Human Health & Performance (HH&P) ***Risk Assessment and Reduction & Open Innovation for Problem Solving***

Institute for Healthcare Improvement
March 4, 2014

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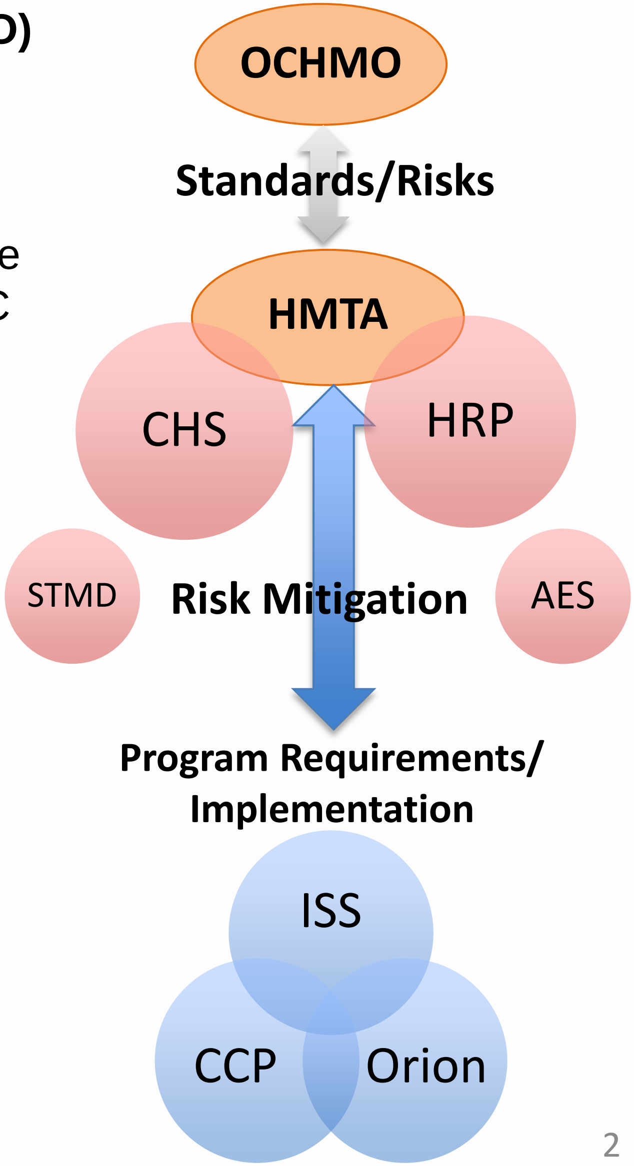
Integrated Risk Mitigation
Crew Health and Safety, Medical Operations, & Research

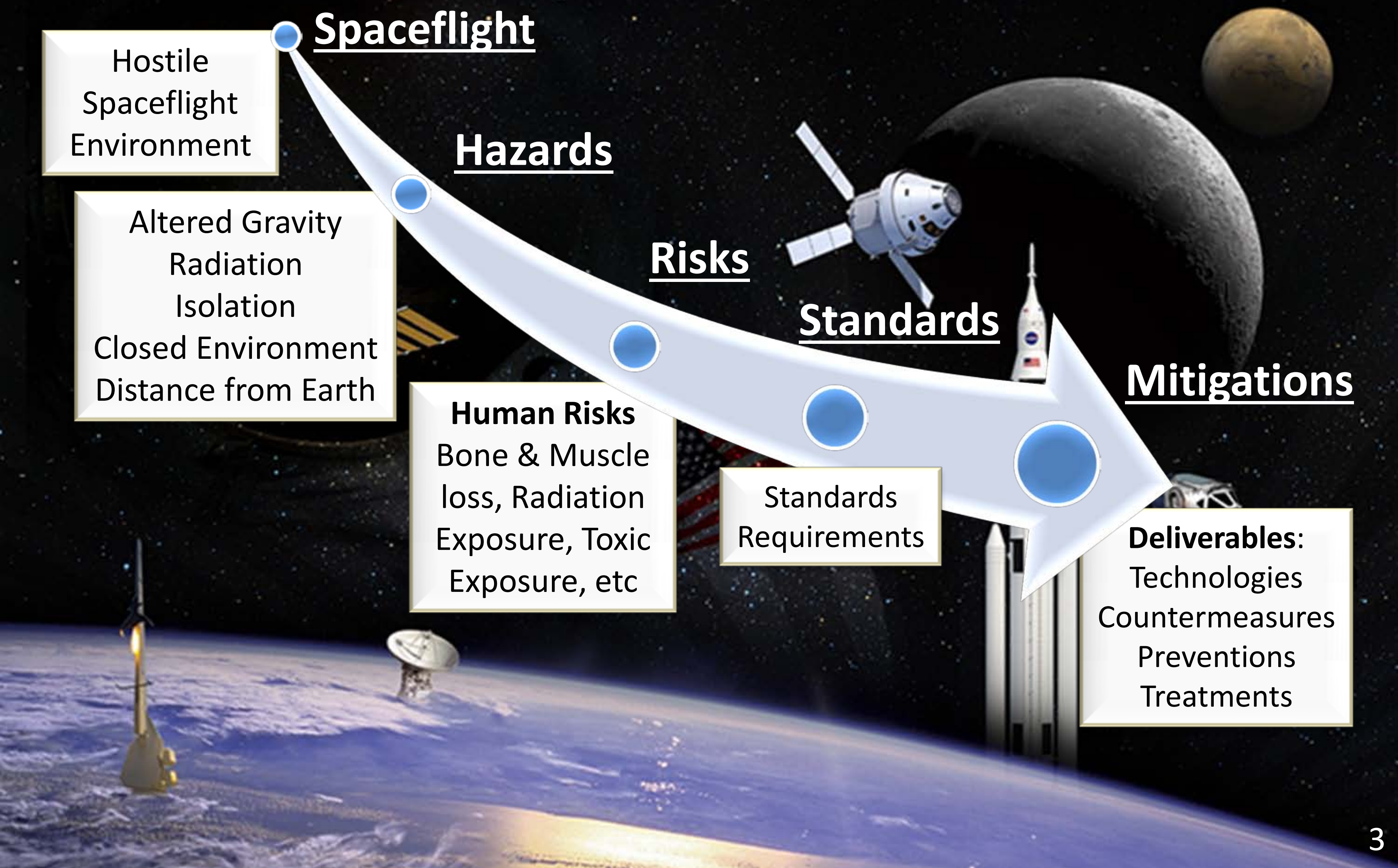
Policy, Operations, and Research are integrated through a Human Health Risk Framework

- **Office of the Chief Health and Medical Officer (OCHMO) – Level I** – NASA HQ
  - Develops Medical Policy, Health and Performance Standards, and Bioethics
  - Risk Assessment and Mitigation - Implemented via the Health and Medical Authority (HMTA) – Level II – JSC
- **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
- **AES & STMD –** Technology/Protocol Development
- **International Space Station (ISS), Orion, Commercial Crew Programs**
  - Implementation of Medical Operations
    - Medical Requirements, Tests and hardware
    - Engineering Requirements



NASA Human Health and Performance

Goal: Enable Successful Space Exploration by Minimizing the Risks of Spaceflight Hazards



Hazards of Spaceflight

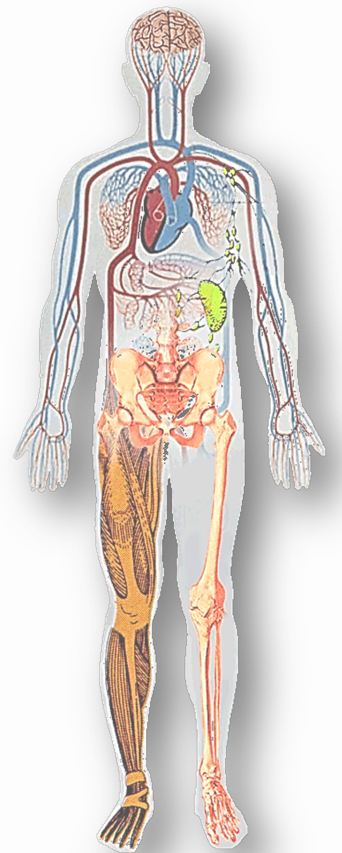
Hazards Drive Human Spaceflight Risks

Altered Gravity - Physiological Changes

Balance Disorders
Fluid Shifts
Cardiovascular Deconditioning
Decreased Immune Function
Muscle Atrophy
Bone Loss

Space Radiation

Acute In-flight effects
Long term cancer risk



Distance from earth

Drives the need for additional "autonomous" medical care capacity – cannot come home for treatment

Hostile/ Closed Environment

Vehicle Design
Environmental – CO_2 Levels, Toxic Exposures, Water, Food

Isolation & Confinement

Behavioral aspect of isolation
Sleep disorders

4

Summary of Human Risks of Spaceflight
Grouped by Hazards – 30 Human Risks, 2 Concern/Watchlist Items

