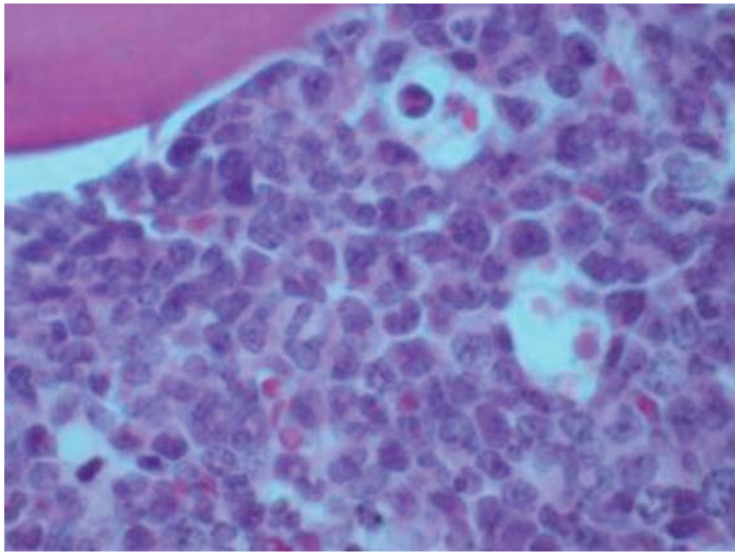
- ***Cancer (morbidity and mortality risk)***
- ***Acute and Late Central Nervous System (CNS) risks***
  - ✓ immediate or late functional changes
- ***Chronic & Degenerative Tissue Risks***
  - ✓ cataracts, heart-disease, etc.
- ***Acute Radiation Sickness***
  - ✓ Prodromal risks

Differences in biological damage of heavy nuclei in space with x-rays, limits Earth-based data on health effects of heavy ions

- **New biological knowledge on risks must be obtained**



Lens changes in cataracts (E. Blakely)



First experiments for leukemia induction with GCR (R. Ullrich)

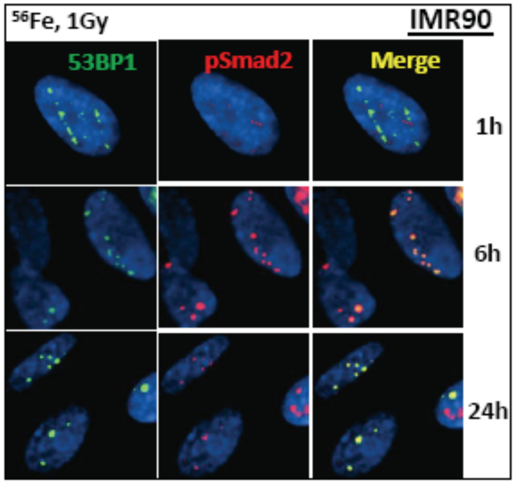
Space Safety Requirements

- Congress has chartered the National Council on Radiation Protection (NCRP) to guide Federal agencies on radiation limits and procedures

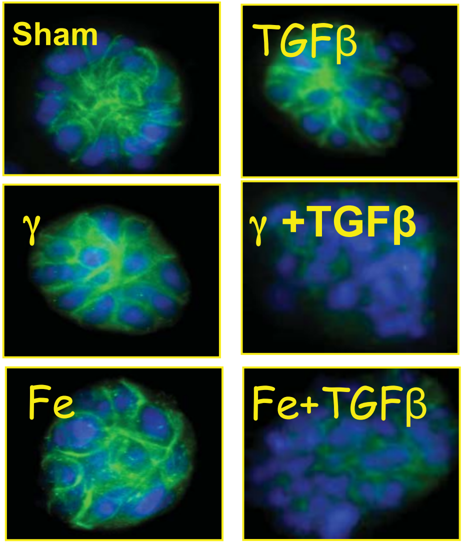
- Crew safety
  - limit of 3% fatal cancer risk
  - NASA limits the 3% risk at a 95% confidence level to protect against uncertainties in risk projections
  - prevent radiation sickness during mission
  - new exploration requirements limit central nervous system (CNS) and heart disease risks from space radiation

- Mission and Vehicle Requirements
  - shielding, dosimetry, and countermeasures

- NASA programs must follow the ALARA principle to ensure astronauts do not approach dose limits

