NASA, Astronaut Occupational Surveillance Program and Lifetime Surveillance of Astronaut Health, LSAH: Astronaut Exposures and Risk in the Terrestrial and Spaceflight Environment

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Dr. William Tarver, Mary Van Baalen PhD, Torin McCoy, Johnson Space Center, National Aeronautics and Space Administration
This presentation represents the efforts of a large number of very dedicated Health and Engineering professionals over many years at NASA and the Johnson Space Center.
Overview

→ **Background** Organizations responsible for Astronaut Health,
  – Human Exploration and Operations Directorate, HEOMD, NASA Johnson Space Center, Human Health and Performance Directorate, HHPD, Human Research Program HRP,

→ **NASA Astronaut Corp**
  – Flight Operations Directorate

→ **Early Astronaut Medical Care and Surveillance, Longitudinal Surveillance of Astronaut Health LSAH**
  – Early mission and focus
  – Mission Operations Philosophy
  – Shuttle Years and Retirement, time for change....

→ **Changes to Lifetime Surveillance of Astronaut Health, LSAH New Focus and Direction**
  – International Space Station ISS era
  – Outside Orgs, ASAP, IOM,
  – Benchmarking DOD, NIOSH

→ **Astronaut Occupational Health Program AOHP Occupational Medicine, Risk System/Human System Risk Board**
  – Astronaut Occupational Health Management Group
  – LSAH Advisory Board
  – OHMG
  – Astronaut Corp (Similar Exposure Group)

→ **The Workplace Environment**
  – Terrestrial
  – Space

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Organizations

Organizational Structure:
Human Exploration and Operations Mission Directorate

Public Affairs/Communications
Legislative Affairs
Int’l/Interagency Relations
General Counsel

Associate Administrator
Deputy Associate Administrator
Deputy AA for Policy & Plans
Deputy AA for Program Strategy

Chief Technologist
Chief Scientist
Chief Engineer
Safety & Mission Assurance
Chief Health & Medical Officer

Strategic Analysis & Integration
• Architecture studies and analysis
• Mission analysis
• Risk and requirements coordination

Mission Support Services
• HR
• E & PO
• IT
• Mgt processes & internal controls

Resources Management

Space Comm & Navigation
Launch Services

Space Shuttle
Exploration Systems Development
• SLS
• MPCV
• 21st Century Ground Systems

Human Spaceflight Capabilities
• Core Capabilities (MAF, MOD, SFCO, EVA)
• RPT

ISS
• System O&M
• Crew & Cargo Transportation Services

Commercial Spaceflight Development
• Commercial Crew
• COTS

Advanced Exploration Systems
• AES
• Robotic precursor measurements

Space Life & Physical Sciences Research & Applications
• HRP, CHS
• Fund. Space Bio
• Physical Sciences

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Organizations

Human Research Program (HRP)
- Director: William H. Patsios, Ph.D.
- Deputy Director: Barbara J. Carter
- Chief Scientist: John S. Charles, Ph.D.
- Deputy Chief Scientist: Pamela A. Fogarty, Ph.D.
- Associate Chief Scientist, International Collaborations: Robert L. Churnside, Ph.D.
- Program Clinician: Scott, Ph.D.
- Operations Representative: Richard M. Linnehan, GVM

Program Business Management
- Program Science Management
  - Manager: Michelle H. Peshock, Ph.D.
  - Deputy Manager: Gary Childs

Space Human Factors & Habitability (SHFI)
- Manager: J. Rehfeld, Ph.D.
- Deputy Manager: M. Paul
- Scientist: M. Blair, Ph.D.
- Deputy Scientist: P. Huggett, Ph.D.

Behavioral Health & Performance (BHP)
- Manager: L. Rollins
- Deputy Manager: S. G. Eng
- Scientist: E. Antonow, Ph.D.
- Deputy Scientist: R. Shoh, Ph.D.

Exploration Medical Capability (EMC)
- Manager: J. C. Finn
- Deputy Manager: R. Pasco
- Scientist: R. Shoh, Ph.D.
- Deputy Scientist: A. Rice, Ph.D.

Human Health Countermeasures (HHC)
- Manager: D. Bowers
- Deputy Manager: J. Rimell
- Scientist: F. Nishi, Ph.D.
- Deputy Scientist: Y. Sato, M.D., MSF

Space Radiation (SR)
- Manager: J. V. Litschke
- Deputy Manager: B. H. Mauer
- Scientist: J. Steckler, Ph.D.
- Deputy Scientist: P. Huggett, Ph.D.

ISS Medical Projects (ISMP)
- Manager: D. McElwee
- Deputy Manager: S. M. Ackerman
- Scientist: J. Steckler, Ph.D.
- Deputy Scientist: P. Huggett, Ph.D.