Altered Gravity Field

Primary Effect

1. **Spaceflight-Induced Intracranial Hypertension/Vision Alteration** ★
2. Urinary Retention
3. **Space Adaptation Back Pain**
4. Renal Stone Formation ★
5. **Risk of Bone Fracture due to spaceflight Induced bone changes** ★
6. Impaired Performance Due to Reduced Muscle Mass, Strength & Endurance ★
7. **Reduced Physical Performance Capabilities Due to Reduced Aerobic Capacity** ★
8. Impaired Control of Spacecraft, Associated Systems and Immediate Vehicle Egress due to Vestibular / Sensorimotor Alterations associated with space flight. ★
9. **Cardiac Rhythm Problems** ★
10. Orthostatic Intolerance During Re-Exposure to Gravity ★
11. Adverse Health Effects due to Alterations in Host Microorganism Interaction ★

Concerns/Watchlist

1. **Concern of Clinically Relevant Unpredicted Effects of Medication**
2. **Intervertebral Disc Damage**

Radiation

Primary Effect

1. **Risk of Space Radiation Exposure on Human Health** ★

Distance from Earth

Primary Effect

1. **Unacceptable Health and Mission Outcomes Due to Limitations of In-flight Medical Capabilities** ★
2. Risk of Ineffective or Toxic Medications due to Long Term Storage

Isolation

Primary Effect

1. **Risk of performance decrements due to adverse behavioral conditions** ★

Standards	
★	NASA-STD-3001, VOLUME 1, CREW HEALTH
★	NASA-STD-3001, VOLUME 2, HUMAN FACTORS, HABITABILITY, & ENVIRONMENTAL HEALTH
★	Clinical Practice Guidelines

Hostile/Closed Environment-Spacecraft Design

Primary Effect

1. **Toxic Exposure** ★
2. Acute and Chronic Carbon Dioxide Exposure ★
3. **Hearing Loss Related to Spaceflight** ★
4. Risk of reduced crew performance prior to adaptation to mild hypoxia.
5. **Injury and Compromised Performance due to EVA Operations** ★
6. Decompression Sickness ★
7. **Injury from Sunlight Exposure** ★
8. Incompatible Vehicle/Habitat Design
9. **Risk of Inadequate Human-Machine Interface** ★
10. Risk to crew health and compromised performance due to inadequate nutrition ★ ★
11. **Adverse Health Effects of Lunar (Celestial) Dust Exposure** ★
12. Performance Errors Due to Fatigue Resulting from Sleep Loss, Circadian Desynchronization, Extended Wakefulness, and Work Overload ★
13. **Injury from Dynamic Loads** ★
14. Risk of Altered Immune Response ★
15. **Risk of electrical shock** ★

★ Standards in process of review/change/addition

Health and Medical Policy and Standards

Standards based on best available scientific/clinical evidence & expert recommendations (medical practice, lessons learned, analogue environments, research findings, risk management data)

Policy Document
NPD 8900.5 NASA Health and Medical Policy for Human Space Exploration

Space Flight Health Standard
NASA-STD-3001, VOLUME 1, CREW HEALTH
March 2007, In process of update

Sets standards for fitness for duty, space flight permissible exposure limits, permissible outcome limits, levels of medical care, medical diagnosis, intervention, treatment and care

Human Factors/Environmental
NASA-STD-3001, VOLUME 2, HUMAN FACTORS, HABITABILITY, & ENVIRONMENTAL HEALTH
January 2011

Defines standards for spacecraft (including habitats & suits), and related equipment and software systems with which the crew interfaces during space operations

NASA Crewmember Medical Standards
Volume I, JSC 25396
NASA Astronaut Medical Standards Selection & Annual Medical Certification

Human Integration Design Handbook (HIDH) - NASA/SP-2010-3407

Compendium of human space flight knowledge.
Resource for preparing program-specific requirements.

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

Discipline	Type	Standard
Bone	POL	Maintain bone mass at ≥-2SD
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 80% of baseline muscle strength
Radiation	PEL	≤ 3% REID (Risk of Exposure Induced Death)

FFD - fitness for duty, PEL - space flight permissible exposure limits, POL - permissible outcome limits

Risk of Bone Fracture due to Spaceflight-induced Changes to Bone

Risk Title: Risk of Bone Fracture due to Spaceflight-induced Changes to Bone

Risk Statement: Given that crewmembers may experience a decline in bone mass/strength in microgravity & skeletal adaptation may not be reversible after return to earth, there is an increased possibility of bone fracture during the mission & post mission.

Primary Hazard: μ-gravity	**Secondary Hazard:** radiation, Vehicle design	**Countermeasure:** ***Prevention:*** selection standard, exercise, task design, diet, pharmaceuticals. ***Treatment:*** In-flight treatment/medical kit, meds, post-mission rehabilitation
Contributing Factors: nutrition, visual-neuro-muscular declines, radiation		

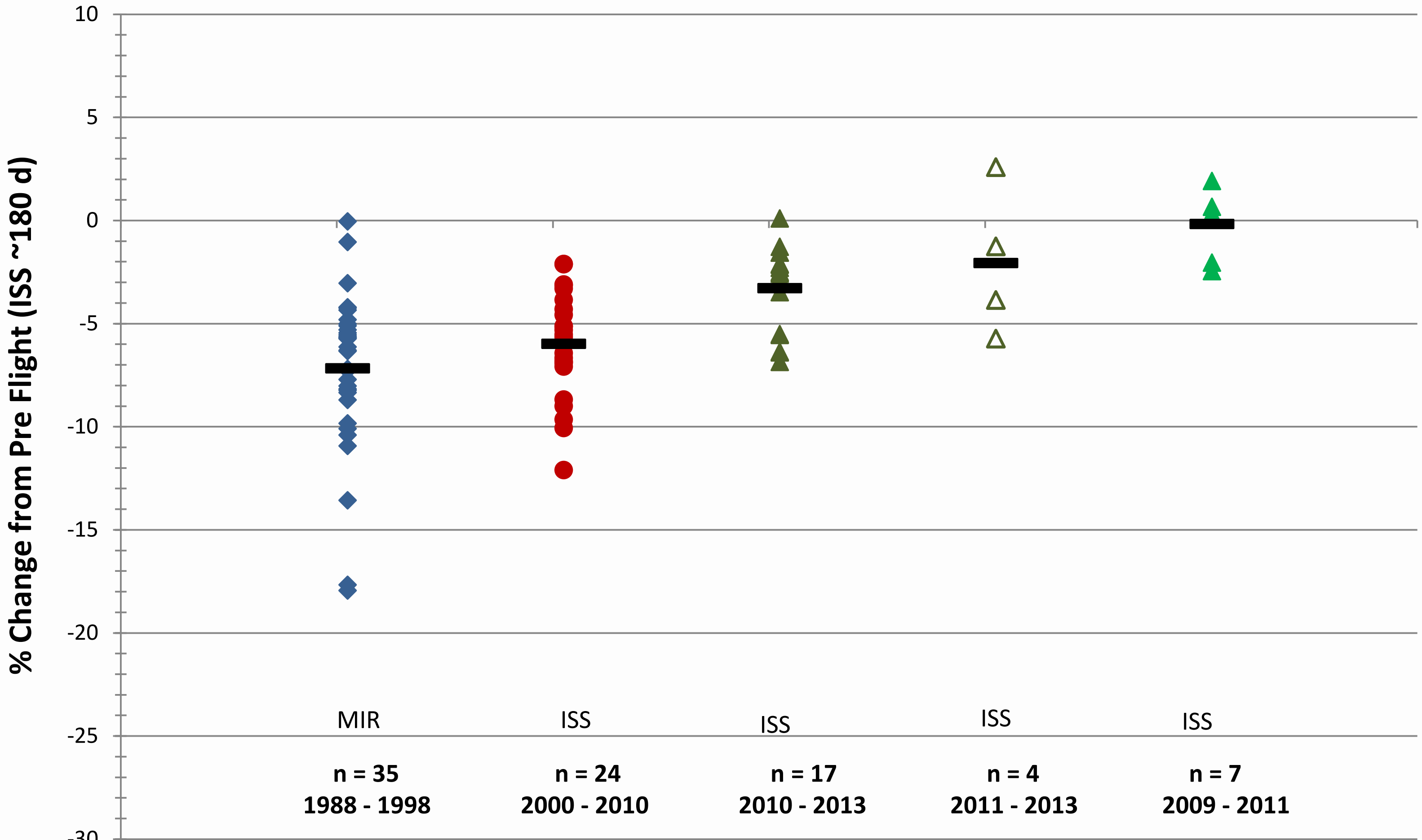
State of Knowledge: Fracture probability dependent upon loading and bone strength. BMD is widely used as a surrogate for bone strength but its sole use recognized to be insufficient for risk assessment. Extensive pre/post flight Bone Mineral Density data. ARED/T2 6 days/week exercise regimens have minimized declines in BMD to meet Permissible Outcome Limits (POL). Changes to trabecular bone, whole bone structure and hip strength estimations are limited to two research studies with and without pharmaceuticals.