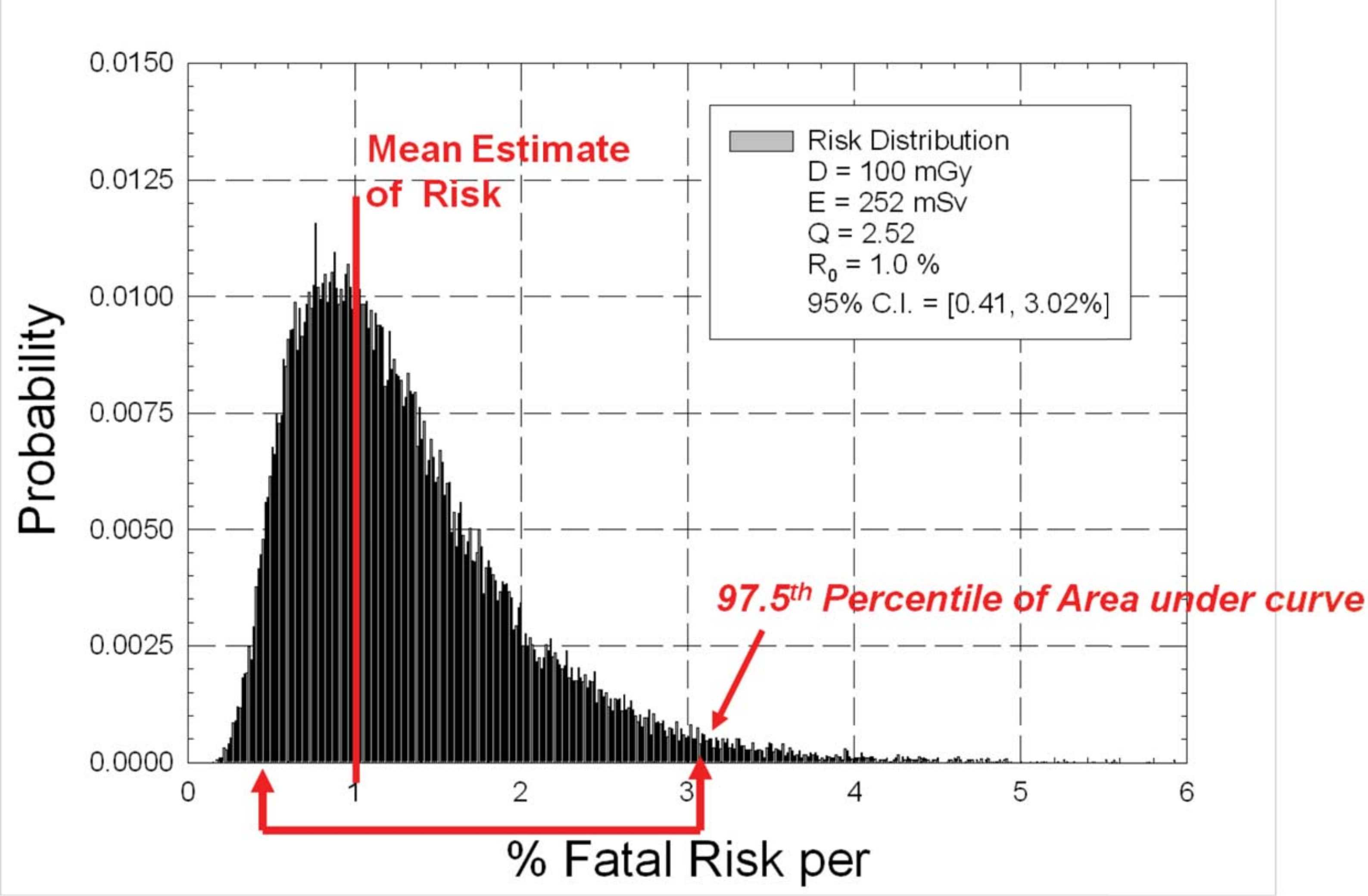


DNA damage and tissue controls (M. Wang/NASA)



Space Radiation in breast cancer formation (M. Barcellos-Hoff)/NYU)

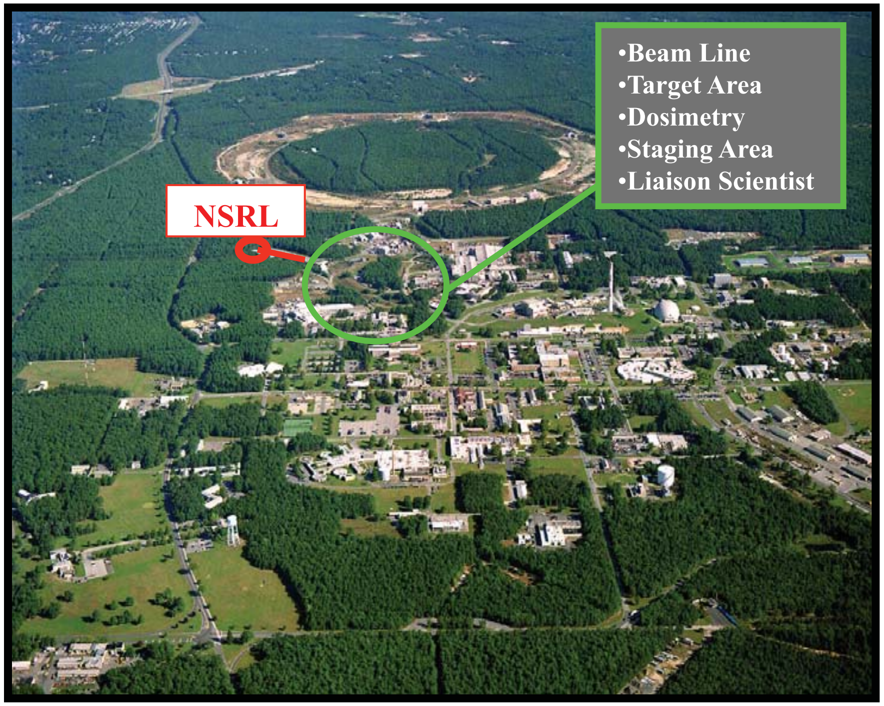
ISS Mission Nominal Fatal Cancer Risk



95% Confidence Interval: 1 in 20 Chance True Answer falls outside this interval from 2.5th to 97.5th Percentiles (95% Area under Curve)

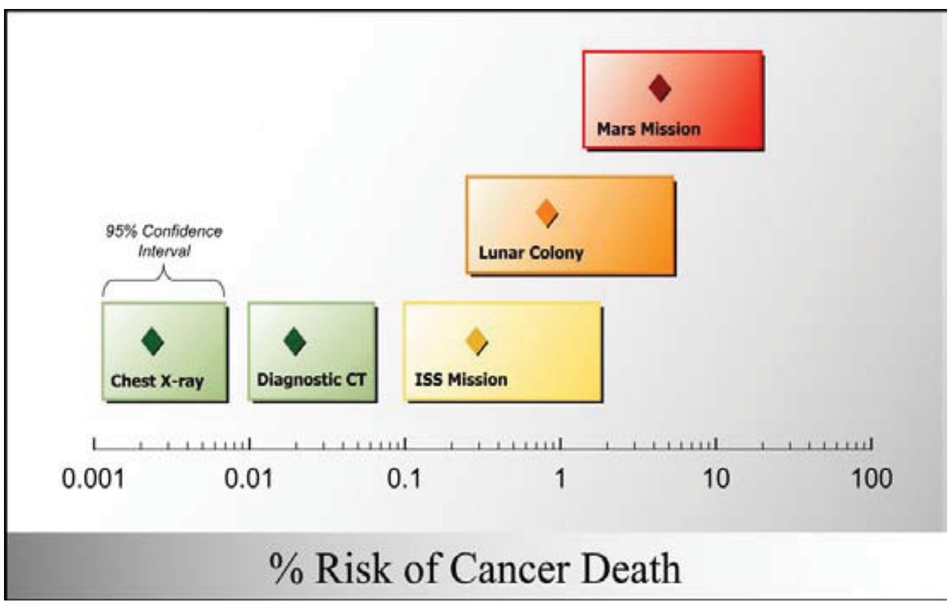
NASA Space Radiation Laboratory at the Brookhaven National Laboratory (BNL)

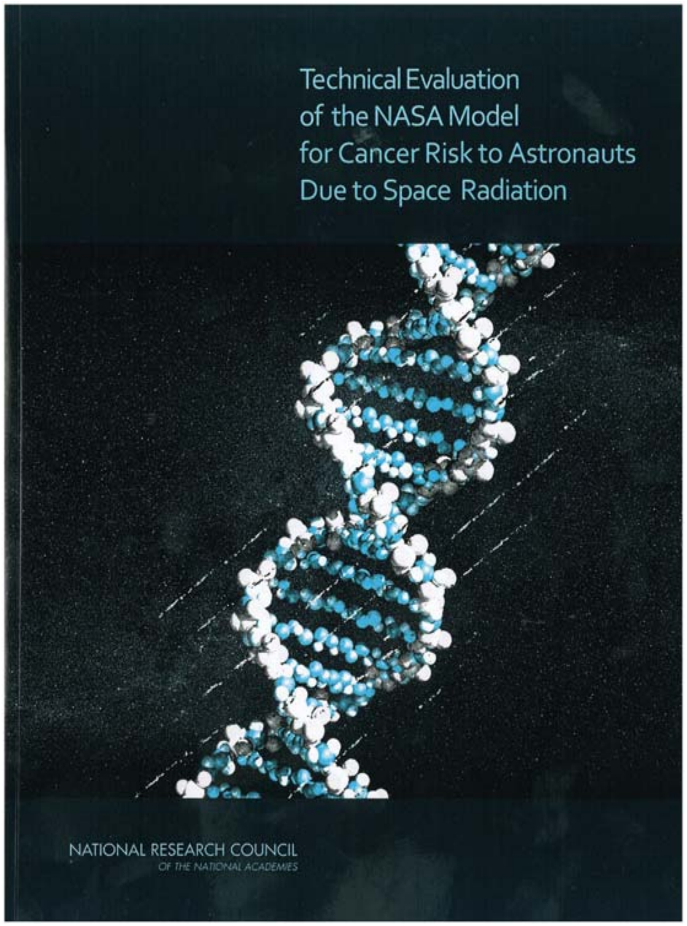
- **Within a year of creation of NASA in 1958, it was realized that cosmic rays are substantial threat to human space missions and a need for particle accelerator simulation was identified**
- **The NASA Space Radiation Laboratory (NSRL) at BNL is critical to enabling deep space missions**
  - It is the only place in the USA and one of the few places in the world that can simulate the harsh cosmic (heavy ion) and solar radiation environment found in space
- **New research results are impacting risk estimates for ISS and deep space missions**
- **NSRL is operated under a DOE/NASA MOU**



