The Human System: Enabling Successful Human Exploration and Mitigating Risk

Bonnie J. Dunbar, PhD

Purpose:

To Describe How the **Human System** Drives Exploration Spacecraft Design, Mission Design, and Operations:

- **What** do we know now about the human in space and what don’t we know?
- **When** Must Critical Decisions Be Made?
- **What** Is the Role of the ISS for Supporting Human Health and Systems Design?

The Origin of Flight Medicine

"During World War I, Great Britain discovered that out of every 100 fliers killed, only two died in combat and eight died due to defective aircraft. Ninety of those killed died due to individual causes, with 60 of these being physical defects. With the institution of an aviation medical program, deaths due to physical defects were reduced to 12% in 3 years…..

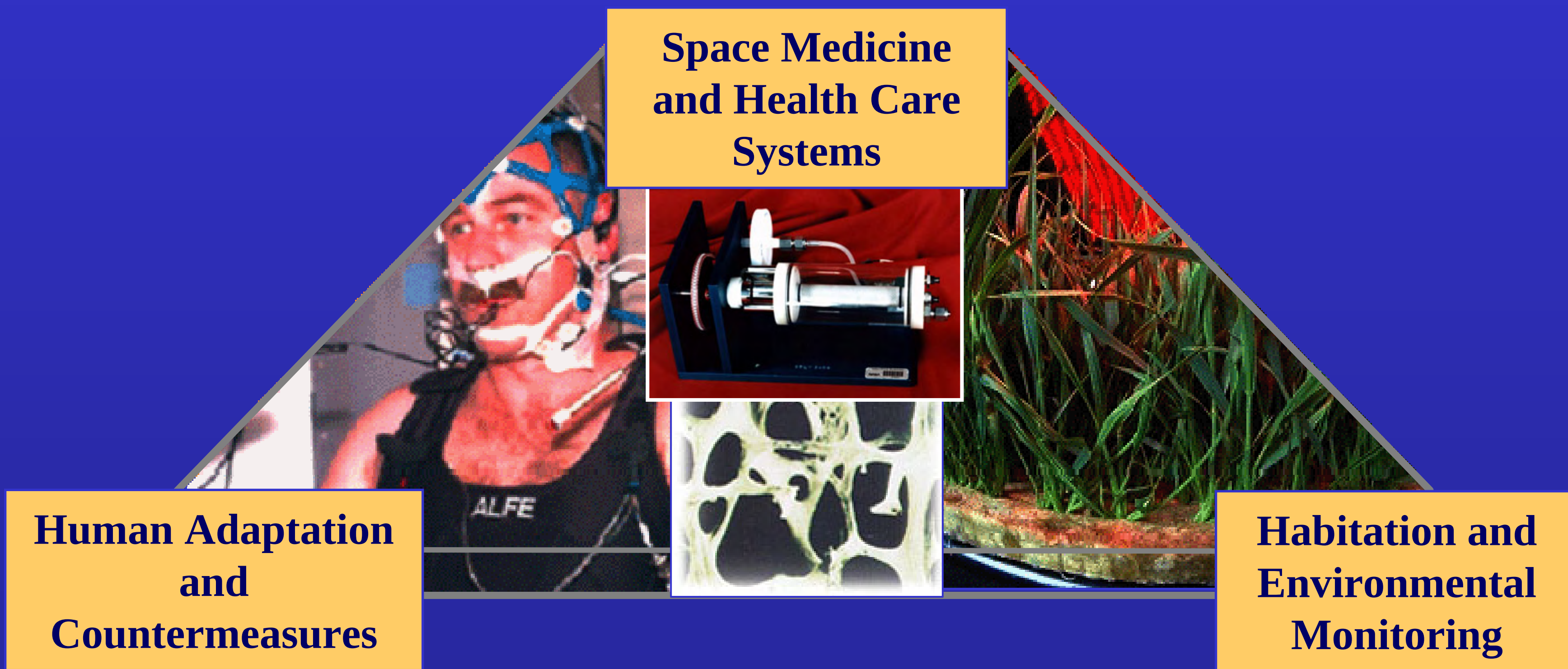
In the latter 20th century, a renewed emphasis on the "human" has occurred. As USAF Aircraft and missions become more complex, aircrews have increasingly become more tasked to stay ahead of the machine."

---USAF Flight Surgeon's Guide---


USAF Aerospace Medicine and the bioastronautics community began as early as 1949, leveraged from data developed by the Germans at Peenemunde. Later led to the establishment of School of Aviation Medicine at Brooks Air Force Base.

Bioastronautics Elements

All elements of Bioastronautics rely upon development and integration of enabling technologies.



Three Missions dedicated to the acquisition of data related to the effects of space on the human body. Utilized by the Soviet Union to extend Salyut Flights.