Metric

Risk of Bone Fracture due to Spaceflight-induced Changes to Bone

1371B - January 2014 Bone & Mineral Lab Data Analysis

Mean % Change in Total Hip DXA BMD



Countermeasures:	Treadmill	Treadmill - TVIS iRED - 300 lb force 6 days/wk	Treadmill - T2 ARED - 600 lb force 6 days/wk	Treadmill - T2 ARED - 600 lb force 3 days/wk each, high intensity	Treadmill - T2 ARED - 600 lb force 6 days/wk + antiresorptive drug

Design Reference Missions Categories

All of the Human Health and Performance Risks will be evaluated against the following categories:

DRM Categories	Mission Duration	Gravity Environment	Radiation Environment	Earth Return
Low Earth Orbit	6 months	Microgravity	LEO - Van Allen	1 day or less
	1 year	Microgravity	LEO - Van Allen	1 day or less
Deep Space Sortie	1 month	Microgravity	Deep Space	< 5 days
Lunar Visit/Habitation	1 year	1/6g	Lunar	5 Days
Deep Space Journey/ Habitation	1 year	Microgravity	Deep Space	Weeks to Months
Planetary Visit/Habitation	3 years	Fractional	Planetary*	Months

*Planet has no magnetic poles, limited atmosphere

Examples of Missions that would fall into the DRM Categories:

Low Earth Orbit – ISS6, ISS12, Commercial Suborbital, Commercial Visits to ISS, future commercial platforms in LEO
Deep Space Sortie: MPCV test flights, moon fly around or landing, visits to L1/L2, deep space excursion
Lunar Habitation: Staying on the surface more than 30 Days (less than 30 days would be similar)
Deep Space Habitation: L1/L2 Habitation, Asteroid visit, journey to planets
Planetary Habitation: Living on a planetary surface, MARS

Human System Risks – Likelihood vs Consequence

Consequence
Mission Health and Performance (OPS)

High: Death or permanently disabling injury to one or more crew (LOC)
OR
Severe reduction of performance that results in loss of most mission objectives (LOM)

Medium: Significant injury, illness, or incapacitation – may affect personal safety
OR
Significant reduction in performance results in the loss of some mission objectives

Low: Minor injury/illness that is self-limiting
OR
Minor impact to performance and operations- requires additional resources (time, consumables)

Very Low: Temporary discomfort
OR
Insignificant impact to performance and operations - no additional resources required

CM = Countermeasure
LOC = Loss of Crew
LOM = Loss of Mission

Consequence	Likelihood: Low (≤0.1 %)	Likelihood: Medium (<1 %)	Likelihood: High (≥1.0%)
High	1 x 4	2 x 4	3 x 4
Medium	1 x 3	2 x 3	3 x 3
Low	1 x 2	2 x 2	3 x 2
Very Low	1 x 1	2 x 1	3 x 1

Likelihood

Consequence
Long Term Health (post mission) (LTH)

High
- Unknown and improbable return to baseline (requires drastic intervention surgery & therapy)
- Major impact on quality of life (permanent reduced function, premature death)

Medium
- Return to near baseline requires extended medical intervention w/ known clinical methods/technologies (pharmaceuticals, etc.)
- Moderate impact on quality of life

Low
- Return to baseline values within 1 year with nominal intervention (time, exercise, nutrition, lenses)
- Negligible effect on quality of life

Very Low
- Return to baseline values within 3 months with limited intervention
- No effect on the quality of life

Quality of Life is defined as impact on day to day physical and mental functional capability and/or lifetime loss of years

Risk Assessment

Bone Fracture due to Spaceflight-induced Changes to Bone

Countermeasures: ***Prevention:*** selection standard, exercise, task design, diet, pharmaceuticals. ***Treatment:*** In-flight treatment/medical kit, meds, post-mission rehabilitation

L x C Driver: OPS Likelihood all except Planetary : < 0.1% likelihood of bone fracture in mission due to existing countermeasures (prevention by selection) effectiveness. **Planetary:** increases due to mission duration and surface operations. **Consequence LEO, Sortie, Lunar:** Bone fracture considered significant injury with in flight treatment and return to Earth. **Deep Space and Planetary Consequence:** Injury may be disabling due to the inability to return to Earth for treatment. **LTH Likelihood LEO, Lunar, Journey**: Likelihood of fracture due to spaceflight > 0.1% and < 1%. Most crew could return to baseline BMD within 3 years. **Sortie:** Likelihood <0.1% due to limited mission duration. **Planetary:** > 1% due to mission duration. **LTH Consequence:** Bone fracture prevention may require extended medical interventions by known methods

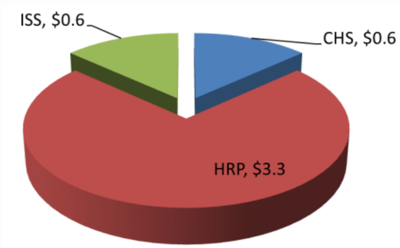
DRM Categories	Mission Duration	L x C OPS	L x C LTH	Risk Evaluation Status
Low Earth Orbit	6 months	1 x 4	2 x 3	Partially Controlled
	1 year	1 x 4	2 x 3	Partially Controlled
Deep Space Sortie	1 month	1 x 4	1 x 3	Partially Controlled
Lunar Visit/ Habitation	1 year	1 x 4	2 x 3	Partially Controlled
Deep Space Journey/Hab	1 year	1 x 4	2 x 3	Partially Controlled
Planetary	3 years	2 x 4	3 x 3	Uncontrolled

Deliverables Required	Responsible Program	Budget ($M)/ (2014-2018)
Knowledge:		
• Surveillance data to supplement bone density with bone quality index	HRP/Grant	$0.25M
• Identify critical risk factors	HRP/Grant	$0.45M
Technology:		
• Develop biomarkers	HRP/Grant	$1.0M
• Need to establish index for CM efficacy	HRP/Contract	$0.05M
• Evaluate pharmacological CMs	HRP/Grant	$1.32M
Operational Protocols:		
• Continued crew monitoring	ISS/CHS/HRP	$1.35M
Guideline/Requirements/Standards:		
• Leverage terrestrial Level 4 Evidence	CHS/HRP	$0.05M

Countermeasures

Total Budget 2014-19 = $4.5M

Note: ISS Exercise H?W – Sustaining, Logistics and Maintenance: $27M



Requirements Flow down – Bone Fracture

Risks

Bone Fracture due to Spaceflight-induced Changes to Bone	Impaired Performance Due to Reduced Muscle Mass, Strength & Endurance	Reduced Physical Performance Capabilities Due to Reduced Aerobic Capacity

Standard(s)

Space Flight Health Standard
NASA-STD-3001, VOLUME 1, CREW HEALTH
March 2007, In process of update

4.2.9.3 The post-flight (end of mission) bone mass DXAT score shall not exceed -2.0 (-2.0 SD below the mean Bone Mineral Density).

Requirements

ISS

SSP 50260 International Space Station Medical Operations Requirements Document - MORD

6.2.4.1 IN-FLIGHT EXERCISE
Daily physical exercise shall be scheduled for each ISS crewmember, consisting of 1.5 hours daily of actual exercise time with varying amounts of resistive and aerobic exercise.

Commercial Crew

CCT-REQ-1130 ISS Crew Transportation Requirements Document

N/A – due to limited duration of mission

MPCV

MPCV Human System Integration Requirements -HSIR

3.5.4.1 Exercise Capability [HS6032]
The system shall provide the capability for aerobic and resistive exercise training for 30 continuous minutes each day per crewmember for missions greater than 8 days.

Risk of Acute and Chronic Carbon Dioxide Exposure

Risk Title: Risk of Acute and Chronic Carbon Dioxide Exposure

Risk Statement: Given CO_2 levels in spacecraft are 6-20 times higher than in the terrestrial atmosphere, there is a possibility that short-term and long-term CO_2 exposures will impact crew health and performance when complex decisions are necessary.

Primary Hazard: Closed Environment - CO_2 (local pockets of high concentration)

Secondary Hazard: Micro-g fluid shift
Dist. from Earth - autonomous ops

Countermeasures: Standards/SMAC Levels - CO_2 scrubbing
Corrective CM: Ground Control and Monitoring.