NASA Space Radiation Cancer Risk Model

- **NASA has updated its Space Radiation Cancer Risk Model based on recent research results and epidemiological studies**
  - The National Academy of Sciences, National Research Council completed its Evaluation of Space Radiation Cancer Risk Model: Report published March 2012
  - Model will be used to project the cancer risk for current ISS crews and future explorations missions.





Maximum "Safe" Days in Deep Space (NASA 2012)

- Uncertainties in Estimating Risks are major limitation to space travel
- Solar Min Maximum Days in Deep Space (heavy shielding) to 95% Confidence to be below NASA Limits for cancer risk: (parenthesis is deep solar min of 2009)

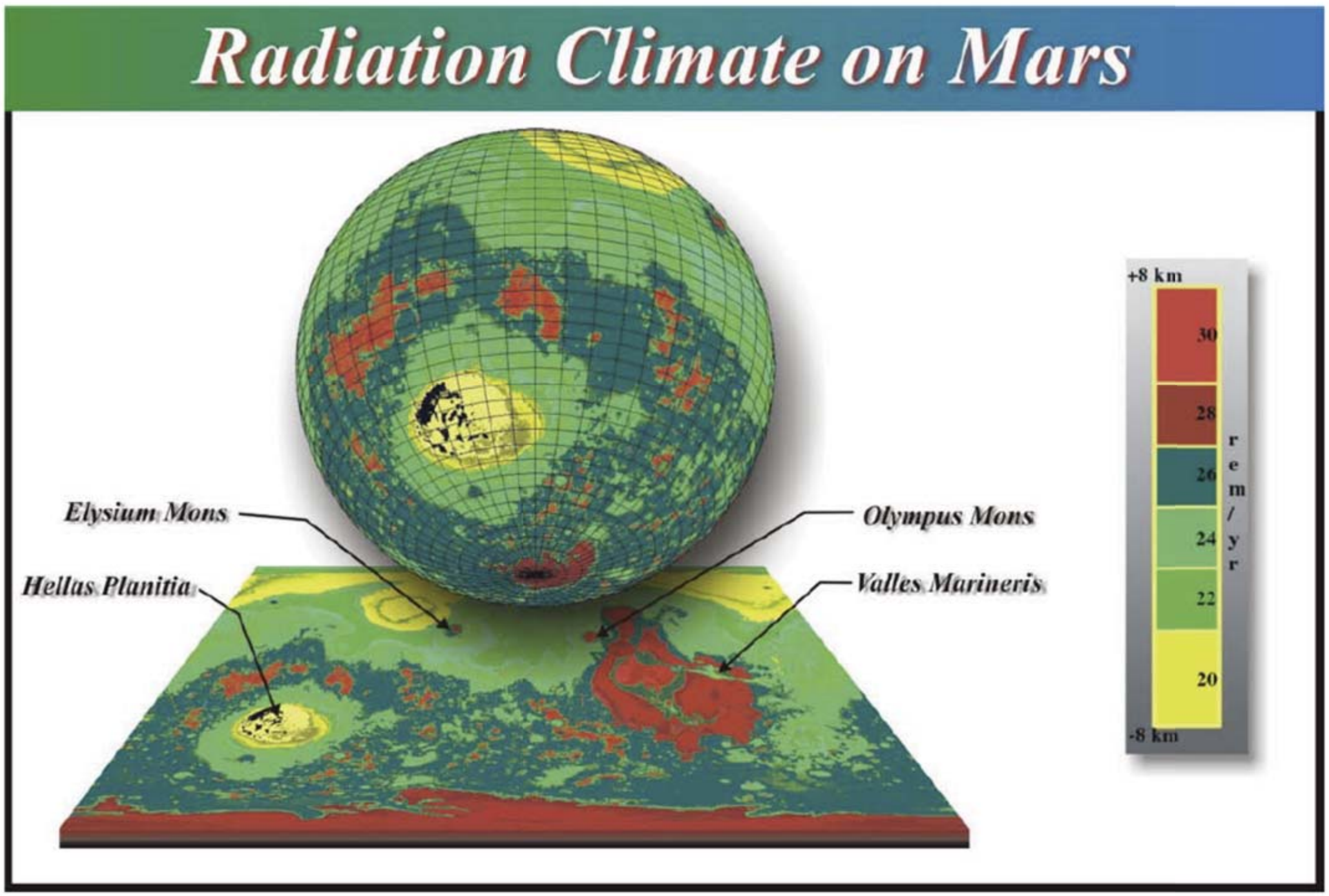
a_E, y	NASA 2005	NASA 2012 U.S. Avg. Population	NASA 2012 Never-smokers
		Males	
35	158	209 (205)	271 (256)
45	207	232 (227)	308 (291)
55	302	274 (256)	351 (335)
		Females	
35	129	106 (95)	187 (180)
45	173	139 (125)	227 (212)
55	259	161 (159)	277 (246)

- Solar Max Maximum Days in Deep Space (heavy shielding) to 95% Confidence to be below NASA Limits for cancer risk alone (parenthesis is for case of ideal storm shelter which negates any SPE cancer risk):

a_E, y	NASA 2012 U.S. Avg. Population	NASA 2012 Never-smokers
	Males	
35	306 (357)	395 (458)
45	344 (397)	456 (526)
55	367 (460)	500 (615)
	Females	
35	144 (187)	276 (325)
45	187 (232)	319 (394)
55	227 (282)	383 (472)

Mars Radiation varies with Atmospheric height

Vertical atmospheric depth of 18 g/cm^2 CO_2 at mean surface for annual Effective dose from <200 mSv to >300 mSv (2 mSv on Earth)