Discovery of Bone Loss and Other Changes

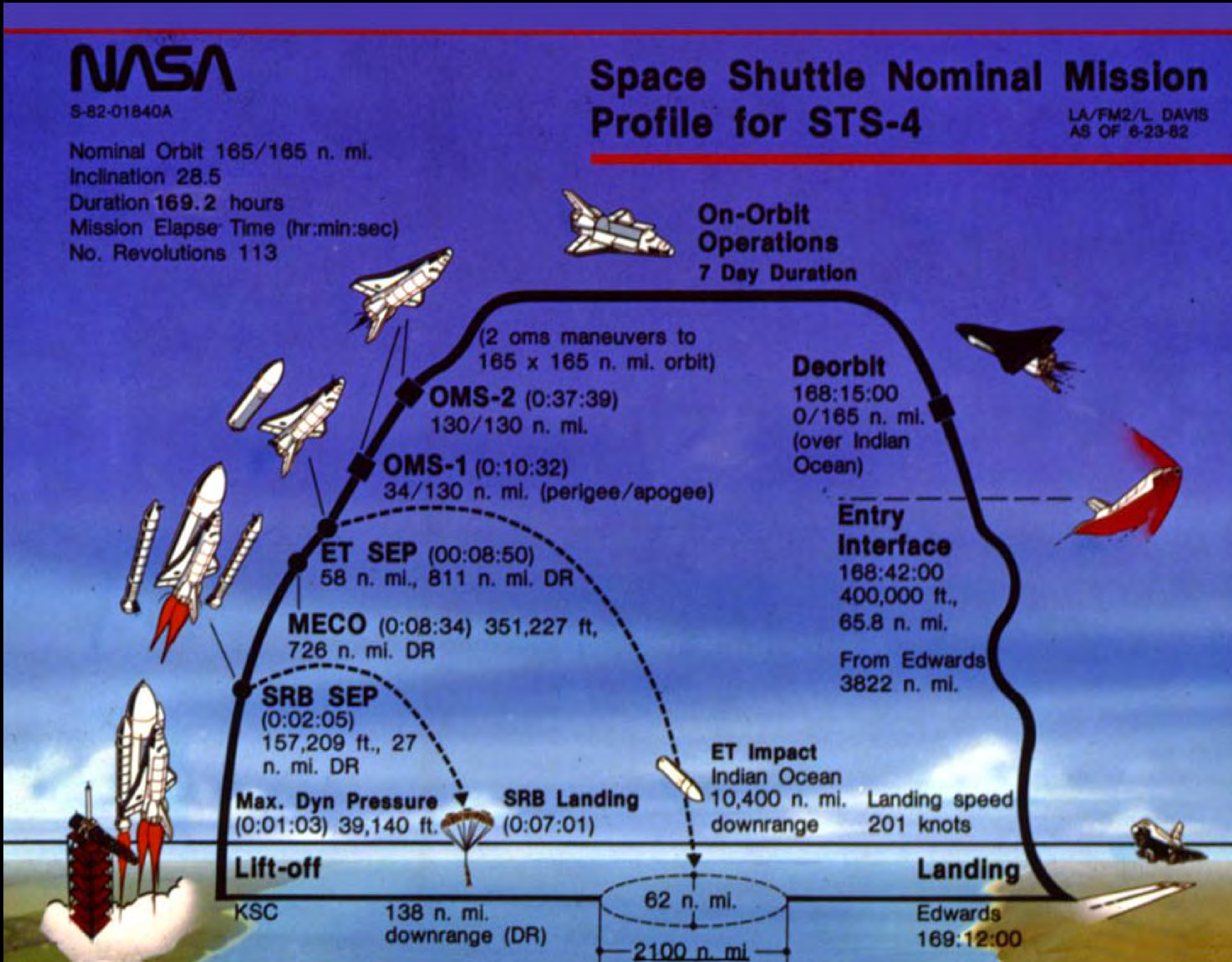
April 1981

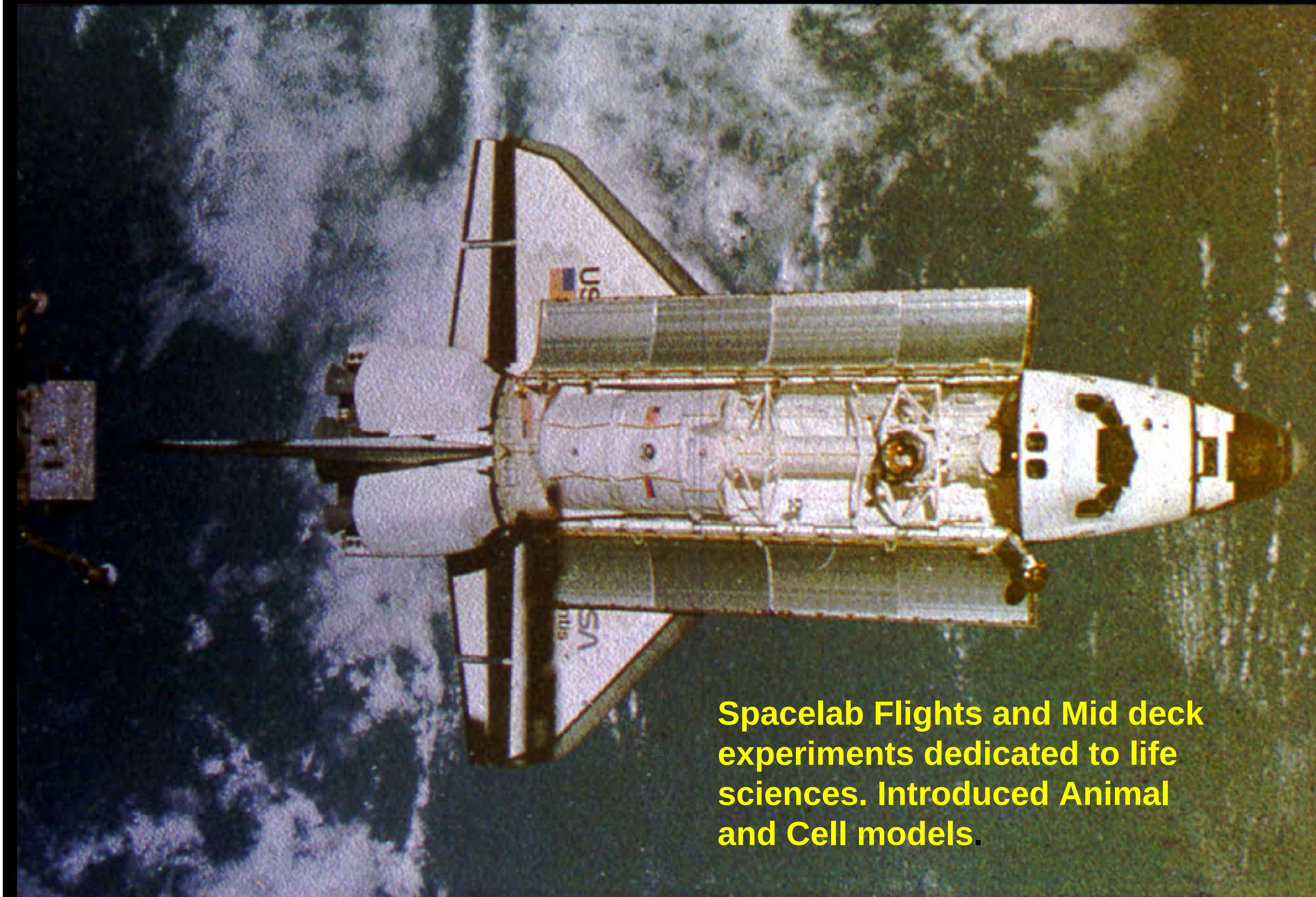
STS-1

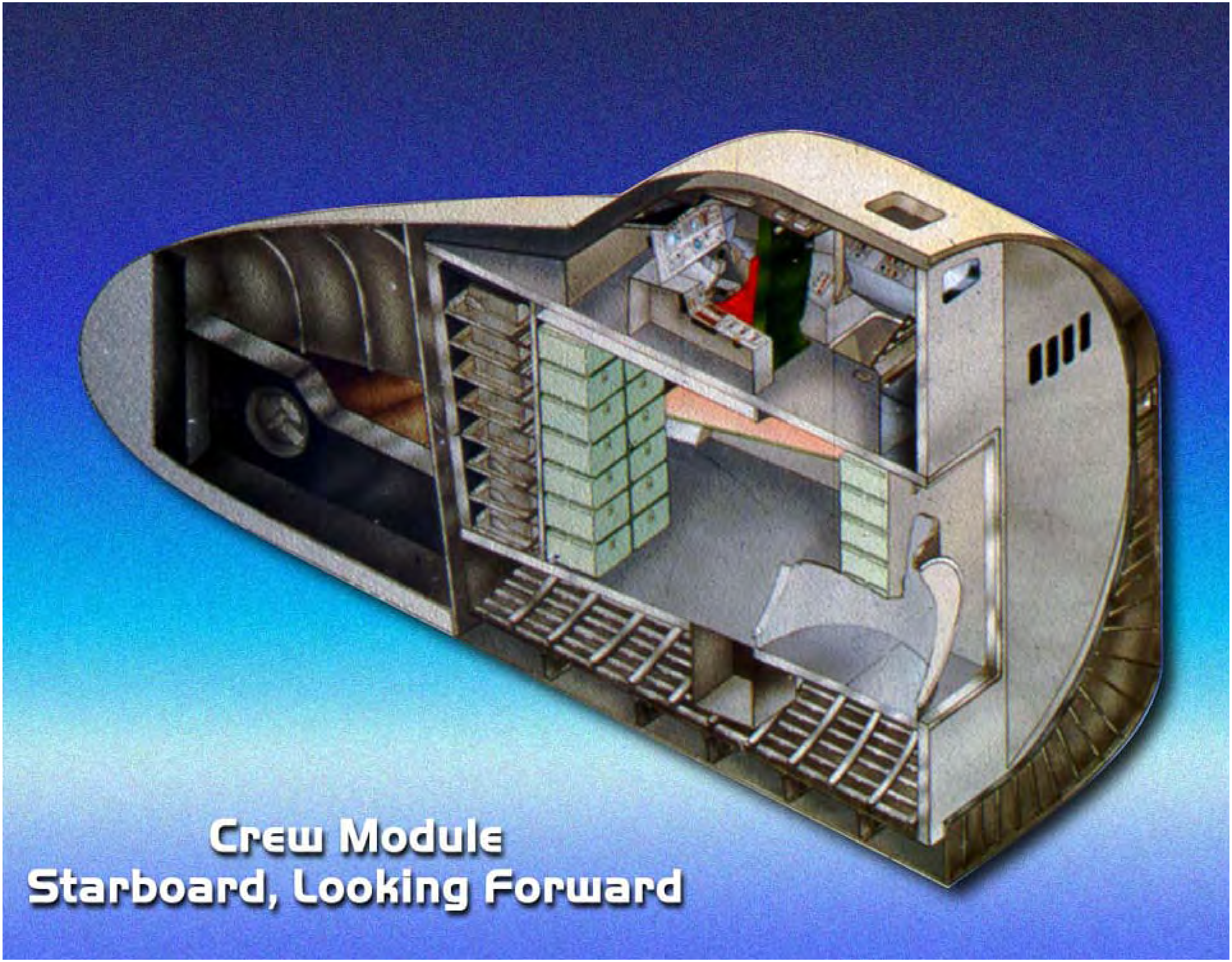
Discovery of Fluid Loss

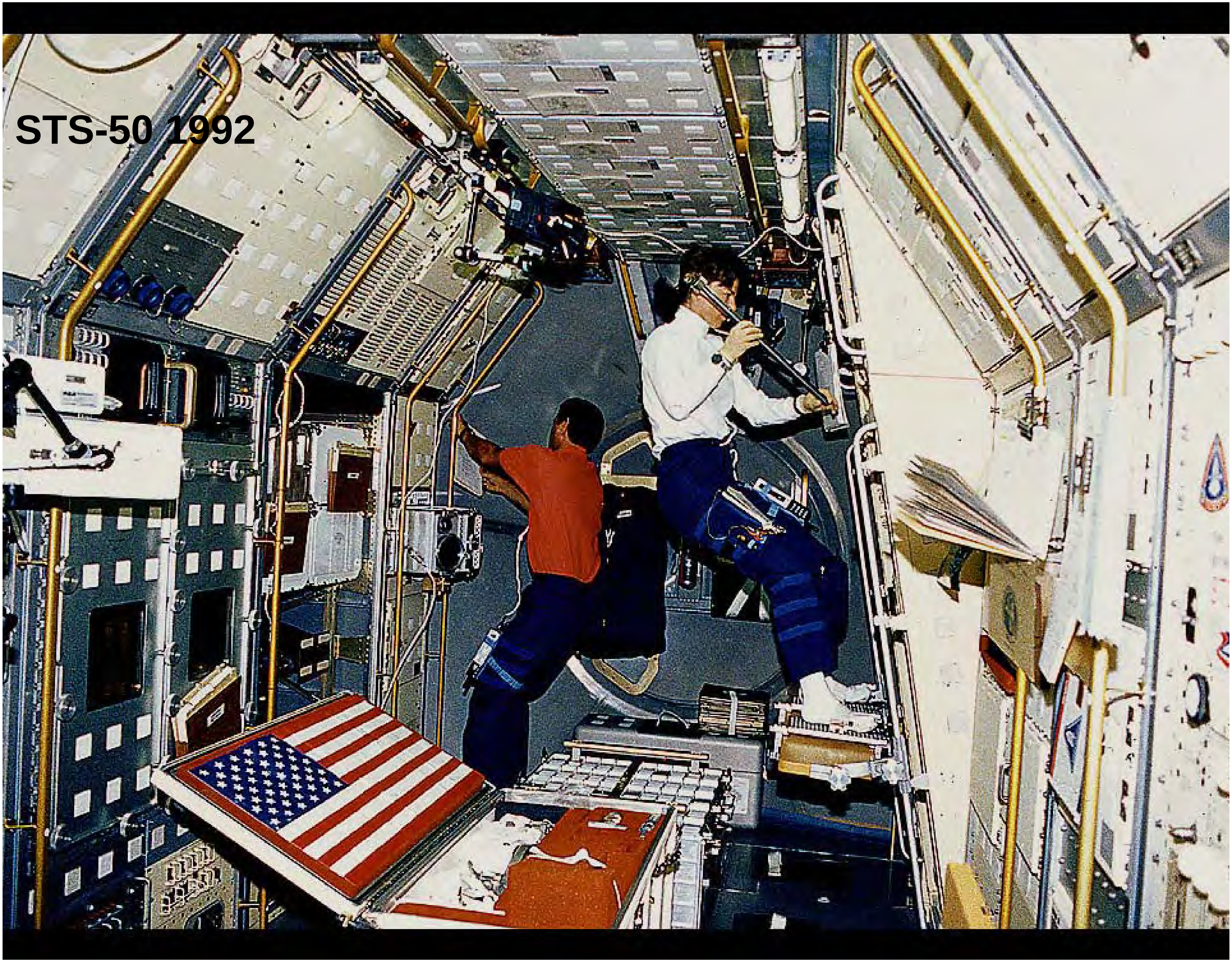
Expansion of Anthropo-metrics

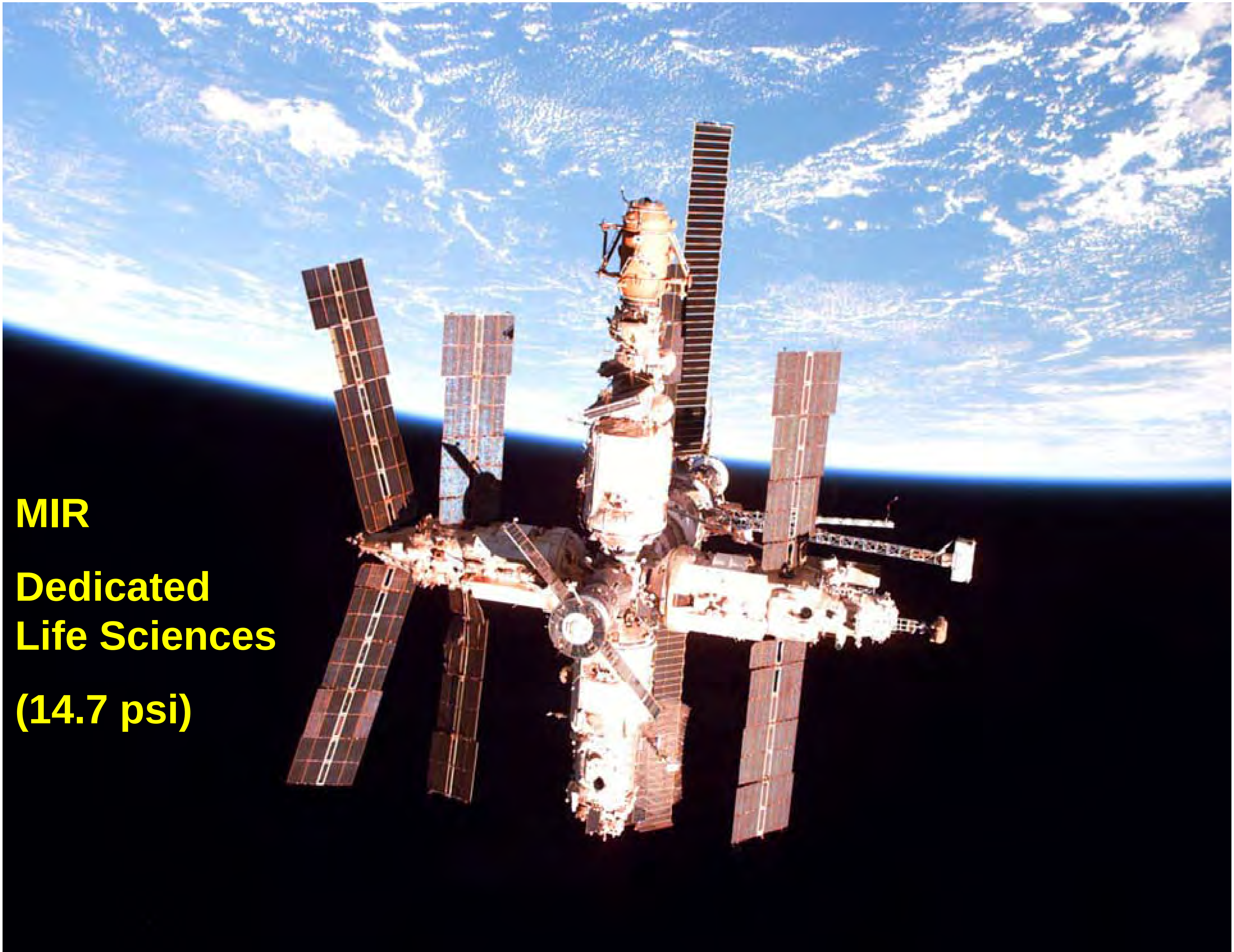

United States


NASA
S-82-01840A
Space Shuttle Nominal Mission Profile for STS-4
LA/FM2/L. DAVIS AS OF 6-23-82
Nominal Orbit 165/165 n. mi.