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NASA

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NASA’s Johnson Space Center
The NASA Astronaut Corps

→ Part of the JSC Flight Operations Directorate

→ 330 Total

→ Current Active Astronauts
  – 57 total
  – 44 males
  – 13 females
  – Average age mid 40’s
    • Mid 30’s at Selection

→ 8 ASCANS selected 2013

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Dr. Peggy Whitson, Commander Expedition 51

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### Military/Civilian Status

#### Active Astronaut Corps:
(as of Sept 2012)

<table>
<thead>
<tr>
<th>Military Branch</th>
<th>M</th>
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<th>Grand Total</th>
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<tr>
<td>USMC</td>
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<tr>
<td>USN</td>
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#### Retired/Deceased Astronaut Corps:
(as of Sept 2012)

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NASA Human Space Flight

One Year ISS and Next Generation Missions

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<th>Average Days</th>
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<tr>
<td>Gemini</td>
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<tr>
<td>Apollo</td>
<td>n = 33</td>
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<td>Apollo-Soyuz</td>
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<tr>
<td>Skylab</td>
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<tr>
<td>Space Shuttle</td>
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<tr>
<td>Mir</td>
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<tr>
<td>International Station</td>
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<tr>
<td>Space Shuttle*</td>
<td>n = 37</td>
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* Person-flights; may include multiple-time flyers within program
# General Demographic Data

<table>
<thead>
<tr>
<th>Program</th>
<th>Avg. Duration (days)</th>
<th>Age at First Launch (yrs)</th>
<th>Count</th>
<th>Gender</th>
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<td>Minimum</td>
<td>Average</td>
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<td>ASTP</td>
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<td>NASA-Mir</td>
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*Person-flights; may include multiple-time flyers within program*
Astronaut Surveillance

- Longitudinal Surveillance of Astronaut Health (LSAH) I 1959-1989
- Longitudinal/Lifetime Surveillance of Astronaut Health LSAH II 1989-2009
- AOHP 2012- NASA Astronaut Occupational Surveillance Program, Lifetime Surveillance of Astronaut Health
Longitudinal Study of Astronaut Health

LSAH

→ Phase 1
→ Phase 2
→ Workforce controls for comparison
→ Low Statistical Power
→ No Consent
LSAH Challenges

→ Standard issues with space biomedical research
  – Small n, competing priorities in flight, lack of consistent data, etc.

→ Healthy Worker Effect: observation that employed populations tend to have a lower mortality experience than the general population.
  – Likely exacerbated in extremely fit worker populations such as military, firefighters, and the astronaut corps
    o Rigorous selection criteria
    o Specialized medical care provided by NASA
      o Frequent, more comprehensive screenings than those available to the public
      o Incentives for health maintenance not available to the general public
    o Educational level

→ Further illustrates the need for an appropriate control population
The end of the Shuttle Program
Time for Change NEW LSAH

→ For Human Spaceflight, NASA acts as;

- NORA
- NIOSH
- OSHA
- Employer

For the astronauts
External Program Reviews

National Academies: Institute of Medicine

• Committee on Aerospace Medicine and the Medicine of Extreme Environments (CAMMEE)
Institute of Medicine Recommendations for Human Spaceflight

1. Must serve two sometimes conflicting goals of research and occupational surveillance...

2. No comparison group can meet every goal or need, it should be individualized...

3. Increase the quality and quantity of preventive care to increase the data...

4. NASA should assume responsibility for the lifelong health care of its active and former astronauts.
Additional Drivers for an Astronaut Occupational Surveillance Program

→ **Legal obligation**

→ **Ethical obligation to protect our Astronauts workforce**
  - Space related medical outcomes may manifest beyond current workers compensation statutes.
Why Change Now?

→ Spaceflight paradigm shift- Shuttle Retirement, ISS construction completed and into full operations

→ ISS, Emphasis on long duration habitation

→ External Reviews and findings of NASA Astronaut Health and Human Research programs
  
  • Integration of evolving medical evidence base into requirements development (vehicles, design reference missions, spacesuits, habitats) for exploration missions

  • How does astronaut surveillance compare to what we have to do for JSC employees, how is it different???
What is the Astronaut Occupational Health Surveillance Program (AOHP)?

• AOHP is a comprehensive program to monitor health outcomes due to the health risks of workplace exposures and develop strategies to best protect the astronaut.

• The modified strategy is more in line with traditional occupational surveillance with additional considerations for the unique environment.
Astronaut Occupational Health Program

Primary responsibility for policy and decision-making, recommendations for requirements/standards/causation determination

Astronaut Medical Services:
- Primary responsibility for implementing all elements of astronaut ‘clinical’ care from selection through retirement.

Lifetime Surveillance of Astronaut Health:
- Primary responsibility for data integrity and management, and building and disseminating clinical evidence base.