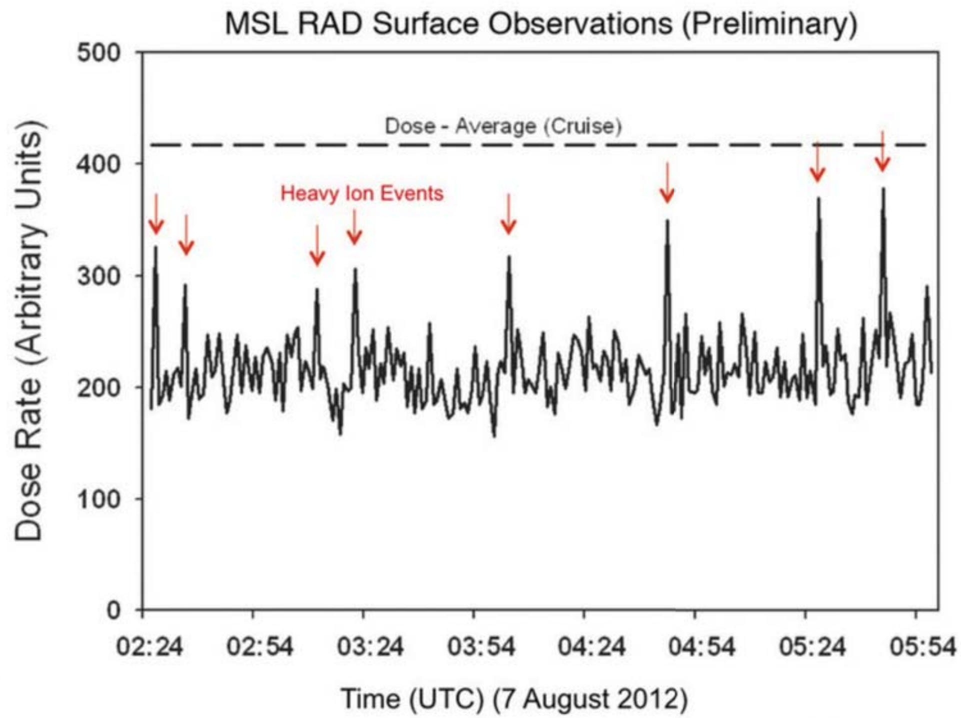


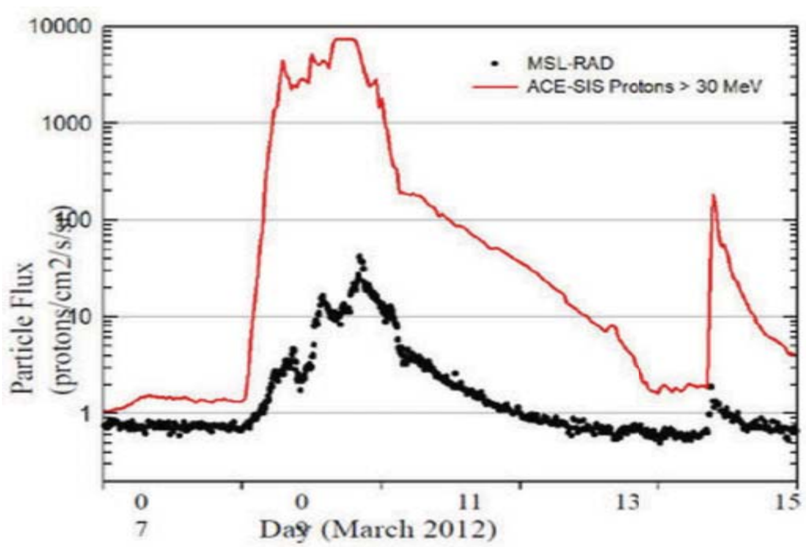
Saganti/Cucinotta: Space Science Reviews 2004

Mars Curiosity Rover: Radiation Assessment Detector (RAD)

Curiosity's First Radiation Measurements on Mars: 3.5-hour observation on August 7 with a time resolution of one minute. For reference, the average radiation dose observed during Cruise has been included to show that Deep Space Radiation levels are higher than those on Mars.

Surface: .7mSv/day
Cruise: 1.9 mSv/day





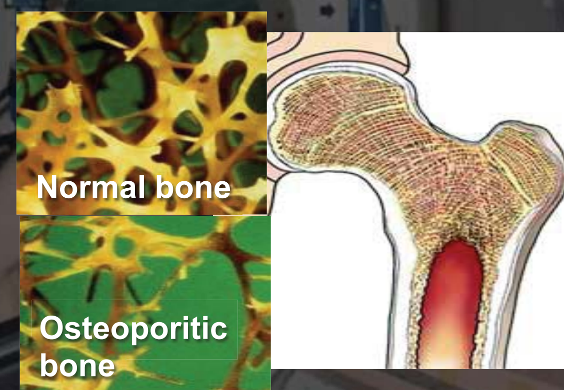
Coronal Mass Ejection registered by the Advanced Composition Explorer (ACE) Spacecraft (Sun-Earth Lagrange Point 1, 1.5 Million Kilometers from Earth). MSL was significantly further away from the Sun and from Earth at that point, explaining why RAD detected the increased particle flux later than ACE. The graph shows that MSL's hull was able to provide significant shielding from the impinging radiation.

Musculoskeletal Exploration Concerns

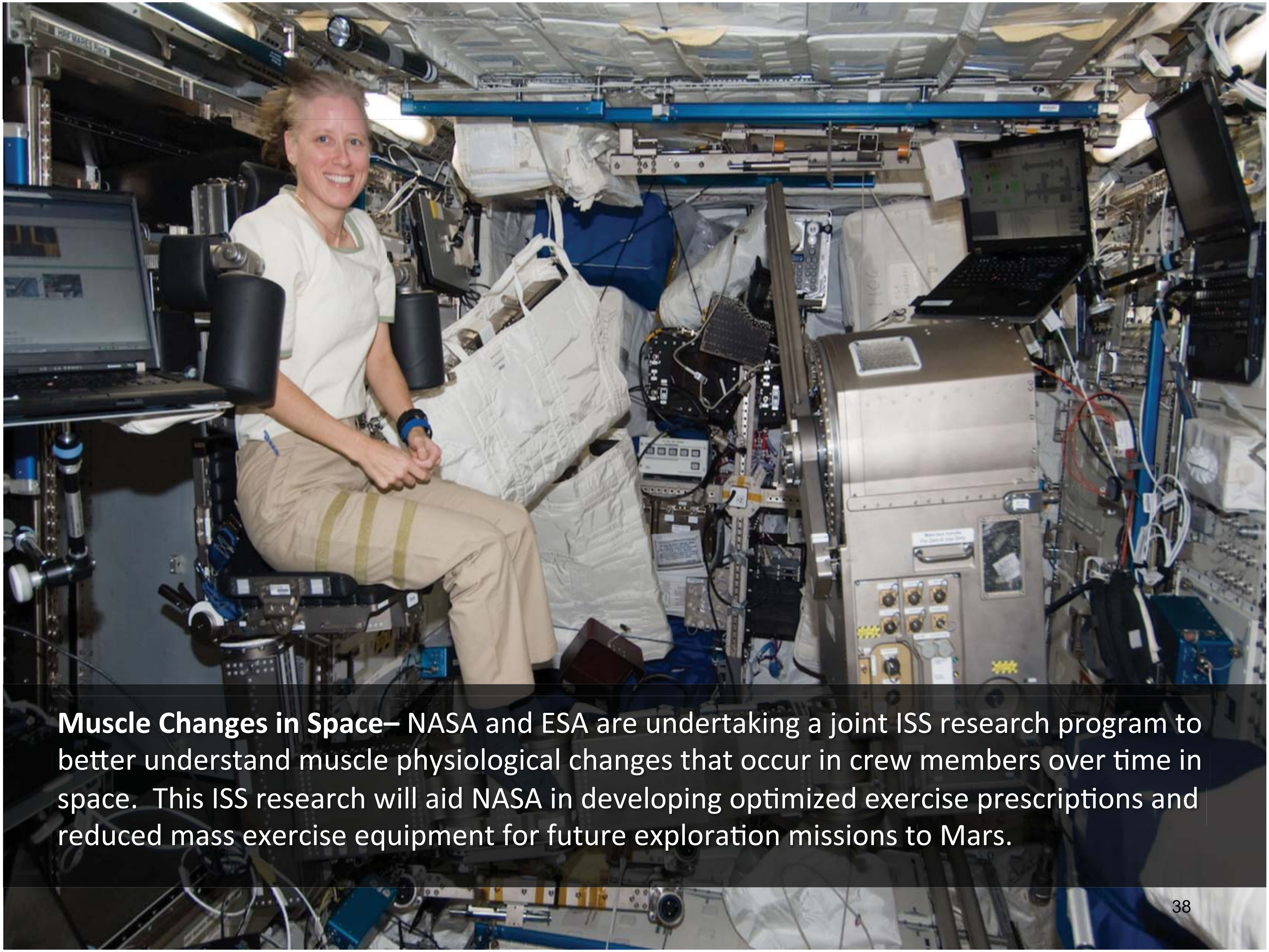
- **Collective impact: muscular atrophy, bone loss, aerobic capacity combined with planned physical activity, unexplored terrains**
- **Decline in human performance increases risk for accidents**