Inclination 28.5
Duration 169.2 hours
Mission Elapse Time (hr:min:sec)
No. Revolutions 113
On-Orbit Operations
7 Day Duration
(2 oms maneuvers to 165 x 165 n. mi. orbit)
OMS-2 (0:37:39) 130/130 n. mi.
OMS-1 (0:10:32) 34/130 n. mi. (perigee/apogee)
ET SEP (00:08:50) 58 n. mi., 811 n. mi. DR
MECO (0:08:34) 351,227 ft, 726 n. mi. DR
SRB SEP (0:02:05) 157,209 ft., 27 n. mi. DR
Max. Dyn Pressure (0:01:03) 39,140 ft.
SRB Landing (0:07:01)
Lift-off
KSC
138 n. mi. downrange (DR)
ET Impact Indian Ocean 10,400 n. mi. downrange
62 n. mi.
2100 n. mi
Deorbit 168:15:00 0/165 n. mi. (over Indian Ocean)
Entry Interface 168:42:00 400,000 ft., 65.8 n. mi.
From Edwards 3822 n. mi.
Landing speed 201 knots
Landing
Edwards 169:12:00


Spacelab Flights and Mid deck experiments dedicated to life sciences. Introduced Animal and Cell models.


Crew Module
Starboard, Looking Forward


STS-50 1992


MIR
Dedicated
Life Sciences
(14.7 psi)