Occupational Health Management:
- Integration??
  - Primary responsibility for integration within and external to Occ HL, such as HRP, ISSPO, other elements of HEOMD.
AOHP Goals

• Goal 1: Develop and Provide a Comprehensive Annual Medical Exam for each LSAH Participant
• Goal 2: Conduct Occupational Surveillance
• Goal 3: Improve Communication, Data Accessibility, Integrity and Storage
• Goal 4: Support Operational and Health Care Analyses
• Goal 5: Support NASA Research Objectives
Healthcare/Exposures

Pre-NASA Exposures  ASCAN Training  Active Astronaut  Retirement

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NIOSH 9/17/2012
Astronaut Occupational Health Program

→ Benchmarked off of similar programs in DoD and the Department of Energy
→ Allows insight into long-term sequelae from exposures in the workplace
→ Presented Draft Model to NIOSH
Occupational Surveillance for Astronauts

→ Meets Ethical and Moral obligation
→ Increases data available to research
→ Identifies and prevents exposure related disease
→ Allows feedback into spacecraft design
→ Allows NASA to follow long term health impacts
Similar Exposure Groups SEG

Following the fairly standardized process well known in the industrial environment, the astronauts are considered an SEG. We monitor them as a group, then as specific individuals, based on exposures and other factors, throughout their “NASA” career.
### NASA JSC Human Spaceflight Risks

#### Human Systems Risk Board HSRB

#### HMTA Integrated Human System Risk Summary

<table>
<thead>
<tr>
<th>ODM Categories Details</th>
<th>In Mission Risk - Operations</th>
<th>Post Mission Risk - Long Term Health</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Low Earth Orbit (1 Year)</td>
<td>Deep Space (1 Year)</td>
</tr>
<tr>
<td></td>
<td>4 Months</td>
<td>1 Year</td>
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<tr>
<td>Brain Stone Formation</td>
<td>Accepted</td>
<td>Accepted</td>
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<tr>
<td>Intake Medical Conditions</td>
<td>Accepted</td>
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<tr>
<td>Cardiac Rhythm Problems</td>
<td>Accepted with Monitoring</td>
<td>Accepted with Monitoring</td>
</tr>
<tr>
<td>Cognitive or Behavioral Conditions</td>
<td>Accepted with Monitoring</td>
<td>Requires Mitigation</td>
</tr>
<tr>
<td>Inadequate Food and Nutrition</td>
<td>Accepted with Monitoring</td>
<td>Required</td>
</tr>
<tr>
<td>Bone Fracture</td>
<td>Accepted / Standard Refinement</td>
<td>Accepted / Standard Refinement</td>
</tr>
<tr>
<td>Psychological Adaptation within a Team</td>
<td>Accepted with Monitoring</td>
<td>Requires Mitigation</td>
</tr>
<tr>
<td>Inadequate Human System Interaction Design</td>
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<td>Requires Mitigation</td>
</tr>
<tr>
<td>Sleep Loss</td>
<td>Accepted / Optimize</td>
<td>Accepted / Optimize</td>
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<tr>
<td>Heat Exposure</td>
<td>Accepted with Monitoring</td>
<td>Requires Mitigation</td>
</tr>
<tr>
<td>Altered Immune Response</td>
<td>Accepted with Monitoring</td>
<td>Requires Mitigation</td>
</tr>
<tr>
<td>Malignant Hemoglobin Interactions</td>
<td>Accepted with Monitoring</td>
<td>Requires Mitigation</td>
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<tr>
<td>Reduced Aerobic Capacity</td>
<td>Accepted / Optimize</td>
<td>Accepted / Optimize</td>
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<tr>
<td>Reduced Muscle Tone, Strength</td>
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<tr>
<td>Nausea/Breathlessness</td>
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<td>Accepted / Accepted</td>
</tr>
</tbody>
</table>

**Show Likelihood vs Consequence Scales**
The Work Environment
Terrestrial Aircraft Operations
Terrestrial Neutral Buoyancy Lab
Terrestrial Extreme Environments

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International Space Station

- Module Length: 167.3 feet (51 meters)
- Truss Length: 357.5 feet (109 meters)
- Solar Array Length: 239.4 feet (73 meters)
- Mass: 924,739 pounds (419,455 kilograms)
- Habitable Volume: 13,696 cubic feet (388 cubic meters)
- Pressurized Volume: 32,333 cubic feet (916 cubic meters)
- Power Generation: 8 solar arrays = 84 kilowatts
- ISS is larger than a six-bedroom house.
- ISS has an internal pressurized volume of 32,333 cubic feet, or equal that of a Boeing 747.
- More than 115 space flights were conducted. Five different types of launch vehicles, over the course of the station’s construction.
- More than 100 telephone-booth-sized rack facilities can be in the ISS for operating the spacecraft systems and research experiments.
- The ISS is almost four times as large as the Russian space station Mir and about five times as large as the U.S. Skylab.
- In the International Space Station’s U.S. segment alone, 1.5 million lines of flight software code run on 44 computers communicating via 100 data networks transferring 400,000 signals
- The ISS manages 20 times as many signals as the space shuttle.
- U.S. control computers have 1.5 gigabytes of total storage, compared to modern PCs, which have ~500 gigabyte hard drives.
- The entire 55-foot robot arm assembly is capable of lifting 220,000 pounds, which is the weight of a space shuttle orbiter.
Occupational Hazards in Space