Research Targets

- **Characterize and minimize loss of musculoskeletal mass and strength**
- **Exercise hardware requirements to supply sufficient loads**
- **Countermeasures (hardware and protocols)**
  - Advanced exercise equipment within confines of exploration vehicles
  - Duration effects/thresholds



Mitigating Bone Loss: *Astronauts lost an average of 1.5% bone/month and took 3 years to get back to pre-flight bone density. More effective exercise hardware (ARED) has significantly reduce bone loss and muscle atrophy. Current studies: Bisphosphonates (pharmaceutical), Pro K (nutritional)*



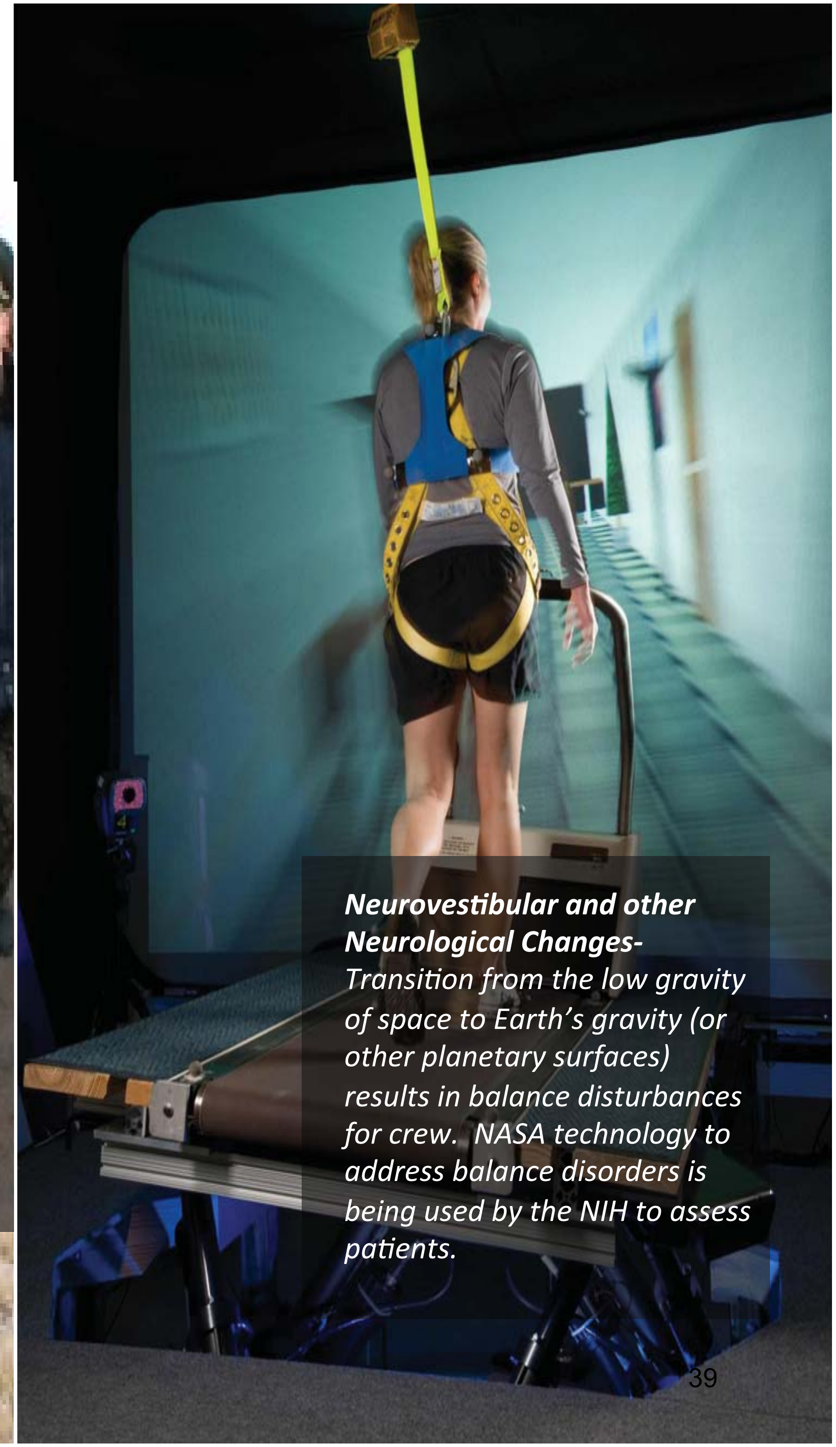
Muscle Changes in Space– NASA and ESA are undertaking a joint ISS research program to better understand muscle physiological changes that occur in crew members over time in space. This ISS research will aid NASA in developing optimized exercise prescriptions and reduced mass exercise equipment for future exploration missions to Mars.