STS-89

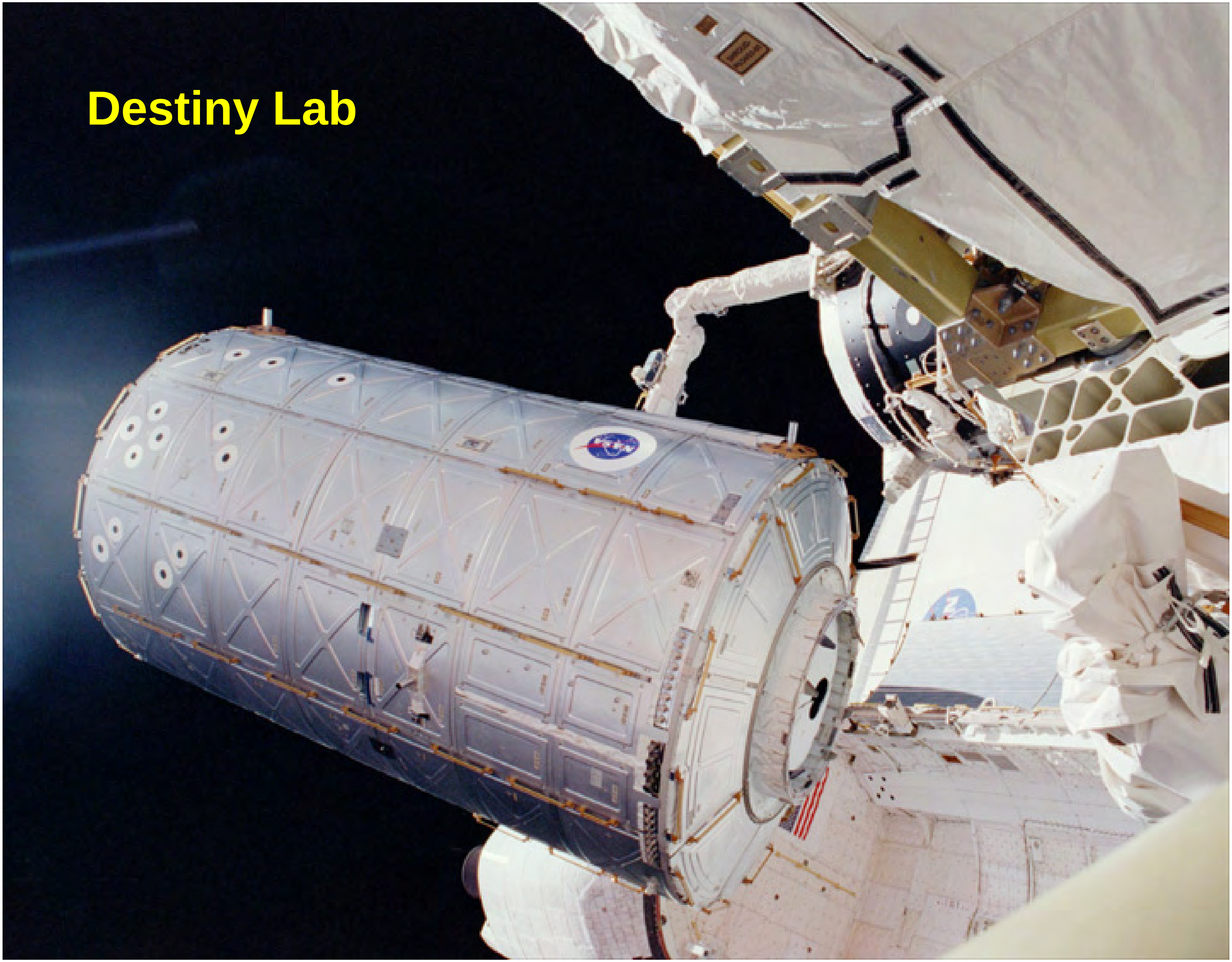
January 22-31, 1998

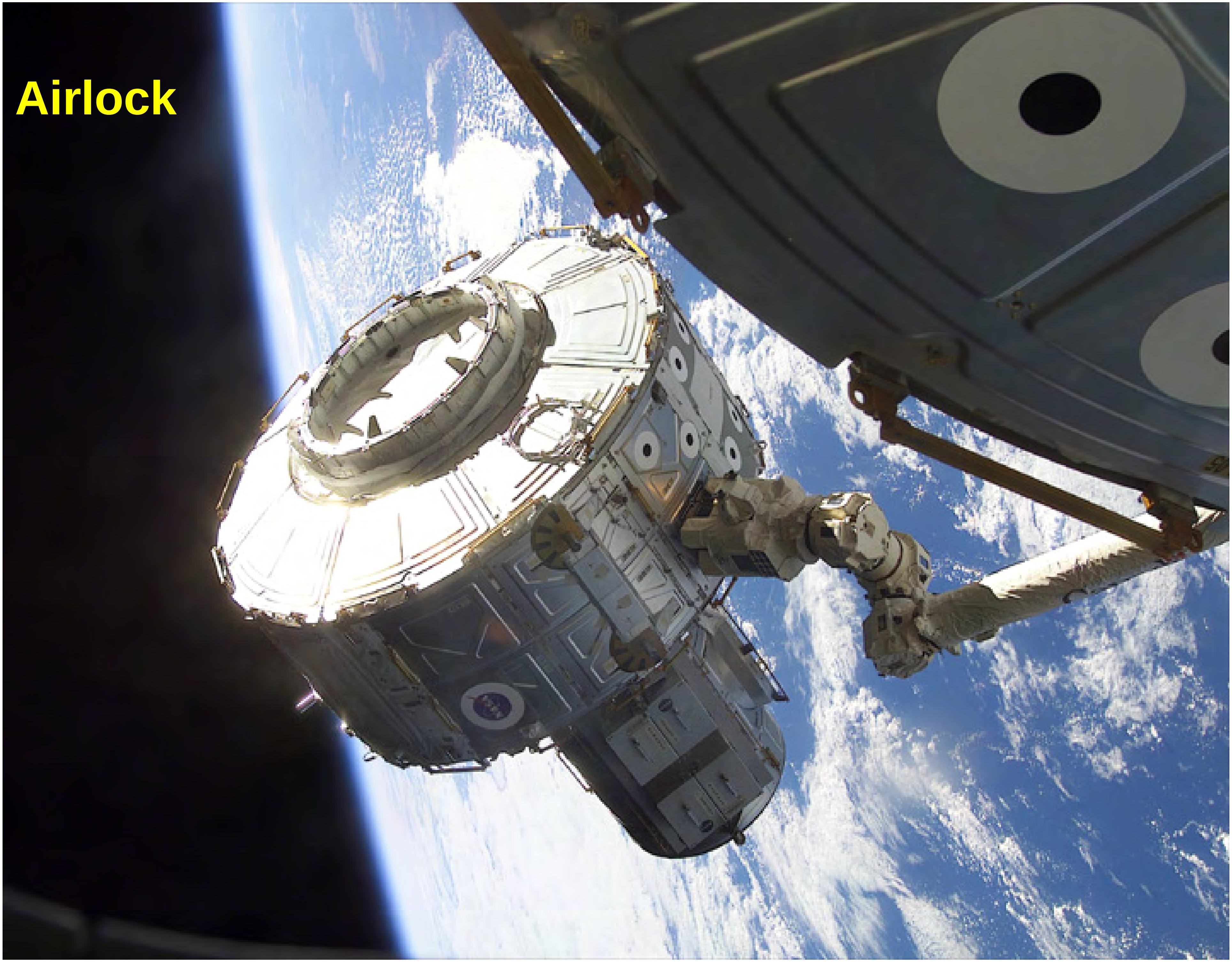
Eighth docking mission to

Russian Space Station MIR


ISS
14.7 psi
Life Sciences

Destiny Lab




Airlock

Where is US Human Spaceflight Biomedical, Habitability, and Environmental Expertise Captured?

JSC Space Life Sciences Directorate (SLSD) is the Agency Core Capability for Human Health Risk Mitigation During Space Exploration

Mercury---Gemini---Apollo---Apollo-Soyuz---Skylab---Space Shuttle/Spacelab---MIR Space Station---International Space Station

- **Over 45 years of Experience in**
  - **Microgravity Health Research and Risk Mitigation**
  - **Real Time Medical Support: Flight Surgeons**
  - **Medical Care Kits**
  - **Human Performance Specifications for Spacecraft Design**
  - **Food Systems**
  - **Environmental Control and Life Support System (ECLSS) Quality Specifications**

- **World Center For Bioastronautics Subject Matter Experts, Habitability and Environmental Engineers**
  - **Agency Resource for all new spacecraft: SLI, OSP, X-38, CEV**
  - **Resource for Domestic Policy Makers/Technical Forums**
  - **Recognized as the International Professional Organization Lead by ESA, JAXA, CSA, and RSA**
  - **Nationally and Internationally Recognized Scientists**
  - **Guides and Integrate activities of the National Space Biomedical Research Institute (NSBRI)**
  - **Requirements Generators for Spacecraft Design, Medical Standards, and definition of future research needs (NRA Peer Reviewed).**
  - **Recognized as the US and Agency integrator for Humans into the Spacecraft**

This integrated Corporate Knowledge exists no where else in the US, either in other Federal Agencies, in Universities or in Industry

JSC Space Life Sciences Directorate

- **SA/DIRECTORATE OFFICE**
  Director - *Jeffrey R. Davis, M.D.*
  - **SA5/Office of the ISS Program Scientist**
  - **SA2/Bioastronautics, Exploration Research & Technology**
  - **SA3/Bioastronautics, Operations**
  - **SA4/Institutional Management and Program Support**

Support to Space Shuttle, ISS, and Exploration Programs

- **SD/Space Medicine & Health Care Systems Office**
  - SD2/Medical Operations
  - SD3/Occupational Medicine
  - SD4/Medical Informatics and Health Care Systems
- **SF/Habitability & Environmental Factors Office.**
  - SF2/Environmental Factors
  - SF3/Habitability and Environmental Factors
- **SK/Human Adaptation & Countermeasures Office**
  - SK2/Biomedical Research & Countermeasures Projects
  - SK3/Biomedical Research & Operations Laboratories

Guiding Principles

- **Agency is responsible for Crew Health and Safety**
  - Ensure Mission Success through crew health and performance
  - Protect against or mitigate lifetime health effects
- **Agency Supports CAIB Recommendations**
  - Must Prove the System is Safe with Data
- **Research and Technology Investments are directed towards Risk Mitigation of adverse effects on the Human System which impact mission success**

RISK MITIGATION STRATEGIES

General Process for Human Health Risk Identification and Mitigation

- Risk Identification:
  - Identified through actual spaceflight events on a continuing basis (likely to continue with expanding exploration)
  - Identified through focused in flight research (e.g. Skylab, DSOs, Spacelab, MIR, ISS)
  - Identified through peer evaluations/analyses (e.g. radiation exposure limits)
  - Captured in “Bioastronautics Roadmap”,

- Risk Mitigation:
  - Development of “Countermeasures”, (e.g. exercise, drugs, shielding, etc)
  - Tested (if possible) on Earth with animal and human subjects (e.g. bedrest and Artificial Gravity Centrifuge: microgravity analogs)
  - Research supported by cell science, and other analytical tools
  - Tested and Verified with Humans in Microgravity (Shuttle, ISS, Long Duration Lunar)

- Real Time Monitoring
  - Continuous Real Time support by Certified Flight Surgeons
  - Ensure implementation of Risk Countermeasures
  - Identification and remediation of real time medical problems
  - For new problems- Collaboration with Bioastronautics Discipline Scientists (Human Adaptation and Countermeasures Office) and with Habitability and Environmental Factors Office ----reinitiates the Risk Identification Cycle.

Formalized Human Health Systems Risk Management Processes and Strategy

IDENTIFY

- Pre Mercury Animal
- Mercury
- Gemini
- Apollo
- Apollo Soyuz
- Skylab
- Space Shuttle
    - Spacelab
    - Extended Duration Orbiter (EDO)
    - Detailed Supplemental Objectives (DSO)
- Shuttle-MIR Phase 1
- ISS
- NASA Research Announcements (NRA)
- Earth Analogs: cells, animals, and human bedrest
- **HSIS 3000**
- **Bioastronautics Roadmap**

ANALYZE

- SLSD Discipline Scientists
- Discipline Working Groups (DWGs)
- NRA's
- NSBRI
- Tools:
    - PRA

PLAN

- Artificial G
- Human Health and Countermeasures
- ISS Utilization
- Radiation Protection
- NSBRI
- Discipline Leads