- Microgravity
- Space Adaptation Syndrome
- Circadian Rhythm Disruption
- Radiation of the Space Variety
- Behavioral Health
- Noise
- Chemicals/Carbon Dioxide
- Lasers
- Rocket propellants
- Biological hazards from mice experiment

From Scientific American
Extended Weightlessness

- Radiation
- Bone
- Neurovestibular
- Cardiovascular
- Muscle
- Behavior & performance

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NASA Health Standards for Human Spaceflight

  - 4.2.3 Fitness-for-Duty Aerobic Capacity Standard
  - 4.2.4 Fitness-for-Duty Sensorimotor Standard
  - 4.2.5 Fitness-for-Duty Behavioral Health and Cognition Standard
  - 4.2.6 Fitness-for-Duty Hematology and Immunology Standard
  - 4.2.7 Permissible Outcome Limit for Nutrition Standard
  - 4.2.8 Permissible Outcome Limit for Muscle Strength Standard
  - 4.2.9 Permissible Outcome Limit for Microgravity-Induced Bone Mineral Loss Performance Standard (Baseline with Measured Tscore)
  - 4.2.10 Space Permissible Exposure Limit for Space Flight Radiation Exposure Standard
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Microgravity Adaptation

Relative to terrestrial normal, the returning de-conditioned, microgravity-adapted crew has:

→ • Hypovolemia –12% to 15% less blood volume (like dehydration)
→ • Anemia –10% to 12% less red blood cells
→ • Neurosensory deconditioning
→ • Aerobic deconditioning –15% to 20% deficit
→ • Decreased strength (postural muscles)
→ • Decreased bone density (postural joints)
→ • Increased spinal length (about 6%; may affect suit fit)
Microgravity Adaptation

- Space Adaptation Syndrome (SAS)
  - Typically experienced in microgravity during first 2-3 days of spaceflight.
  - Nausea, Vomiting, Visual Illusions, Spatial Disorientation, Pallor, Fatigue, Malaise, Cold Sweat
  - Experienced by significant % of crews

- Entry Adaptation Syndrome (EAS)
  - Response to transitioning from microgravity back to 1G
  - Inverse of SAS
  - Similar symptomology and manifestations contribute to dehydration and orthostatic intolerance
  - Experienced by similar percentage of returning crews
Countermeasures
Research

Operational

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Behavior and Performance

→ **Occurrence**
  - All subjected to factors that affect
    - Psychological well-being
    - Interactions with other crewmembers, families, and ground personnel
    - Performance of duties

→ **Due to**
  - Mission design
  - Events (9/11; holidays)
  - Spacecraft environment
  - Close quarters

→ **Consequences – changes to**
  - Interpersonal environment
  - Safety and productively
  - Team problem solving
  - Decision making
  - Communication
Habitability & Environmental Factors
Nutrition

→ Occurrence
  – All crewmembers to varying degrees, more severe in long-duration missions

→ Due to
  – Changes in sense of taste
  – Limited food choices (currently ~10 day rotation)
  – Scarce fresh fruits/vegetables

→ Consequences
  – Decreased calories eaten and decreased vitamin/mineral intake
  – Performance decrements?
  – Immune, bone, other system impacts
  – Decreased muscle mass
  – Weight loss / dehydration
  – Electrolyte disturbances

→ Countermeasures?
  – Prevention
  – In-flight nutrition questionnaires, pre/in/post-flight tracking
  – Vitamins, supplements
Vehicle Surveillance Capability

Environmental Health System -
- Acoustics: Area Sound Level Meters
- Carbon Dioxide Monitoring
- Compound Specific Analyzers:
  - Oxygen
  - Combustion Products
- Toxicological ‘Grab’ Air Sampling
- Microbial Air & Surface Sampling
- Total Organic Carbon Analyzer
- Water Quality Monitoring
- Active and Passive Radiation Monitoring
- Combustion Products Analyzer
- Formaldehyde Monitoring

Vehicle Systems –
- Atmosphere Control and Supply System (ACS)
- Atmosphere Revitalization System (ARS)
- Internal Thermal Control System (ITCS)
- Passive Thermal Control System (PTCS)
- Regenerative Environmental Control and Life Support System (Regen ECLSS)

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Hearing Conservation/Acoustics