Sensorimotor Exploration Concerns

- **Collective impact: disruptions in gait and neuromuscular control, combined with planned physical activity, unexplored terrains and human behavior**
- **Decline in human performance increases risk for accidents**

Research Targets

- **Risk characterization associated with long-duration missions**
- **Develop sensorimotor countermeasures**
  - Sensorimotor Adaptability Training
  - Sensory Augmentation & Substitution



Neurovestibular and other Neurological Changes- *Transition from the low gravity of space to Earth's gravity (or other planetary surfaces) results in balance disturbances for crew. NASA technology to address balance disorders is being used by the NIH to assess patients.*

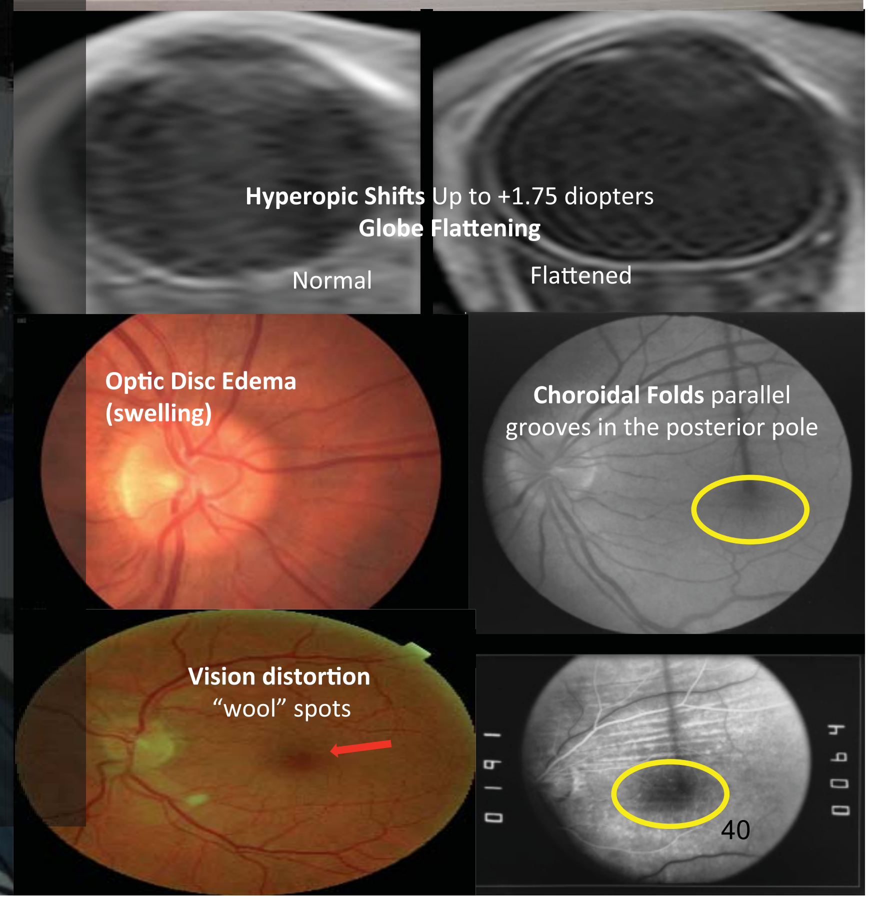
Ocular Impairment Exploration Concerns

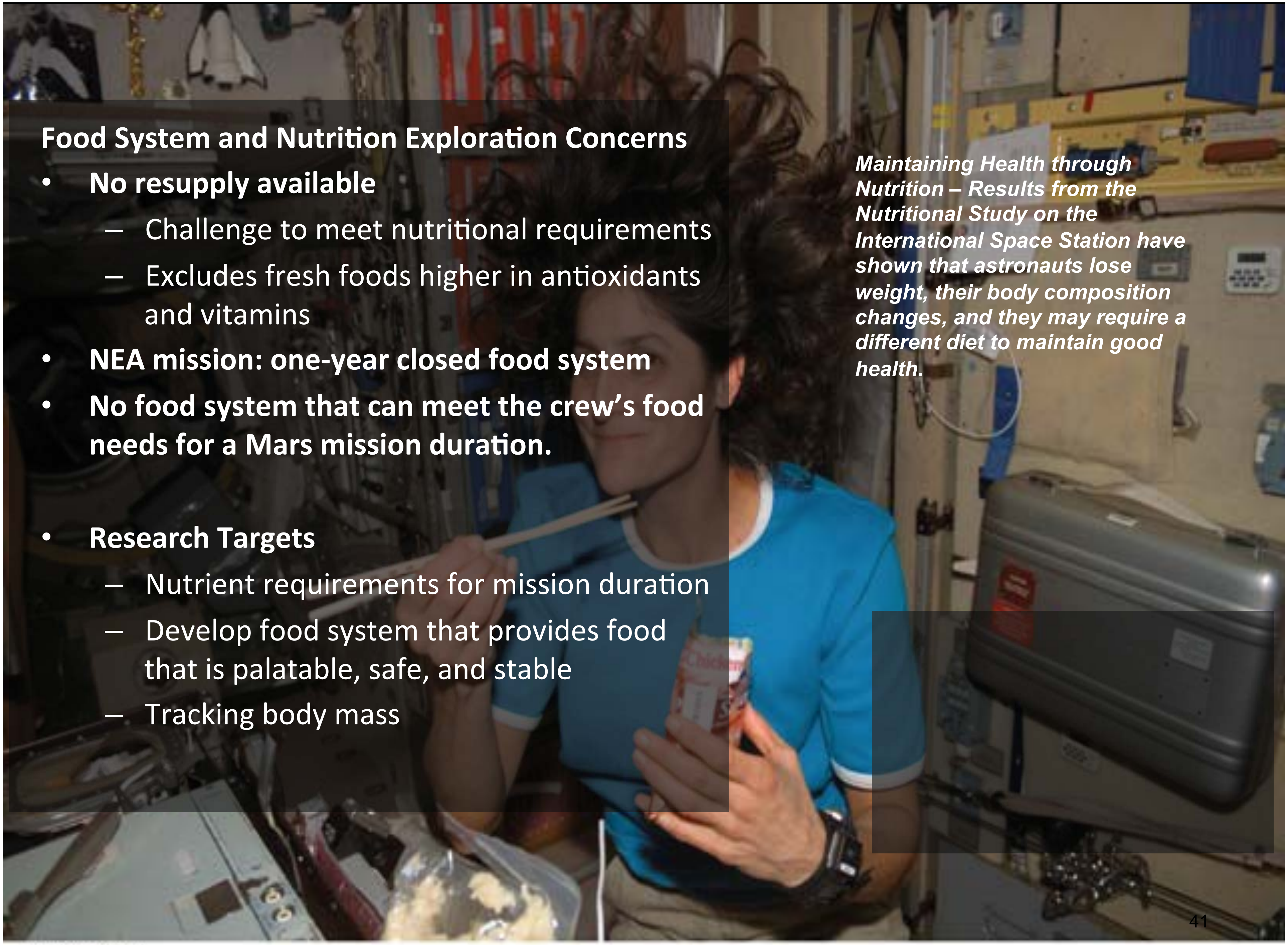
- **Ocular changes and intracranial pressure resulting from exposure to microgravity**
  - Over 50% of Astronauts
- **No countermeasures currently exist**
- **Further research is required to acquire information necessary understanding and develop countermeasures to arrive at an acceptable risk posture.**
- Mission and long-term health risks
  - Ocular Impairment is a factor in crew assignment criteria for ISS-6 missions
  - Lunar missions are rated as insufficient as we are unable to quantify the protective nature of the Lunar gravity

Research Targets

- **Mechanisms and risk factors for Ocular Impairment, Individual susceptibility, Monitoring and Countermeasures**

Addressing Critical Health Issues for Exploration- ISS research is necessary to address a recently discovered health issue related to long duration space exposure. As a result of elevated intracranial pressure in space, visual acuity changes are occurring in over 50% of astronauts.