TRACK

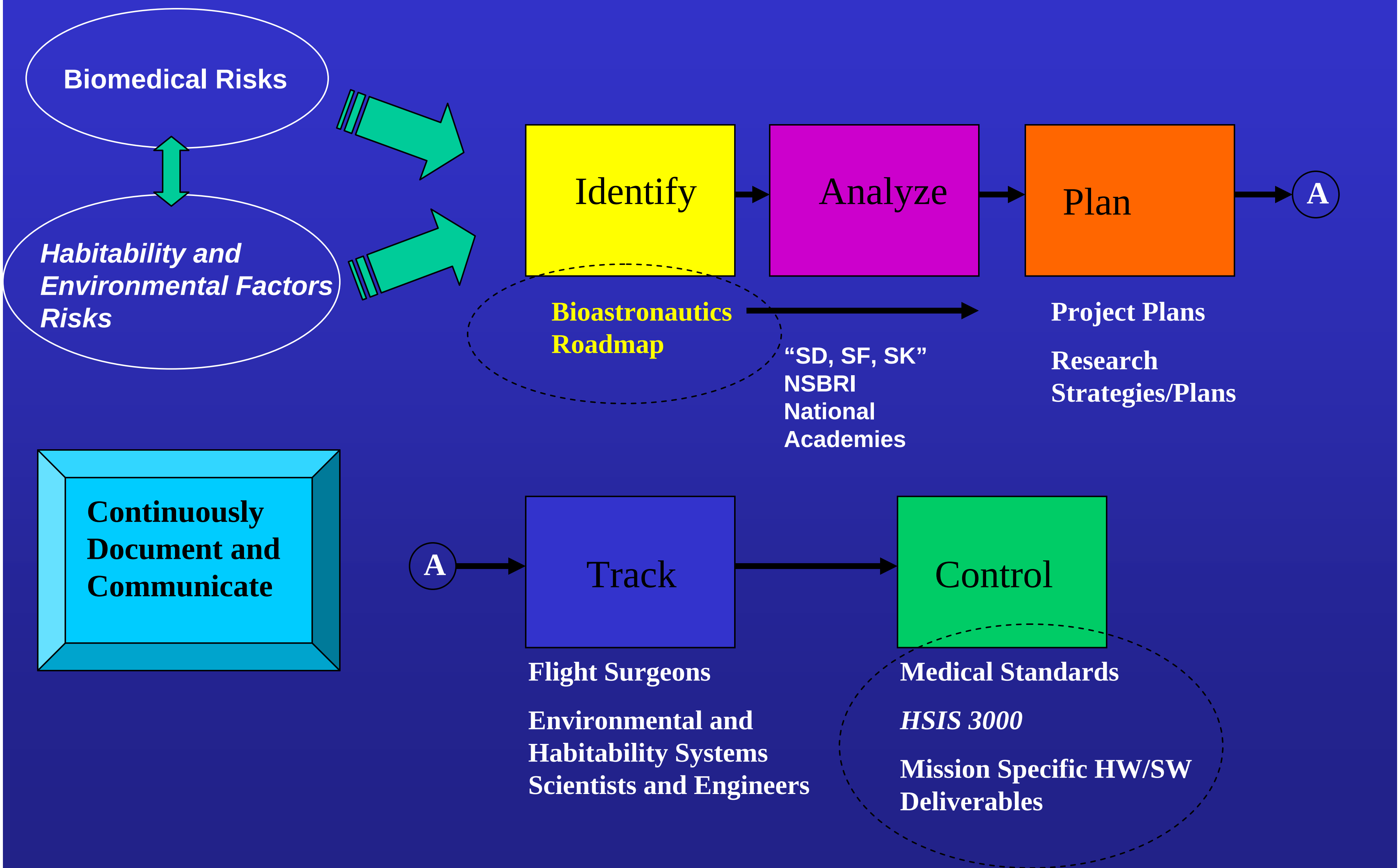
- Project CCBs
- EVM
- SLSD IRMP
- SLSD DCB
- JSC IRMA
- ISS IRMA
- SSP IRMA
- ESMD Constellation ARM
- ESMD HSRT ARM

CONTROL

- Budget
- Orbital Environment Access and return mass
- Earth Based Analogs: cells, animals, and bedrest
- Real Time Flight Surgeons
- Real Time Habitability and Environmental Control Engineers
- MORD Equivalents
- **Medical Standards**
- HSIS Std 3000
- PEL/POL Standards

Continuously Document and Communicate

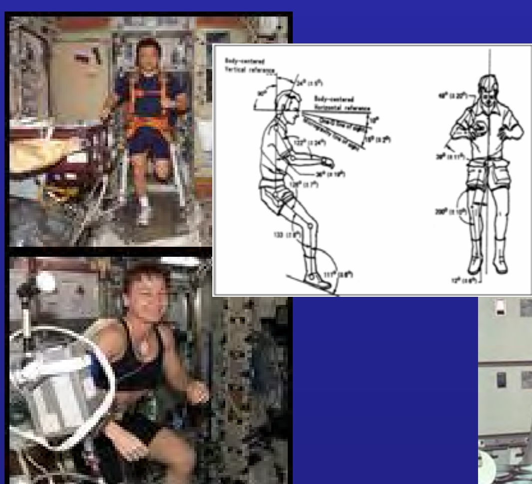
Exploration Focused Process for Human Health Risk Identification and Mitigation



What *Do* We Know About Humans in Space?

What *Don't* We Know?