ISS Modules’ Noise Levels

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<th>Module</th>
<th>NC-Level</th>
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<th>STIL(*)</th>
<th>Survey Date</th>
<th>Normal Level</th>
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<td>40.8 dB</td>
<td>July 31, 2015</td>
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<tr>
<td>JLP</td>
<td>NC 43.0</td>
<td>50.0</td>
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<td>49.1</td>
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<td>53.0</td>
<td>43.3 dB</td>
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<td>Node 1</td>
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<td>45.7 dB</td>
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<td>NC 53.8</td>
<td>58.6</td>
<td>51.3 dB</td>
<td>Apr 1, 2015</td>
<td>NC 61.0</td>
</tr>
<tr>
<td>Node 3</td>
<td>NC 56.8</td>
<td>61.1</td>
<td>53.3 dB</td>
<td>Sept 15, 2014</td>
<td>NC 56.0</td>
</tr>
<tr>
<td>Node 3</td>
<td>NC 56.8</td>
<td>60.9</td>
<td>51.2 dB</td>
<td>Sept 21, 2015</td>
<td>NC 55.0</td>
</tr>
<tr>
<td>FGB</td>
<td>NC 57.1</td>
<td>62.2</td>
<td>53.6 dB</td>
<td>Mar 29, 2016</td>
<td>NC 58.0</td>
</tr>
<tr>
<td>US Lab</td>
<td>NC 57.5</td>
<td>60.1</td>
<td>52.7 dB</td>
<td>Mar 29, 2016</td>
<td>NC 52.0</td>
</tr>
<tr>
<td>MRM1</td>
<td>NC 58.6</td>
<td>62.9</td>
<td>54.6 dB</td>
<td>Sept 21, 2015</td>
<td>NC 65.0</td>
</tr>
<tr>
<td>MRM2</td>
<td>NC 59.9</td>
<td>64.4</td>
<td>57.6 dB</td>
<td>July 31, 2015</td>
<td>NC 62.0</td>
</tr>
<tr>
<td>SIM</td>
<td>NC 60.4</td>
<td>64.7</td>
<td>56.6 dB</td>
<td>Mar 29, 2016</td>
<td>NC 60.0</td>
</tr>
<tr>
<td>Node 2</td>
<td>NC 60.5</td>
<td>62.8</td>
<td>52.2 dB</td>
<td>Mar 29, 2016</td>
<td>NC 49.0</td>
</tr>
</tbody>
</table>

ISS Sleep Stations’ Noise Levels

<table>
<thead>
<tr>
<th>Sleep Station</th>
<th>NC-Level</th>
<th>dBA</th>
<th>SIL(4)</th>
<th>Survey Date</th>
<th>Fan Speed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Deck CQ</td>
<td>NC 43.7</td>
<td>48.6 dBA</td>
<td>30.2 dB</td>
<td>Mar 29, 2016</td>
<td>High</td>
</tr>
<tr>
<td>Std CQ</td>
<td>NC 46.1</td>
<td>49.9 dBA</td>
<td>37.6 dB</td>
<td>Mar 29, 2016</td>
<td>High</td>
</tr>
<tr>
<td>Ovhd CQ</td>
<td>NC 48.1</td>
<td>51.8 dBA</td>
<td>39.5 dB</td>
<td>Mar 29, 2016</td>
<td>High</td>
</tr>
<tr>
<td>Stbd kayula</td>
<td>NC 50.4</td>
<td>54.7 dBA</td>
<td>41.8 dB</td>
<td>Mar 29, 2016</td>
<td>High</td>
</tr>
<tr>
<td>Port CQ</td>
<td>NC 51.8</td>
<td>54.4 dBA</td>
<td>41.1 dB</td>
<td>Mar 29, 2016</td>
<td>High</td>
</tr>
<tr>
<td>Port kayula*</td>
<td>NC 64.4</td>
<td>65.5 dBA</td>
<td>56.0 dB</td>
<td>Mar 29, 2016</td>
<td>High</td>
</tr>
</tbody>
</table>

Pathways to Progress
May 21-26, 2016  #AIHce16  AIHce2016.org

AIHce 2016
CO-SPONSORED BY AIHA® & ACGIH®
- **Galactic Cosmic Rays (GCR):**
  - highly penetrating protons and heavy ions of extra-solar origin
  - large amounts of secondary radiation
  - largest doses occur during minimum solar activity in an 11-year solar cycle

- **Solar Particle Events (SPE):**
  - medium to high-energy protons
  - occur during maximum solar activity
# Radiation Monitoring Instruments