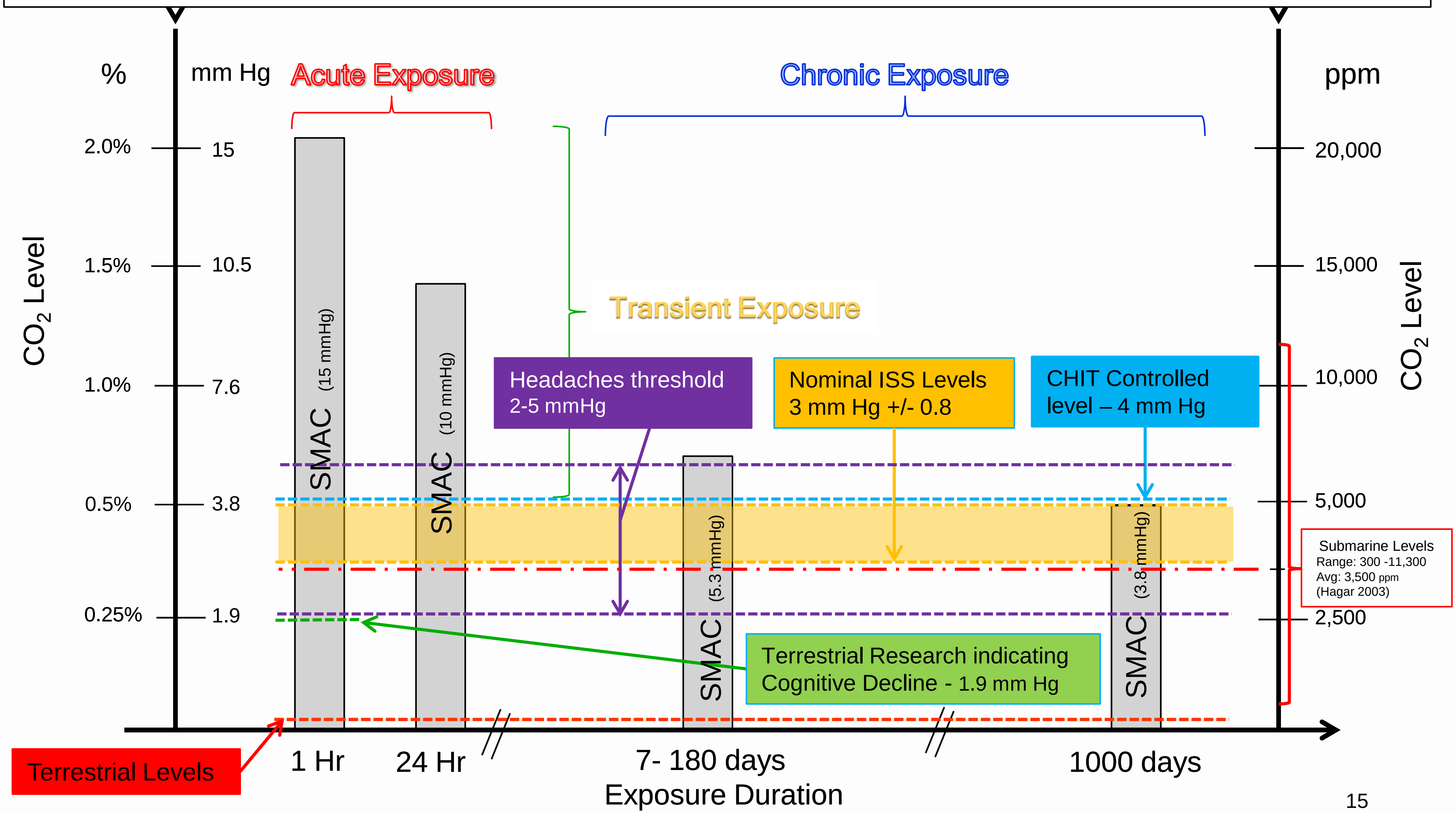
Contributing Factors: 1) Microgravity-related lack of convection and air circulation, 2) Limited carbon dioxide removal capability, 3) genetic factors. Elevated CO_2 concentration appears to be a contributing factor to other risks*

State of Knowledge: Terrestrial evidence indicates that current standards for CO_2 exposures via SMACs, Flight Rules, and CHITs may not be adequate to mitigate neuro-cognitive effects. Additionally, ISS data suggest a higher incidence of headaches with acute increases of CO_2 over the range of 2 to 5 mmHg, with resultant "p" values so small indicating statistical significance with regard to the association of headaches and CO_2 levels.

*Areas of Concern:
Crew Headaches
Contribution to Intracranial Pressure Increase – Vision Impairment/ICP
Possible Cognitive Impacts

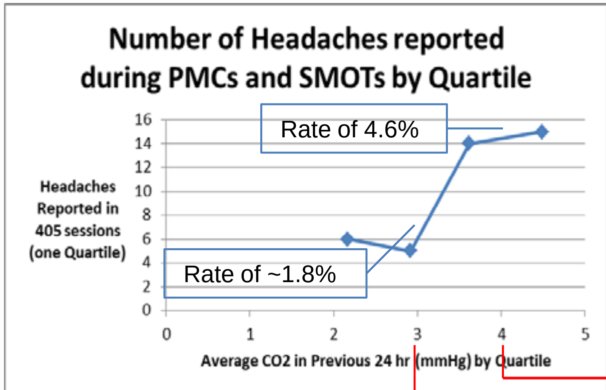
Risk of Acute and Chronic Carbon Dioxide Exposure

Risk Statement: Given CO_2 levels in spacecraft are 6-20 times higher than in the terrestrial atmosphere, there is a possibility that short-term and long-term CO_2 exposures will impact crew health and performance when complex decisions are necessary. Coupled with microgravity fluid shift may compound the effects.

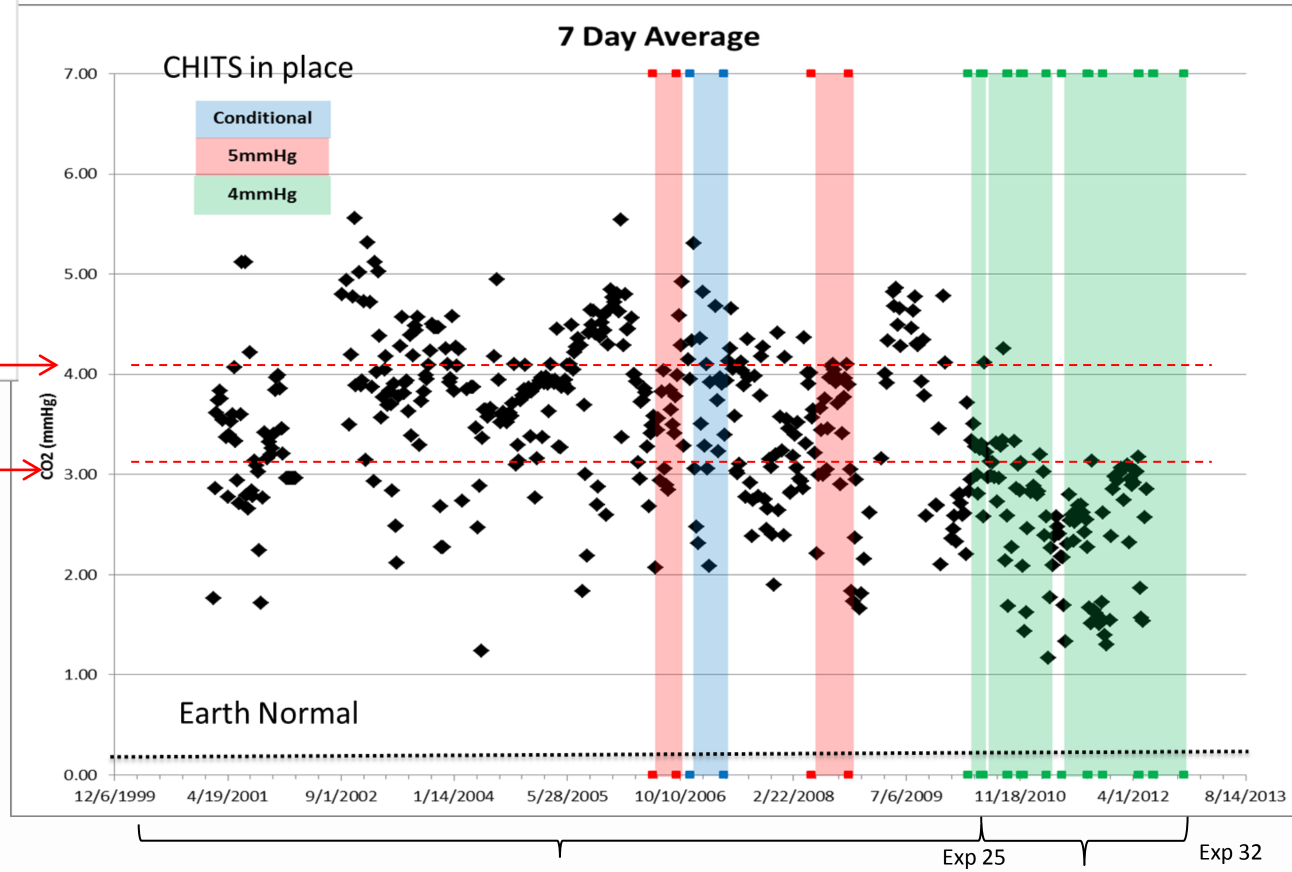


Risk of Acute and Chronic Carbon Dioxide Exposure

Headaches that were not alleviated by Analgesics



Weekly Average CO_2 Level



The following was observed since 2001:

- 46 headaches that were not alleviated by analgesics were observed
- 1670 non-headaches were observed
- **Prior to the 2010 CHIT**
  - 25 headaches were observed
  - 518 non-headaches were observed
  - Rate of 4.6%
- **Post 2010 CHIT**
  - which lowered the level to < 4 mm Hg
  - 21 headaches were observed
  - 1152 non-headaches were observed
  - Rate of 1.8%