Human Health
Space Craft Habitability and Environmental Factors



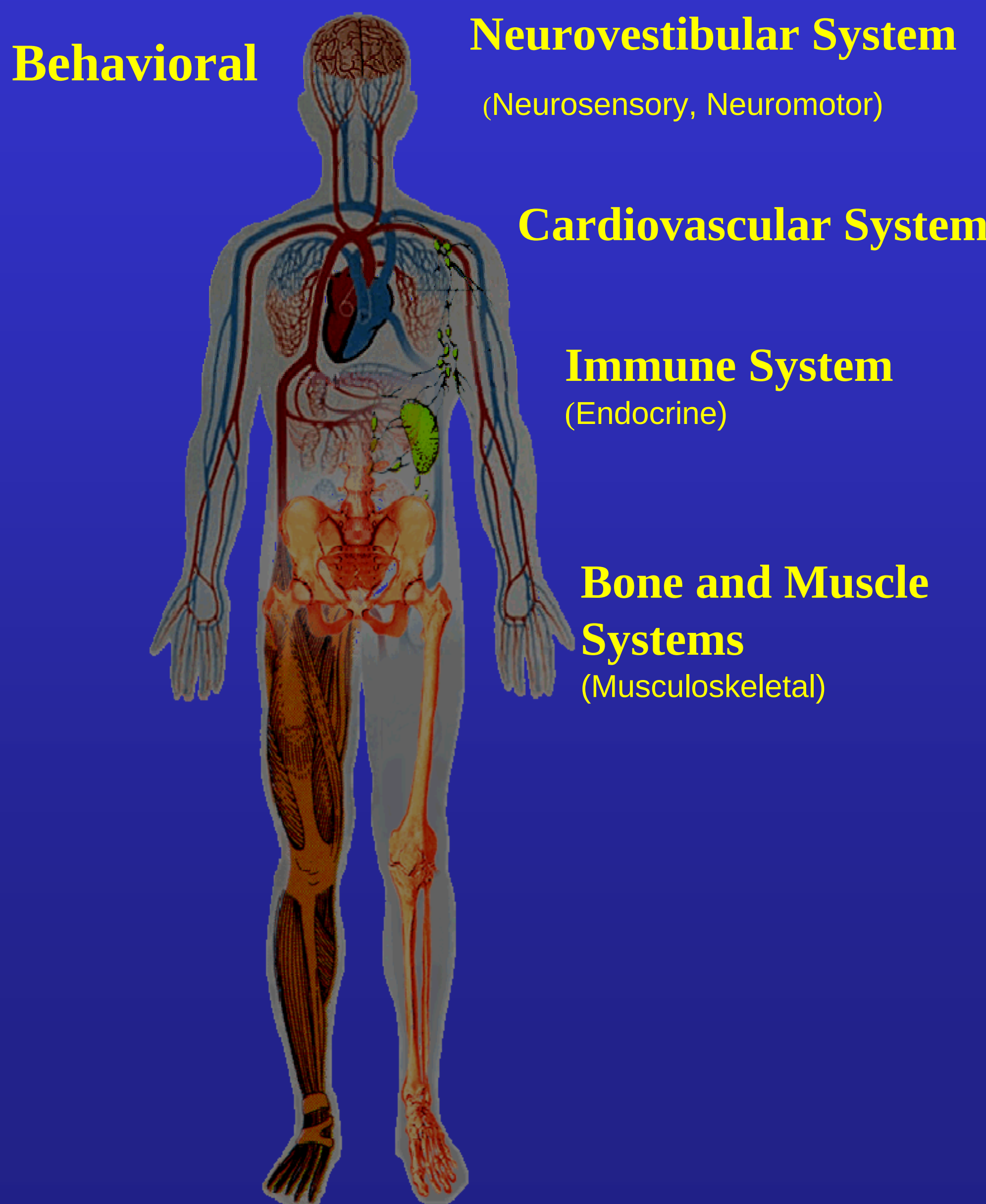
Human Health

Summary of Known Space Flight Medical Risks To the Human System and Subsystems

Astronauts experience a spectrum of adaptations during space flight and even post flight

Behavioral Changes
Balance disorders
Cardiovascular deconditioning
Decreased immune function
Muscle atrophy
Bone loss

Additional influences include the unique Radiation environment and Nutritional/Food Limitations



Expansion of Medical Risks to the Human System in Space

Physiological/Medical Risks

- Carcinogenesis due to *immune* system changes
- Acceleration of age-related osteoporosis *(bone)*
- Manifestation of previously asymptomatic *cardiovascular* disease
- Occurrence of serious *cardiac* dysrhythmias
- *Muscle* Atrophy
- *Vestibular*/Balance disturbances
- Toxic Exposure to air/water/food contaminants
- Nutritional Deficiencies

Effects of Radiation

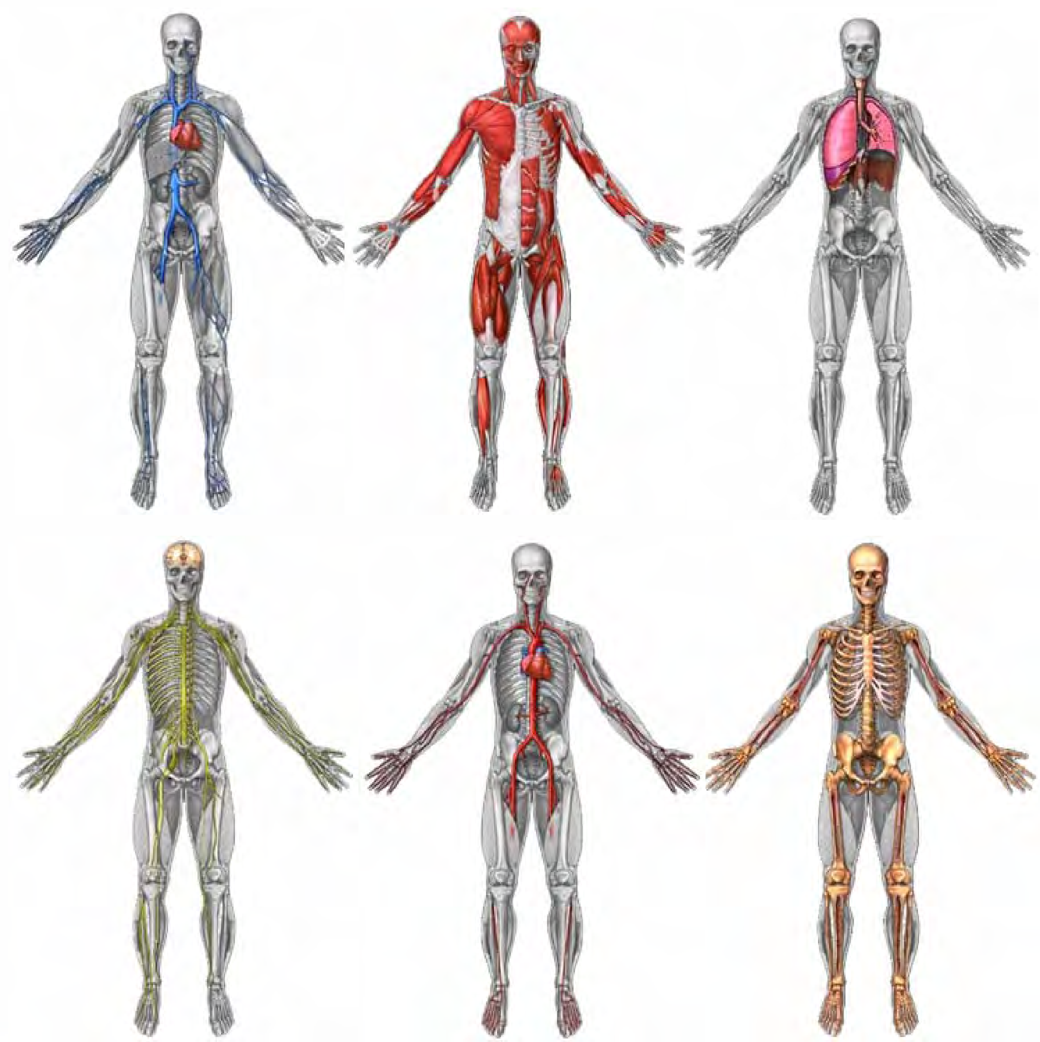
- Carcinogenesis
- Synergistic effects with microgravity or environmental factors
- Late degenerative tissue effects

Medical Practice Problems

- Trauma & acute medical problems
- Illness & ambulatory health problems
- Renal stone formation
- Toxic exposure