<table>
<thead>
<tr>
<th>TIME-RESOLVED RADIATION HARDWARE</th>
<th>REM Radiation Environmental Monitor (SDTO)</th>
<th>TEPC Tissue Equivalent Proportional Counter</th>
<th>IV-TEPC Intravehicular Tissue Equivalent Proportional Counter</th>
<th>RAD Radiation Assessment Detector</th>
<th>EV-CPDS Extravehicular Charge Particle Directional Spectrometer</th>
</tr>
</thead>
<tbody>
<tr>
<td>NASA PROGRAMS</td>
<td>ISS Orion EFT-1 (as BIRD)</td>
<td>ISS Space Shuttle</td>
<td>ISS</td>
<td>ISS</td>
<td>ISS (outside)</td>
</tr>
<tr>
<td>IN-ORBIT STATUS</td>
<td>Active (1) US Lab; (1) COL; (2) JPM; (1) Cupola. ISS Survey instrument</td>
<td>Active SM-P327 Fixed location</td>
<td>Channel 2: Enabled; In Acquire ISS Survey instrument</td>
<td>To be launched on SpaceX-8 ISS Survey instrument</td>
<td>EV3: Active, 50 Truss (aft) Fixed location</td>
</tr>
<tr>
<td>DETECTOR TYPE</td>
<td>Small, low power, active Pixel detector (Timepix) 256 x 256 pixels</td>
<td>Cylindrical Tissue equivalent</td>
<td>Spherical Tissue equivalent Low and high gain detectors</td>
<td>Charged Particle Silicon Detector (CPD) Fast Neutron Detector (FND)</td>
<td>Silicon Detectors</td>
</tr>
<tr>
<td>DIRECTIONALITY</td>
<td>Omni-directional</td>
<td>Omni-directional</td>
<td>Omni-directional</td>
<td>Directional</td>
<td>Directional</td>
</tr>
<tr>
<td>MEASUREMENT CAPABILITY PROTONS &amp; CHARGED PARTICLES</td>
<td>Linear energy spectra 0.1-1000 keV/µm GCR/SAA discrimination</td>
<td>Lineal energy spectra 0.4-1000 keV/µm GCR/SAA discrimination</td>
<td>Lineal energy spectra 0.4-1000 keV/µm GCR/SAA discrimination</td>
<td>Differential Flux and Energy Spectra Z &lt; 3, 30 – 200 MeV/n 3 ≤ Z ≤ 26, 100 – 200 MeV/n</td>
<td>Energy spectra for Z &lt; 4 Proton spectrum up to ~120MeV He spectrum ~300MeV/n</td>
</tr>
<tr>
<td>MEASUREMENT CAPABILITY NEUTRONS</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>Energy Spectra 0.5 – 80 MeV</td>
<td>N/A</td>
</tr>
<tr>
<td>DOSIMETRY</td>
<td>Particle flux, Energy Spectra, Dose &amp; Dose Equivalent</td>
<td>Dose &amp; Dose equivalent</td>
<td>Dose &amp; Dose Equivalent</td>
<td>Particle flux, Event Rates, Dose &amp; Dose Equivalent</td>
<td>Dose rate &amp; Cumulative Dose</td>
</tr>
</tbody>
</table>
In-Flight Active Monitoring

TEPC Data (Corrected)

- Record of radiation doses are used to document occupational exposure.
- Characterization of the radiation environment is used for updating exposure records for risk assessments.

TEPC located at SM panel327
### Table 4-1. Example Career Effective Dose Limits in Units of milli-Sievert (mSv) for 1-year Missions and Average Life-loss for an Exposure-induced Death for Radiation Carcinogenesis (1 mSv = 0.1 rem)

<table>
<thead>
<tr>
<th>Age, yr</th>
<th>Males</th>
<th>Females</th>
</tr>
</thead>
<tbody>
<tr>
<td>25</td>
<td>520 (15.7)</td>
<td>370 (15.9)</td>
</tr>
<tr>
<td>30</td>
<td>620 (15.4)</td>
<td>470 (15.7)</td>
</tr>
<tr>
<td>35</td>
<td>720 (15.0)</td>
<td>550 (15.3)</td>
</tr>
<tr>
<td>40</td>
<td>800 (14.2)</td>
<td>620 (14.7)</td>
</tr>
<tr>
<td>45</td>
<td>950 (13.5)</td>
<td>750 (14.0)</td>
</tr>
<tr>
<td>50</td>
<td>1,150 (12.5)</td>
<td>920 (13.2)</td>
</tr>
<tr>
<td>55</td>
<td>1,470 (11.5)</td>
<td>1,120 (12.2)</td>
</tr>
</tbody>
</table>

Human Health and Performance
Risks of Space Exploration Missions

Evidence reviewed by the NASA Human Research Program
Table 5-1. Dose Limits (in mGy-Eq or mGy) for Non-cancer Radiation Effects (BFO Refers to the Blood-forming Organs and CNS to the Central Nervous System)

<table>
<thead>
<tr>
<th>Organ</th>
<th>30-day limit</th>
<th>1-year limit</th>
<th>Career</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lens*</td>
<td>1,000 mGy-Eq</td>
<td>2,000 mGy-Eq</td>
<td>4,000 mGy-Eq</td>
</tr>
<tr>
<td>Skin</td>
<td>1,500 mGy-Eq</td>
<td>3,000 mGy-Eq</td>
<td>6,000 mGy-Eq</td>
</tr>
<tr>
<td>BFO</td>
<td>250 mGy-Eq</td>
<td>500 mGy-Eq</td>
<td>Not applicable</td>
</tr>
<tr>
<td>Heart**</td>
<td>250 mGy-Eq</td>
<td>500 mGy-Eq</td>
<td>1,000 mGy-Eq</td>
</tr>
<tr>
<td>CNS***</td>
<td>500 mGy-Eq</td>
<td>1,000 mGy-Eq</td>
<td>1,500 mGy-Eq</td>
</tr>
<tr>
<td>CNS*** (Z≥10)</td>
<td>–</td>
<td>100 mGy</td>
<td>250 mGy</td>
</tr>
</tbody>
</table>