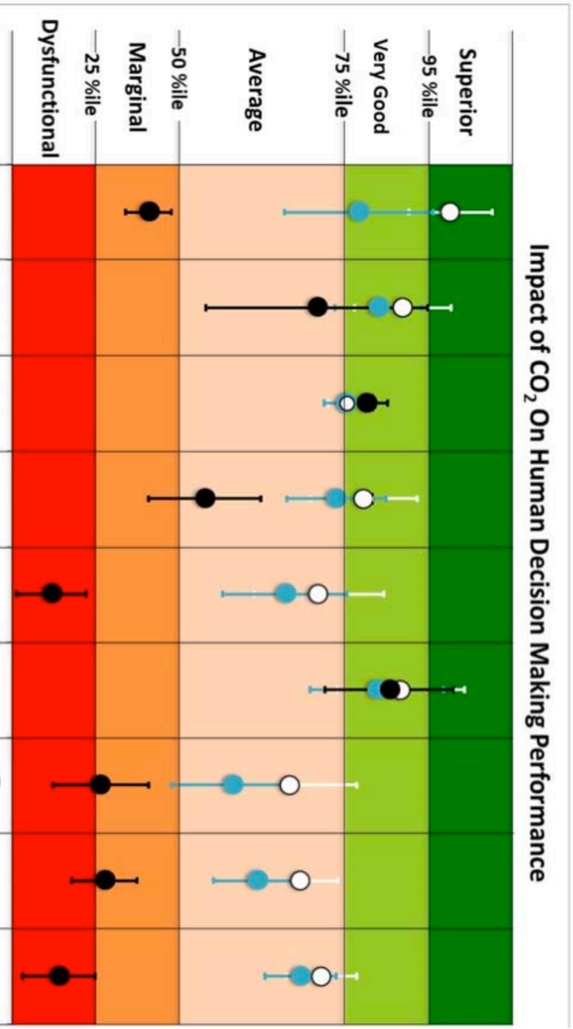
VIIP Occurrence		
	32% no symptoms 31% Class 2 27% with disk edema (CPG Class 3 &4) 18% Class 4 N=22	22% no symptoms 44% Class 2 22% with disk edema (CPG Class 3&4) 0% Class 4 N = 9

CO_2 Exposures - Acute - Cognitive Function

Decision-Making Decrements (Satish et al. 2012)

● 2500 ppm CO2	● 1000 ppm CO2	○ 600 ppm CO2
0.25% (1.9 mmHg)	0.10% (0.8 mmHg)	0.06% (0.5 mmHg)

Varimax Factors Descript	Factors (based upon analytic varimax rotation)
Number of actions	Basic Activity
Opportunistic actions	Applied Activity
Level of activity that pertains to a specific task	Focused Activity
Focus on concurrent task demands	Task Orientation
Ability to generate activity w/o an overt external stimulus	Initiative
Open to seeking new information	Information Orientation search
Ability to utilize information effectively	Information Utilization
Ability to think along multiple dimensions to find different solutions to problems	Breadth of Approach
Ability to form systematic plans and actions that are optimally sequenced and goal-directed in the long term	Basic Strategy



Relevance to Operations:

- Decision Making
- Situational Awareness

The Challenge of Aviation Emergency and Abnormal Situations

Barbara K. Burian, Immanuel Barshi and Key Dismukes

when experiencing <u>stress and high workload</u>, crews are vulnerable to <u>missing important cues related to their situation</u> and are likely to experience <u>difficulty pulling together disparate pieces of information and making sense of them</u>. This is especially true when some of that information is incomplete, ambiguous, or contradictory. Pilots' <u>problem-solving abilities may be impaired</u>, and they will generally have difficulty performing complex mental calculations (Hendy, Farrell, & East, 2001)… In contrast, <u>well-learned motor skills</u>, such as those demonstrated by experienced pilots when operating flight controls, <u>are quite robust and are much less affected by stress</u> (Cohen & Weinstein, 1981).

See Slides 50 & 51: Skill v. Prob. Solving

Risk of Acute and Chronic Carbon Dioxide Exposure

Countermeasures: Preventive: Standards/SMAC Levels - CO_2 scrubbing
Treatment/Corrective CM: Ground Control and Monitoring.

LxC Driver: Based on cognitive function impairment and lack of awareness of such inability, the consequences could be severe reduction of performance resulting in loss of most mission objectives for LEO, Lunar Missions, and Deep Space Sortie. For Deep Space Journey/Hab and Planetary missions, it could lead to LOC.
Primary LxC Driver – Access to Ground Communication. **Is this sufficient to mitigate risk?**

DRM Categories	Mission Duration	L x C OPS	L x C LTH	Risk Evaluation Status
Low Earth Orbit	< 180 days	3 x 2	3 x 1	Partially Cont.
	> 180 days	3 x 2	3 x 1	Partially Cont.
Deep Space Sortie	< 30 days	3 x 3	3 x 1	Partially Controlled
Lunar Visit/ Habitation	> 30 Days	3 x 2	3 x 1	Partially Controlled
Deep Space Journey/Hab	<365 Days	3 x 4	3 x 1	Uncontrolled
Planetary	>365 Days	3 x 4	3 x 1	Uncontrolled

Deliverables Required	Responsible Program/Mechanism	Budget ($M)/Timeline (2013-2018)
Knowledge:		
• Cognitive Function	TBD	TBD
• ICP Impacts	TBD	*TBD*
Technology:		
• Amine Swing bed		
• Advance ECLSS		
Countermeasures – **Operational Protocols:**		
• Flight Rule Changes		
• Operational Changes	ISS/MPCV/CCP	In-work 2014
	ISS	In Work 2014
Countermeasures – **Guideline/Requirements/Standards:**		
• SMAC Levels Updates (Standards)	ISS	

Uncontrolled (Rationale):

1. Ground data → Dysfunctional decision making at CO_2 exposures half the current ISS CHIT Levels of 4mmHg, which may explain ISS historical accounts of decision making errors.
2. Flight crews unable to recognize decision making impairment thereby increasing risk during autonomous mission phases
3. Suggestive evidence → incidence of reported headaches on ISS is associated with higher 24-h average CO_2 levels well below the CHIT.

Requirements Flow down – Risk of Acute and Chronic Carbon Dioxide Exposure

Risks

- Risk of performance decrements due to adverse behavioral conditions
- Risk of Acute and Chronic Carbon Dioxide Exposure
- Spaceflight-Induced Intracranial Hypertension/Vision Alteration

Standard(s)

Human Factors/Environmental
NASA-STD-3001, VOLUME 2, HUMAN FACTORS, HABITABILITY, & ENVIRONMENTAL HEALTH

6.2.1.3 Carbon Dioxide Levels [V2 6004]
CO2 levels shall be limited to the values stated in the tables located in JSC 20584, Spacecraft Maximum Allowable Concentrations for Airborne Contaminants.

Requirements

ISS

- International Space Station ISS Flight Rules

Flight Rule B13-53 (“PPCO$_2$ Constraints”) prescribes required actions when station ppCO$_2$ levels approach or exceed the permissible exposure limit of 7.6 mm Hg. CHIT – 4.0 mmHg

Flight Rule B13-251 (“EMU PPO$_2$ and PPCO$_2$ Constraints”)

Commercial Crew

CCT-REQ-1130 ISS Crew Transportation Requirements Document

Table 3.10.11.1.1-1: Atmospheric Habitability Limits
d. Cabin ppCO2 Maximum: 4.0 mmHg (0.077 psia)

MPCV

MPCV 70024 Human Systems Integration Requirements -HSIR

3.2.1.1 HS3004C The system shall maintain the partial pressure of carbon dioxide in the internal atmosphere to less than 4.0 mmHg (0.077 psia) average over any 1-hour time frame.