Food System and Nutrition Exploration Concerns

- **No resupply available**
  - Challenge to meet nutritional requirements
  - Excludes fresh foods higher in antioxidants and vitamins
- **NEA mission: one-year closed food system**
- **No food system that can meet the crew's food needs for a Mars mission duration.**

- **Research Targets**
  - Nutrient requirements for mission duration
  - Develop food system that provides food that is palatable, safe, and stable
  - Tracking body mass

Maintaining Health through Nutrition – Results from the Nutritional Study on the International Space Station have shown that astronauts lose weight, their body composition changes, and they may require a different diet to maintain good health.

ISS014E13728

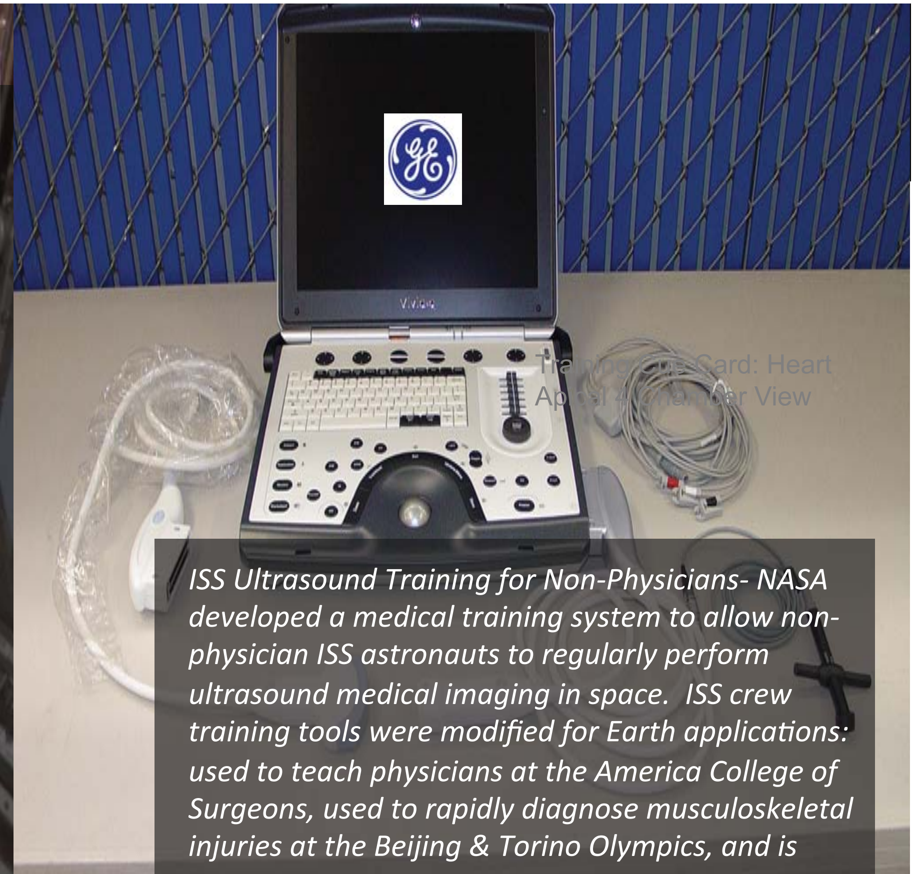
Maintaining Bone Health through Vitamin D Research – NASA and the NSF Antarctic research station study on supplementation of vitamin D in at risk populations to avoid weakened immune function and osteoporosis. Insufficient exposure to the ultraviolet light in sunshine leads to decreased production of Vitamin D and requires astronauts in spaceflight to take supplementation and is important for the elderly. The data was used by the National Academies to update recommended dietary allowances of Vitamin D for the U.S. population.

Autonomous Medical Care Exploration Concerns

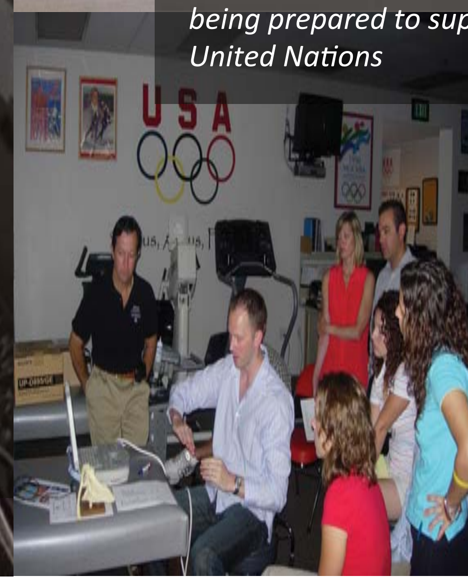
- **Extreme remoteness driving the need for autonomy**
- **Occupational hazards associated with long-duration**
  - Integrated medical model will provide most likely medical events (infection, eye abrasions, wounds, dental conditions, fractures, smoke inhalation, toxic exposure)
  - Conditions arising from frequent EVA: decompression sickness, fingernail delamination and paresthesias and other conditions such as skin abrasions

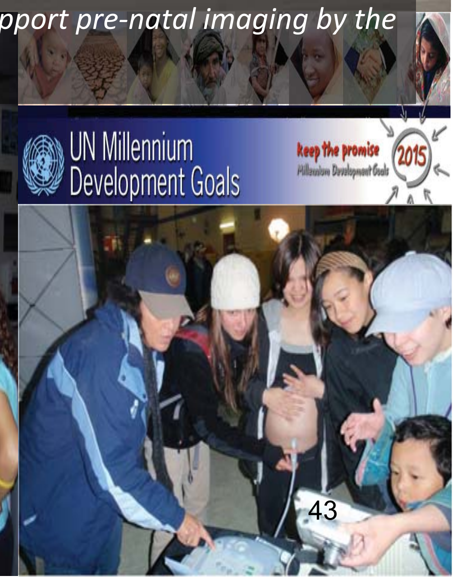
Research Targets

- **Characterize likelihood of mission-related medical risks – medical kits**
- **Develop autonomous medical capabilities for monitoring and treatment**
- **Remote guidance and managing communication delay**



ISS Ultrasound Training for Non-Physicians- NASA developed a medical training system to allow non-physician ISS astronauts to regularly perform ultrasound medical imaging in space. ISS crew training tools were modified for Earth applications: used to teach physicians at the America College of Surgeons, used to rapidly diagnose musculoskeletal injuries at the Beijing & Torino Olympics, and is being prepared to support pre-natal imaging by the United Nations