*Lens limits are intended to prevent early (<5 years) severe cataracts (e.g., from an SPE). An additional cataract risk exists at lower doses from cosmic rays for subclinical cataracts, which may progress to severe types after long latency (>5 years) and are not preventable by existing mitigation measures; they are deemed an acceptable risk to the program, however.

**Heart doses calculated as average over heart muscle and adjacent arteries.

***CNS limits should be calculated at the hippocampus.

Human Health and Performance
Risks of Space Exploration Missions

Evidence reviewed by the NASA Human Research Program
### Spaceflight Chemical Exposure Standards

#### Spacecraft Maximum Allowable Concentrations for Airborne Contaminants

**Chemical:**
- E3-60 Aliphatic Saturated Aldehydes
  - Synonyms:
  - NRC Vol. #: 5
  - CAS #: various
  - Year SMAC was Set/Reviewed: 2008
  - Remarks: Gassing values

<table>
<thead>
<tr>
<th>SMACs</th>
<th>Potential Exposure Duration</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Chemical</strong></td>
<td><strong>1 hr</strong></td>
</tr>
<tr>
<td><strong>E3-60 Aliphatic Saturated Aldehydes</strong></td>
<td>ppm (mg/m³)</td>
</tr>
<tr>
<td>Organ</td>
<td>Effect</td>
</tr>
<tr>
<td>Nasal Cavity</td>
<td>Injury</td>
</tr>
<tr>
<td>45</td>
<td>(varies)</td>
</tr>
</tbody>
</table>

**Ammonia**
- Synonyms:
- NRC Vol. #: 5
- CAS #: 7664-41-7
- Year SMAC was Set/Reviewed: 2008
- Remarks: Casing values

| **Chemical** | **1 hr** | **24 hr** | **7 d** | **30 d** | **180 d** | **1000 d** |
|-------|-----------------------------|
| **Ammonia** | ppm (mg/m³) | ppm (mg/m³) | ppm (mg/m³) | ppm (mg/m³) | ppm (mg/m³) | ppm (mg/m³) |
| Organ | Effect | Organ | Effect | Organ | Effect | Organ | Effect |
| Eye | Irritation | Eye | Irritation | Eye | Irritation | Eye | Irritation |
| 30 | (29) | 20 | (14) | 3 | (2) | 3 | (2) |

Pathways to Progress

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Archival Water Sample Collection Packets

- Archival water samples (500 mL) collected prior to vehicle returns
- Allows for comprehensive assessment of water quality
ISS Total Organic Carbon Analyzer (TOCA)

- TOCA measures total organic carbon (TOC) and total inorganic carbon (TIC) in a water sample but does not identify individual contaminants.
- Uses non-dispersive infrared detector to measure CO2 generated during oxidation of organic contaminants.
- U.S. potability limit for TOC < 3.0 mg/L.
- TOC concentrations are typically < 0.3 mg/L.

Analysis Schedule:
- Weekly samples from WPA product tank via TOCA hose
- Monthly samples from the Potable Water Dispenser (PWD) collected in sample bags
Colorimetric Water Quality Monitor Kit (CWQMK)

- Provides the capability to measure ionic silver (Ag⁺), molecular iodine (I₂), and total iodine (sum of I⁻, I₂, and I₃⁻) concentrations in water samples on the ISS.
  - Ionic silver – biocide used in RS water systems
  - Molecular iodine – biocide used in US water recovery system
  - Total iodine – monitored at points of crew consumption (medical requirement)
- Monitoring Frequency:
  - Total iodine concentration in US potable water measured quarterly in ambient samples from PWD.
  - Biocide concentrations can be measured to support contingency operations.
Formaldehyde Badges

- Formaldehyde Monitoring Kit (FMK)
- Formaldehyde trapped in badge matrix by diffusion
- Typical exposure time is 48 h (in pairs)
- Formaldehyde eluted from badge on the ground and analyzed by spectrophotometry
- Limitation: Sufficient face velocity of air required for best results

Commercial unit
- 6% upper limit
- 18 h battery life (pump)
- Water & particle filter
- Robust/stable device that uses non-dispersive infrared detector

Limitation:
- Commercial unit
- 6% upper limit
- 18 h battery life (pump)
- Water & particle filter
- Robust/stable device that uses non-dispersive infrared detector

Compound Specific Analyzer – Combustion Products (CSA-CP)