NASA Human Health and Performance (HH&P) Strategy Formulation and Execution

Formulating and Executing our Strategy

- Strategic Plan (2007 and 2012)
  - Develop an improved business model using collaborative approaches to drive health innovations in space and on Earth
- Benchmark to inform implementation
  - Culture change most critical for success
  - Collaboration needed to drive innovation
- Successful open innovation pilots testing new approaches to solving technical problems
- NHHPC, NTL and CoECI: virtual centers built to advance collaboration and the use of open innovation
- Solution Mechanism Guide (SMG) Tool to integrate new tools into HH&P culture

Human Health and Performance Directorate

HH&P Organization

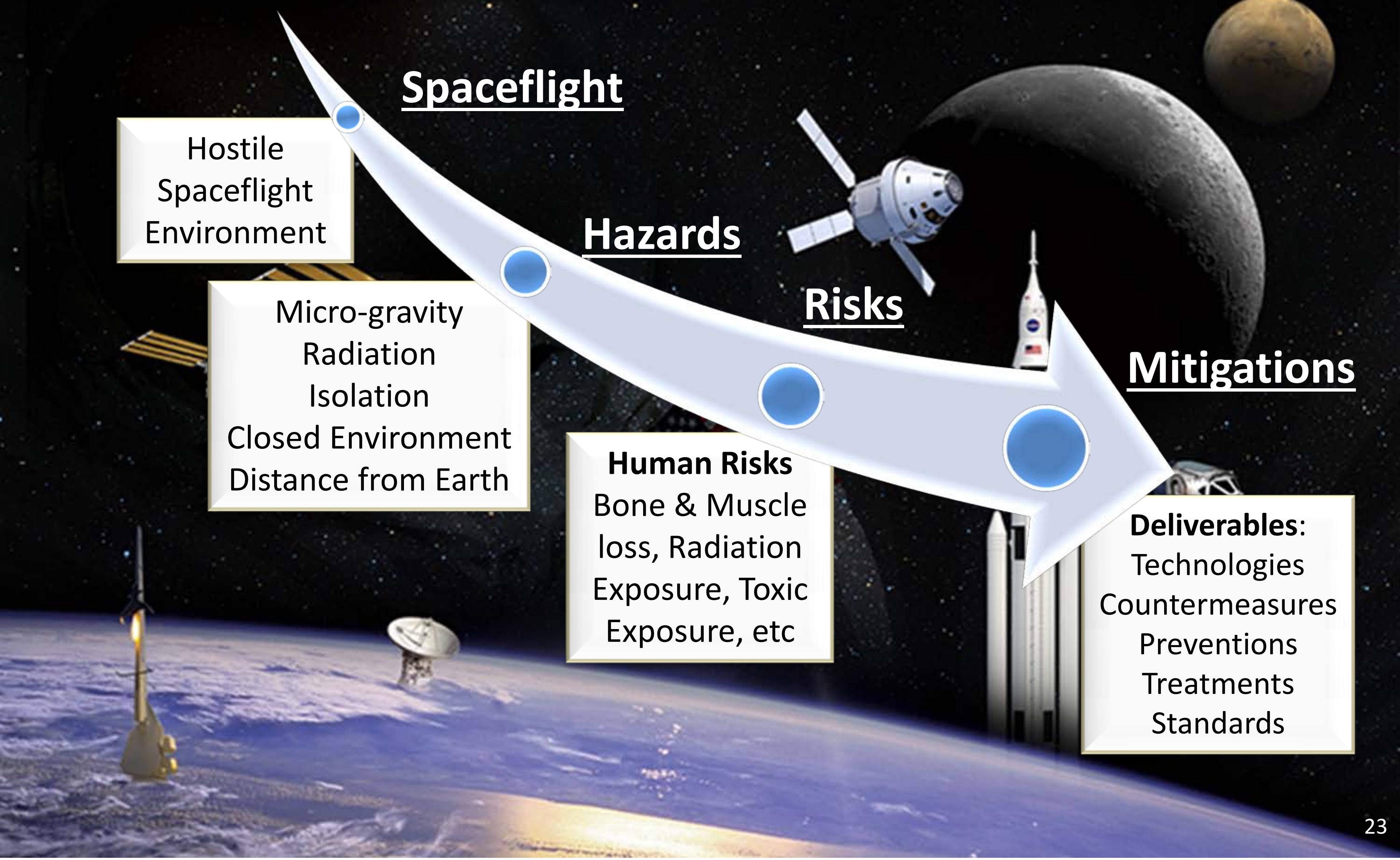
– Space and Clinical Operations
  - Health care and medical systems

– Biomedical Research and Environmental Sciences
  - Physiological, environmental and behavioral effects of spaceflight

– Human Systems Engineering and Development
  - Human centered design (hardware/software), human factors, food systems

NASA Human Health and Performance

Goal: Enable Successful Space Exploration by Minimizing the Risks of Spaceflight Hazards



Risk Assessment
Bone Fracture due to Spaceflight-induced Changes to Bone

Countermeasures: *Prevention:* selection standard, exercise, task design, diet, pharmaceuticals. ***Treatment:*** In-flight treatment/medical kit, meds, post-mission rehabilitation

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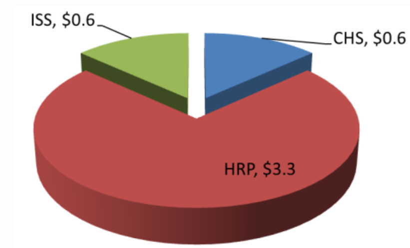
Deliverables Required	Responsible Program	Budget ($M)/ (2014-2018)
Knowledge:		
• Surveillance data to supplement bone density with bone quality index	HRP/Grant	$0.25M
• Identify critical risk factors	HRP/Grant	$0.45M
Technology: (Countermeasures)		
• Develop biomarkers	HRP/Grant	$1.0M
• Need to establish index for CM efficacy	HRP/Contract	$0.05M
• Evaluate pharmacological CMs	HRP/Grant	$1.32M
Operational Protocols: (Countermeasures)		
• Continued crew monitoring	ISS/CHS/HRP	$1.35M
Guideline/Requirements/Standards: (Countermeasures)		
• Leverage terrestrial Level 4 Evidence	CHS/HRP	$0.05M

Total Budget 2014-19 = $4.5M

Note: ISS Exercise H?W – Sustaining, Logistics and Maintenance: $27M



Portfolio Analysis: Models of Collaboration

The Four Ways to Collaborate

There are two basic issues that executives should consider when deciding how to collaborate on a given innovation project: Should membership in a network be open or closed? And, should the network's governance structure for selecting problems and solutions be flat or hierarchical? This framework reveals four basic modes of collaboration.

PARTICIPATION	GOVERNANCE: Hierarchical	GOVERNANCE: Flat
Open	**Innovation Mall** A place where a company can post a problem, anyone can propose solutions, and the company chooses the solutions it likes best ***Example:*** *InnoCentive.com website, where companies can post scientific problems*	**Innovation Community** A network where anybody can propose problems, offer solutions, and decide which solutions to use ***Example:*** *Linux open-source software community*
Closed	**Elite Circle** A select group of participants chosen by a company that also defines the problem and picks the solutions ***Example:*** *Alessi's handpicked group of 200-plus design experts, who develop new concepts for home products*	**Consortium** A private group of participants that jointly select problems, decide how to conduct work, and choose solutions ***Example:*** *IBM's partnerships with select companies to jointly develop semiconductor technologies*

Gary Pisano,
Harvard Business School

HARVARD BUSINESS REVIEW • DECEMBER 2008

NASA Innovation Projects:

Elite Circle

HH&P Elite Circle Projects

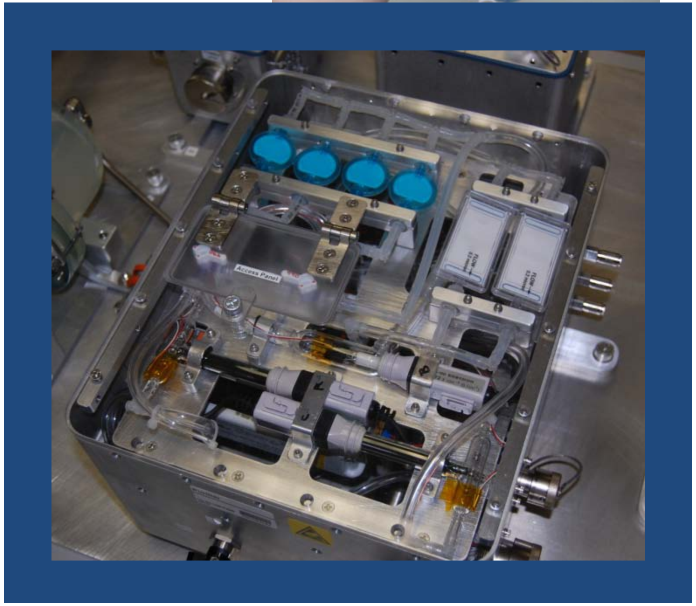
- Intravenous fluid from potable water
- Modified technology – colorimetric water analysis (formerly a device to evaluate paint color)

Exploration Medical Capability

IntraVenous fluid GENeration for exploration (IVGEN)

PRODUCE USP GRADE 0.9% NORMAL SALINE FROM *IN SITU* RESOURCES

- IV fluid required to respond to medical contingencies
- Filter to generate fluid incurs a smaller mass and volume cost than the actual fluid
- System based on deionization and sterilizing filters



FLIGHT TEST: MAY 4-7, 2010

28

Environmental Monitoring: Colorimetric Water Quality Monitoring Kit

Hardware Description

- Solution is a simple, compact, hand-held device that reliably and rapidly measures key water quality indicators in-flight
- Water sample is passed through membrane cartridge resulting in color change on membrane surface in the presence of silver or iodine
- Commercially available Diffuse Reflectance Spectrophotometer (DRS) measures magnitude of color change, which is proportional to the amount of analyte present in sample volume
- **CSPE water quality monitoring kit was delivered to ISS on STS 128/17A**

HH&P Open Innovation Pilot Projects:

Innovation Malls, Innovation Communities, and Consortiums

Open Innovation

- Why Open Innovation?
  - Joy's Law
    - "No Matter Who You Are, Most of the Smartest People Work for Someone Else"
      – Bill Joy, Cofounder Sun Microsystems
  - The Causal Explanation for Joy's Law
    - Knowledge is unevenly distributed in society - Fredrich von Hayek (1945)
    - Knowledge is sticky - Eric von Hippel (1994)
      – from Karim Lakhani, PhD   Harvard Business School

Portfolio Analysis

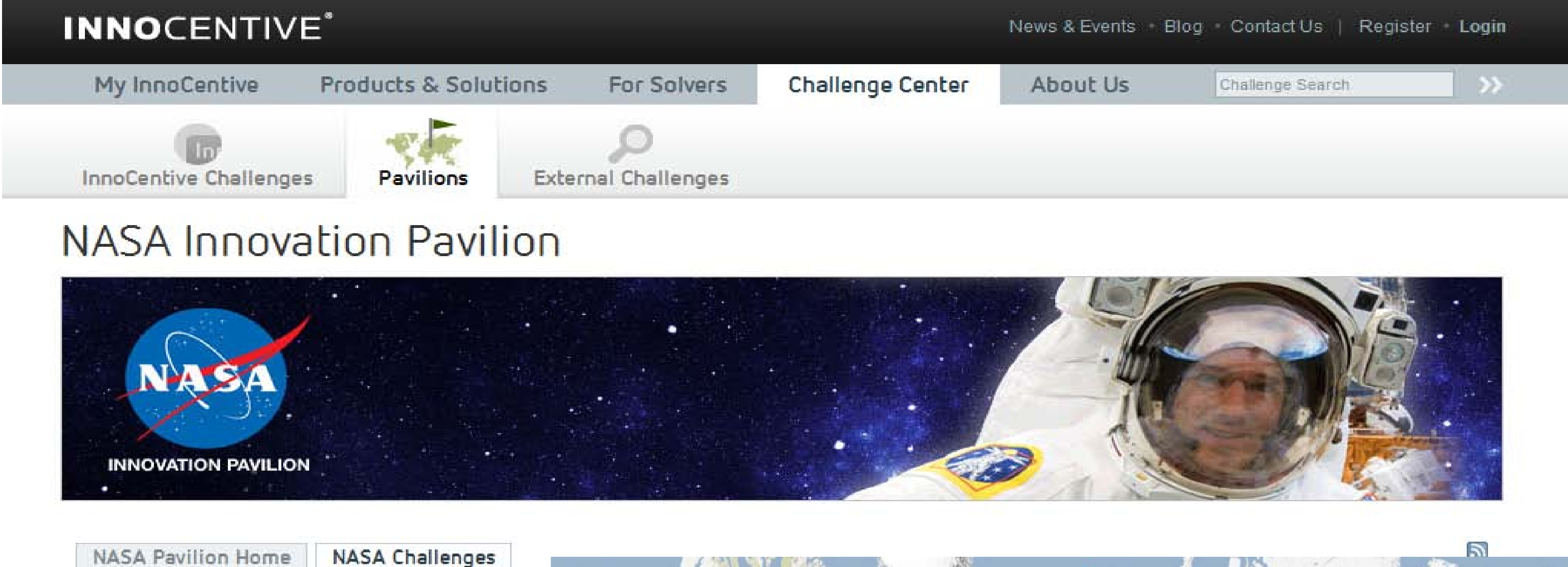
- HH&P Research and Technology Development Portfolio Gaps
  - Food packaging to maintain quality for 5 years
  - Compact (one cubic foot, 20 pound) exercise device for capsules
  - Solar proton event predictive capability for 24 hours
  - Coordinated sensor swarms for planetary research
  - Accurate tracking of medical consumables in flight
  - Motivational enhancement for exercise
  - Inflight laundry system

Open Innovation Pilot Projects

- **InnoCentive**: posts individual challenges/gaps to their established network of solvers (~300,000)
  - financial award if the solution is found viable by the posting entity
- **Yet2.com**: acts as a technology scout bringing together buyers and sellers of technologies
  - Option to develop partnerships
- **TopCoder**: open innovation software company with a large network of solvers (~300,000)
  - variety of skill-based software coding competitions
- **NASA@work**: internal collaboration platform leveraging expertise found across NASA's 10 centers

HH&P Open Innovation Pilot Projects:

Innovation Malls, Innovation Communities, and Consortiums



Global Appeal-

2900 solvers

80 Countries

InnoCentive Successes

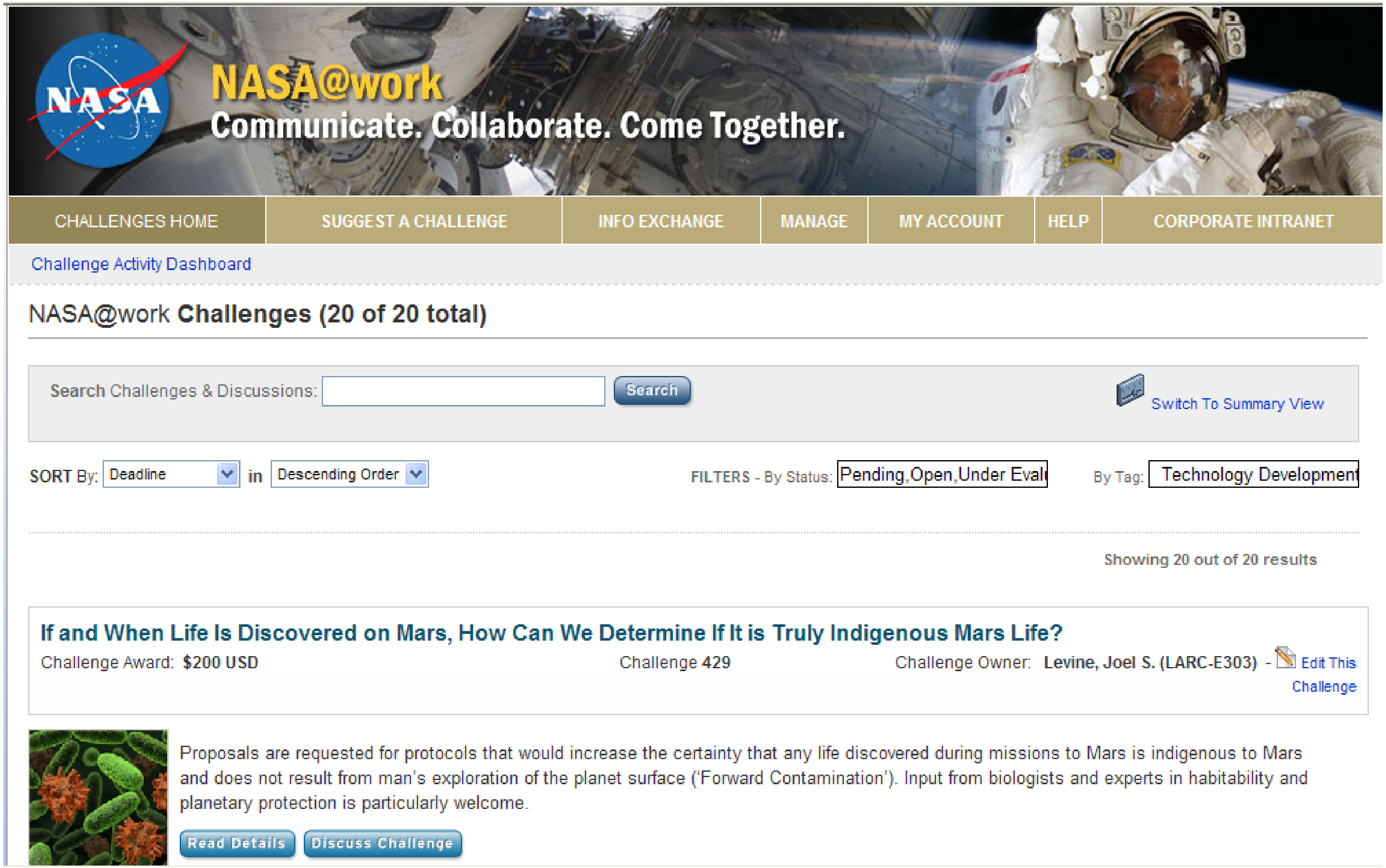
Challenge	TRL*	Submissions	Award
Data-Driven Forecasting of Solar Events (D. Fry) ➢ Resulting model showed a high percent correct (~95%) but with an equally high false alarm rate. Potential for coupling with other modeling efforts	Low	11	$30,000
Non-invasive Meas of Intracranial Pressure (S. Villarreal) ➢ Resulted in a predictive algorithm from UCLA using available physiologic data. Site visit planned to assess UCLA analysis of NASA data via modification of existing NSBRI study.	Med	638	$15,000
Compact Aerobic Resistive Exercise Device Mech (L. Loerch) ➢ Technology was included in Advanced Exercise Concepts trade space for consideration	Low	95	$20,000
Food Packaging and Protection (M. Perchonok) ➢ Monitoring other packaging team evaluations of flexible graphene material proposed as solution	Med	22	$11,000 (partial)