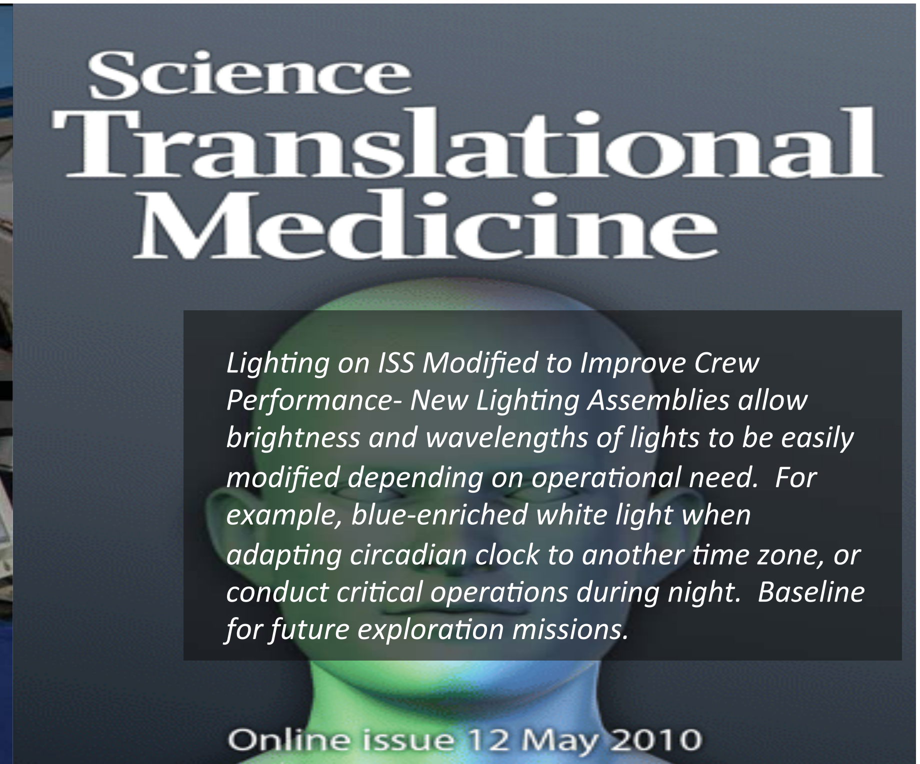


Behavioral Health and Performance Exploration Concerns

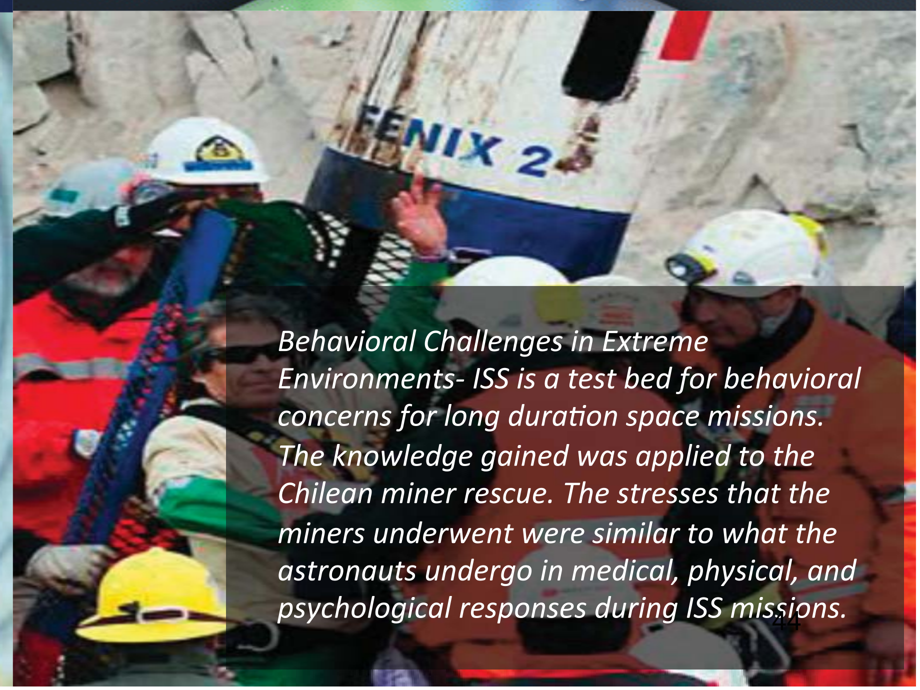
- **Mission duration, remoteness, and isolation**
- **Stability of team dynamics in a constrained environment**
- **Sleep Loss**
  - Increase in autonomous operations adds to fatigue and sleep loss
  - Performance decrements

Research Targets

- **Characterize risk in given exploration environment**
- **Develop diagnostic tools and training methods**
- **Develop countermeasures and an integrated countermeasure suite**



Lighting on ISS Modified to Improve Crew Performance- New Lighting Assemblies allow brightness and wavelengths of lights to be easily modified depending on operational need. For example, blue-enriched white light when adapting circadian clock to another time zone, or conduct critical operations during night. Baseline for future exploration missions.



Behavioral Challenges in Extreme Environments- ISS is a test bed for behavioral concerns for long duration space missions. The knowledge gained was applied to the Chilean miner rescue. The stresses that the miners underwent were similar to what the astronauts undergo in medical, physical, and psychological responses during ISS missions.

Human System Drivers

- **Potentially Mission Duration Limiting**
  - Space Radiation
  - Ocular Impairment
- **Example Major Drivers of DRM Resources (Mass, Power, Volume)**
  - Behavioral Health⇒ Habitable Volume
    - The habitable volume must be large enough and laid out to execute the necessary tasks and to provide a psychologically acceptable space for the long period of confinement. For Mars and NEA, the uncertainty in addressing issues related to expected volume constraints is exacerbated by the longer duration mission.
  - Muscle Atrophy, Cardiovascular Atrophy, Bone Loss⇒ Exercise Equipment
    - Exercise equipment alleviates muscle atrophy, cardiovascular atrophy, and bone loss. The latest equipment deployed on ISS (T2, CEVIS, ARED) occupies 3 ISS Racks.
  - Food⇒ Food Storage and Trash Generation
    - Using current food packaging technology, the amount of food one crew member needs for one year is 670 kg occupying 1.7 m3 (the volume of about three household refrigerators). HRP is currently aiming for 30% and 34% reductions in volume and mass, respectively.
  - Medical Care⇒ Medical Equipment and Supplies
    - HRP's Integrated Medical Model (IMM) simulates medical events during space flight missions and estimates the impact of these events on crew health and mission success. A three-crew, 386 day, asteroid mission simulation with 28, 2-crew EVAs suggests an optimized medical kit having a mass of 62 kilograms and a volume of 0.15 m3.
  - Asteroid/Regolith Characteristics: Dust or Volatiles⇒ ECLSS
    - Permissable exposure limits mitigate the health risks associated with exposure to dust and volatiles. Surface dust or volatile compounds poses a greater environmental risk to the habitable volume. The possibility of such contaminants will necessitate more robust sample handling; sample containment; and environmental treatment and monitoring equipment.