- Commercial unit with electrochemical sensors
- Measures:
  - Carbon Monoxide
  - Hydrogen Chloride
  - Hydrogen Cyanide
  - Oxygen sensors have been removed from current units.
- Post-fire cleanup monitoring
- Mask-doff criteria
- Can be used to investigate sources of combustion products using pump/probe attachment
- Can be zero calibrated inflight

Benefit:
- Track 100’s of compounds

Limitation: Reactive compounds are lost

Archival Air Samples

- Grab Samples Canisters (GSCs) evacuated and doped on the ground
- Sample collected in <5 seconds (by opening valve)
- 2 samples collected every 45 days
- Returned and analyzed at JSC by GC/FID and GC/MS
- Benefit: Track 100’s of compounds
- Limitation: Reactive compounds are lost
Air Quality Monitor (AQM)

- Periodic measurement of volatile organic compounds in-flight
- Gas Chromatograph-Differential Mobility Spectrometer
- Automated run sequence every ~73 hrs
- 3 year operational life
- Operated in pairs (different GC columns)
- Capable of monitoring 22 target analytes.
# AQM Target Compounds

<table>
<thead>
<tr>
<th>AQM 1 (2218 - 624 column)</th>
<th>AQM 2 (2221 - DB5 column)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Methanol</td>
<td>Acetaldehyde</td>
</tr>
<tr>
<td>Acetone</td>
<td>Ethanol</td>
</tr>
<tr>
<td>Hexane</td>
<td>Dichloromethane</td>
</tr>
<tr>
<td>1,2-Dichloroethane</td>
<td>Trimethylsilanol</td>
</tr>
<tr>
<td>Hexanal</td>
<td>2-Butanone</td>
</tr>
<tr>
<td>Acrolein</td>
<td>Ethyl acetate</td>
</tr>
<tr>
<td>Isopropanol</td>
<td>n-Butanol</td>
</tr>
<tr>
<td>Benzene</td>
<td></td>
</tr>
<tr>
<td>Toluene</td>
<td></td>
</tr>
<tr>
<td>o-Xylene</td>
<td></td>
</tr>
<tr>
<td>m-/p-Xylene</td>
<td></td>
</tr>
<tr>
<td>Hexamethylcyclotrisiloxane</td>
<td>Hexamethylcyclotrisiloxane</td>
</tr>
<tr>
<td>Octamethylcyclobutasiloxane</td>
<td>Octamethylcyclobutasiloxane</td>
</tr>
<tr>
<td>Decamethylcyclopentasiloxane</td>
<td>Decamethylcyclopentasiloxane</td>
</tr>
</tbody>
</table>

**Bolded compounds measured by both units**
CO₂ Exposures – Acute, Transient, Chronic
Spacecraft Maximum Allowable Concentrations (SMAC) and CHIT Implemented Levels

<table>
<thead>
<tr>
<th>Exposure Duration</th>
<th>CO₂ Level</th>
<th>CHIT Controlled level</th>
<th>Nominal ISS Levels</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Hr</td>
<td>0.5%</td>
<td>4 mm Hg</td>
<td>3 mm Hg ± 0.8</td>
</tr>
<tr>
<td>24 Hr</td>
<td>1.0%</td>
<td>4 mm Hg</td>
<td>3 mm Hg ± 0.8</td>
</tr>
<tr>
<td>7-180 days</td>
<td>1.5%</td>
<td>4 mm Hg</td>
<td>3 mm Hg ± 0.8</td>
</tr>
<tr>
<td>1000 days</td>
<td>2.0%</td>
<td>4 mm Hg</td>
<td>3 mm Hg ± 0.8</td>
</tr>
</tbody>
</table>

CO₂ Levels

- 0.25% (0.25 mm Hg)
- 0.5% (1.9 mm Hg)
- 1.0% (7.6 mm Hg)
- 1.5% (10.5 mm Hg)
- 2.0% (15 mm Hg)

Terrestrial Levels

Pathways to Progress
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NASA Human Space Flight

One Year ISS and Next Generation Missions

<table>
<thead>
<tr>
<th>Mission</th>
<th>Average Days</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mercury</td>
<td>n = 6</td>
</tr>
<tr>
<td>Gemini</td>
<td>n = 20</td>
</tr>
<tr>
<td>Apollo</td>
<td>n = 33</td>
</tr>
<tr>
<td>Apollo-Soyuz</td>
<td>n = 3</td>
</tr>
<tr>
<td>Skylab</td>
<td>n = 9</td>
</tr>
<tr>
<td>Space Shuttle</td>
<td>*n = 697</td>
</tr>
<tr>
<td>Mir</td>
<td>n = 7</td>
</tr>
<tr>
<td>International Space Station</td>
<td>*n = 37</td>
</tr>
</tbody>
</table>

* Person-flights; may include multiple-time flyers within program
Extra Vehicular Activity
Thank You

Additional Thanks to some other colleagues;
Daniel Gazda,
Dick Danielson,
Eddie Semones
Lots of Others