***TRL = Technology Readiness Level**
Low (1-3), Med (4-6), High (7-9)

TopCoder Pilot Project

- Opportunity presented to NASA by Harvard Business School
  - Research project to compare outcomes of collaborative and competitive teams
  - NASA provided the problem statement
    - Optimize algorithm that supports medical kit design
- Competition began in Nov 2009 and lasted approximately 10 days
  - 2800 solutions were submitted by 480 individuals
  - Useful algorithm developed and incorporated into NASA model
  - Team felt this process was more efficient than internal development
- Result: NASA Tournament Lab with HBS and TopCoder established to seek many novel optimization algorithms for ISS

NASA@work Pilot Project



NASA@work Successes

- Pilot conducted in 2010 and fully operational platform launched in 2012
- Connects 10 NASA centers and offers access to previously untapped expertise
- Enthusiastic response to new business model

Challenges (since Aug 2011)

- Number of Challenges: 27
- Winners to Date: 57
- Average Number of Posts per Challenge: ~36

NASA@work Community (as of July 2013)

- Solvers: 10,036
- Active Solvers: >500

Other HH&P Strategic Initiatives

- Rice Business Plan Competition
  - 42 MBA/technical student teams
  - Offered life science prize for earth/space benefits
    - 5 teams awarded since 2008
    - 2 teams have secured funding
      - Series A funding
      - USDA grant
- LAUNCH (NASA HQ)
  - Early stage technologies identified
  - Netra (MIT Media Lab)

Building upon Pilot Success:
NASA HH&P and Agency Outcomes

The NASA Human Health and Performance Center (NHHPC)

A global convener of government, industry, academic, and non-profit organizations to advance human health and performance innovations to enable space exploration and benefit life on Earth

130+ Member Organizations

➢ *Established Oct 2010*

Engagement Activities

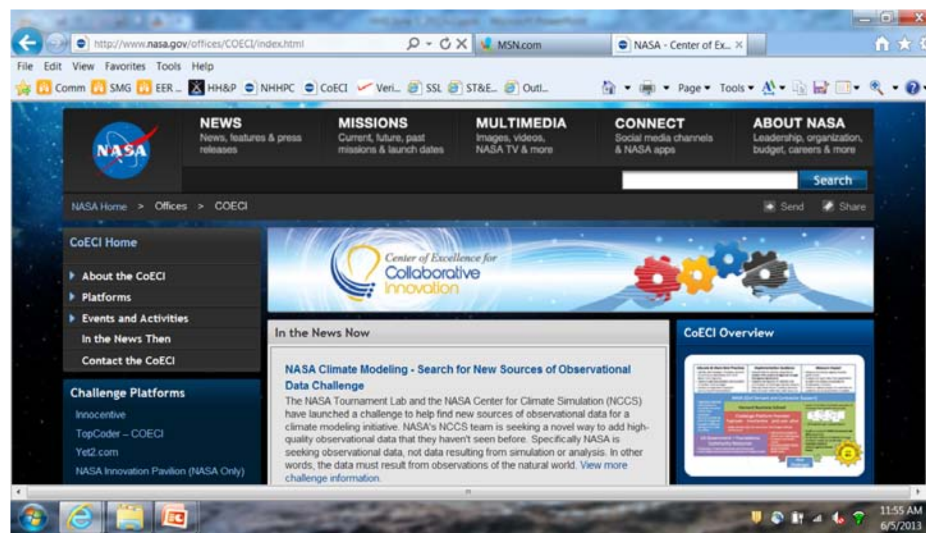
- Annual workshops
- Webcasts: Innovation Lecture Series and Member to Member Connects
- Website postings
- Quarterly NHHPC eNews
- Technical needs postings tied to existing Tech Watch process

The NTL and CoECI

Advancing open innovation in the federal government

- NASA Tournament Lab (NTL)
- NASA Center of Excellence for Collaborative Innovation (CoECI)

- *Established 2010*



- *Established 2011*

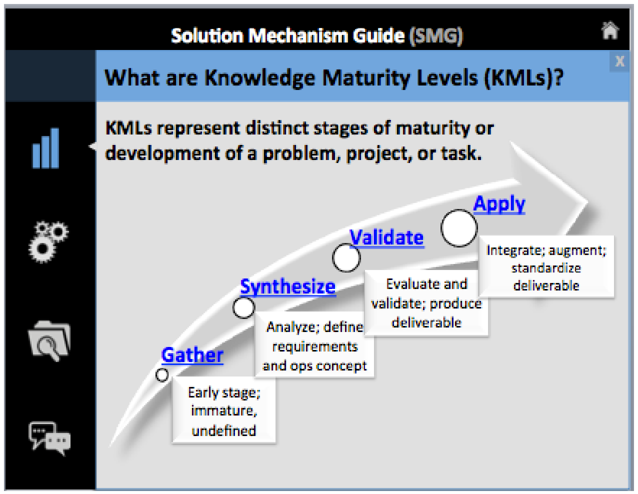
Solution Mechanisms

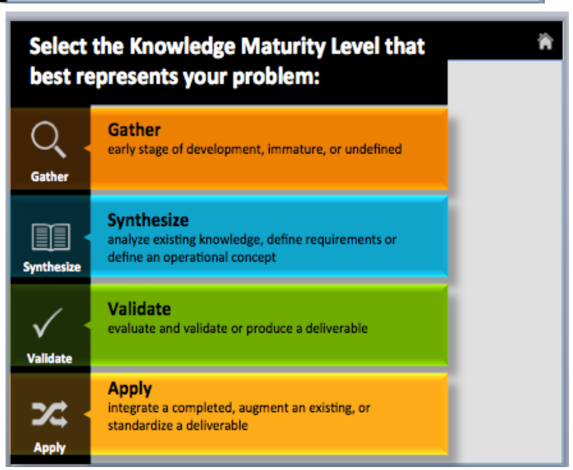
Challenge	Solution Mechanisms	Outcomes	Results
How to measure intracranial pressure (ICP) non-invasively	NASA @ WORK	Top 3 NASA "winners" directed us to take a second look at developers we were already aware	
	INNOCENTIVE Potential $15K Award	638 Solutions Submitted 581 Rejected by InnoCentive 11 Rejected by NASA 46 Reviewed by NASA	2 New Potential Solutions
	yet2.com™	81 Leads Identified 63 Rejected High Interest Solutions: 3 Other Interesting Solutions: 5 Potential Complementary Technologies: 6	2 New Potential Solutions

Building upon Pilot Success: Solution Mechanism Guidance (SMG) Tool

"I'll be happy to give you innovative thinking. What are the guidelines?"

The Solution Mechanism Guide (SMG)





➢ *Creating a culture of innovation*

- A project management tool
  - educates users about options available
  - provides a guide to help subject matter experts decide which tool works best for each stage (TRL) of the project
- Includes options for traditional (grants, SBIRs) and new (open innovation) tools
- Results in the most cost effective, efficient mechanism to address HH&P gaps

Select the Knowledge Maturity Level that best represents your problem:

Gather

Gather
early stage of development, immature, or undefined

Synthesize

Synthesize
analyze existing knowledge, define requirements or define an operational concept

Validate

Validate
evaluate and validate or produce a deliverable

Apply

Apply
integrate a completed, augment an existing, or standardize a deliverable

(SMG)

Gather Knowledge

Gather

Synthesize

Validate

Apply

In order to identify the Solution Mechanisms that best fit your needs, please answer the following:

What are your time constraints?:

30 days — 1 year

☐ Don't filter by

What Deliverable(s) are you looking for?:

☐ Knowledge ☐ Countermeasure

☐ Technology ☐ Requirements & Standards

☐ Don't filter by

Amount of Resources you want to Allocate?:

Free — $1M+

☐ Don't filter by

Submit

Have an Issue: Email for Help

Evaluate & Comment: Submit Feedback

NASA@work

Your first step will be to contact the POC listed; other pertinent information is provided below

NASA@work	
Point of Contact (POC):	Center of Excellence for Collaborative Innovation (CoECI) office – **Kathryn Keeton (Wyle)**
Duration of SM:	Prep: ~ 2-3 weeks Challenge Open/Active: ~ 4-6 weeks Evaluation: 2 weeks
Cost of SM:	Self-Serve: No cost Full-Serve: $2400 (support provided by InnoCentive)
Time Investment:	Program Champion (time varies); Challenge Owner (time varies)
SM Metrics:	3 in prep, 3 active, 42 awarded as of 05/01/13
Repository:	CoECI website

Future HH&P Initiatives

- National Science Foundation Ideas Lab
  - Rapid, iterative proposal development
  - Joint NASA-NSF Workshop Nov. 6
- Marblar
  - A crowd-sourcing platform seeking to repurpose "over-looked technologies" for new applications
  - MSFC has a contract for 40 challenges
  - Evaluating feasibility of NASA-RWJF-Marblar contest using the Intravenous Fluid Generation (IVGen) system which converts potable water into sterile fluid for injection