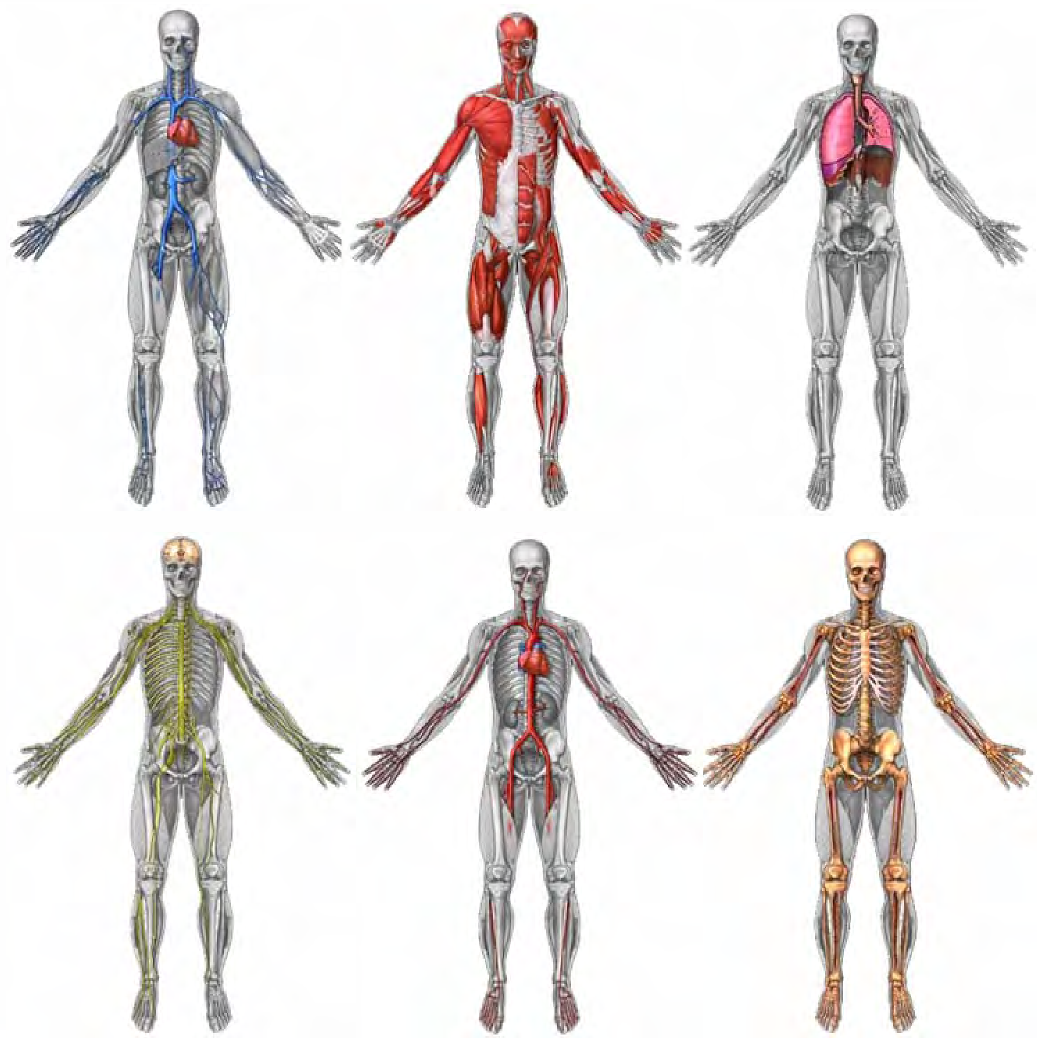
Behavior and Performance Problems

- Disorientation and Inability to perform landing, egress, or other physical tasks, especially during/after g-level changes
- Poor psychosocial adaptation
- Sleep & circadian rhythm problems



Documented Career Medical Events for Healthy Astronauts and Cosmonauts: Implications for In Flight Medical Care

- Ventricular tachycardia, Exercise Induced
- Angina
- Atrial Fibrillation
- Allergic Reaction-Severe
- Retinal Detachment
- Appendicitis (2)
- Diverticulitis (2)
- Choledocholoithiasis (3)
- Pancreatitis (2)
- Hemorrhagic Cyst
- Lower GI Bleeding
- Duodenal Ulcer with Upper GI Bleeding
- Stroke (2)
- Cervical Disc Herniation with Impingement on Spinal Cord
- Kidney Stone (14)
- Clostridium Deficile Infection
- Inguinal Hernia
- Olecranon Bursistis r/o Septic Joint
- Hand Bacterial Tenosynovitis
- Pneumonia (2)
- Corneal Ulcer
- Severe Epistaxis
- Dysmoenorrhea
- Sudden Hearing Loss (2)
- Malignant Melanoma



How The "Physiological/Psychological" Medical Standards" are Developed

Space Flight Experience, Data, Lessons Learned

PLUS

Earth Based Medical Standards for Healthy Humans

Mercury
Gemini
Apollo
Skylab**
Shuttle/Spacelab**
MIR Phase 1
ISS

Bone
Cardiovascular
Neurovestibular
Immunology
Nutrition
Muscle
Behavioral
Radiation

NIH
AMA
DOE
OSHA

Do we know that Space flight affects these human systems? YES

Do we know all the specifics of the impacts to mission success and long term health? NO

Have we designed countermeasures for all mission scenarios under consideration? NO

Have we accommodated physiological changes in spacecraft and human factor designs? YES where known, NO where unknown

What are the Physiological/ Psychological Medical Standards?
(What are the limits of loss during the mission)

Bone	>-1SD Bone Mass (Standard Deviations, 1-2%/month loss)
Cardiovascular	75% of VO2 max
Neurovestibular	Clinical standard
Behavioral	Clinical standard
Radiation	3% Lifetime Reduction (Based on OSHA Standards)
Immunology	Specific counts (Requires in flight blood analyses)
Nutrition	80% (Limitations to current food delivery systems)
Muscle	70% (Loss of strength/mass/function)

Note:

It is assumed that no astronaut returns to earth, even from a short flight, with the same level of physiological/psychological state as they left with at launch. All of these standards assume some degradation, but not at the expense of mission success. Crews are also protected from known debilitating life time effects such as radiation poisoning and severe osteoporosis.

Space Craft Habitability and Environmental Factors

How Human Spacecraft Design Standards are Developed (HSIS 3000)

Space Flight Experience, Data, Lessons Learned

PLUS

Earth Based Data and Knowledge for Aircraft, Submarines, and Antarctica

Mercury
Gemini
Apollo
Skylab**
Shuttle/Spacelab**
MIR Phase 1
ISS

- **Spacecraft Human Factors**
- **Environmental Standards and Monitoring**
  - **Water, Air, Noise, Temperature, Pressure, Flammability, Toxicity, Humidity……**
- **Habitability**
  - **Light, Food, Clothing**
- **EVA Suit Design**

DOD
DOE
OSHA
NSF
NASA ARC









Summary of Habitability and Environmental Factors: Risk Mitigation Requirements (HSIS 3000)

- Anthropometry and Human Factors
  - Changes due to microgravity, population differences
- Human Performance Capabilities
  - Vision, Auditory, Cardiovascular, Vestibular, Kinesthesia, Workload, Microgravity Deconditioning (Force and Torque design limits)
- Natural and Induced Environments
  - Atmosphere, Microgravity, Acceleration, Acoustics, Vibration, Ionizing Radiation, Non-Ionizing Radiation, Thermal, Combined Effects
- Health Management Hardware Systems
  - Nutrition, Personal Hygiene, Biological Payloads, Sleep, Biological Gravity Countermeasures, Medical Monitoring, Medical Care, Crew Survival

Documented Environmental Events in Space
Example: Air Quality

- **Shuttle**
  - Combustion events
  - Wire burnt beneath humidifier (STS-6)
  - Teflon sleeve pyrolyzed by electrical short (STS-28)
  - Combustion products from electronics pyrolysis in 2 data display units (STS-35)
  - Formaldehyde pollution from pyrolysis of motor housing in refrigerator (STS-40)
  - Undersized capacitor overheated in laptop causing odor (STS-50)
  - LiOH dust escaped from CO2 removal canisters
  - Microbial production of methyl sulfides from liquid waste (STS-55)
- **Mir**
  - Frequent leaks of ethylene glycol from cooling loops into air which also contaminated water
  - Formaldehyde escaped containment on Mir-18
  - Oxygen candle fire produced various thermal degradation products, e.g. benzene (Feb 97)
  - Overheating BMP beds produced health threatening levels of CO (Feb 98)
- **ISS**
  - Crew sickened in FGB during poor ventilation, probably from rebreathe of exhaled air/CO2 (Flight 2A.1)
  - Freon 218 leaks from SM air conditioner (Apr 01 to Mar 02)
  - METOX canister regeneration caused noxious air-many pollutants in air (Feb 02)
  - Formaldehyde levels periodically exceed long-term limits, especially when debris restricted ventilation (mid 02 to Feb 03)
  - Strong solvent-like odor from Elektron oxygen generator after repair work (Mar 04)
  - Potential acid preservative aerosol escape from Russian urinal problem (Exp 10/Feb 05)

INTEGRATION OF CREW HEALTH AND VEHICLE DESIGN:

Human Health and Spacecraft Design Risk Mitigation Strategies, Standards and Requirements

Three Documents Guiding Standards to Deliverables:

RISK Identification:

- **Bioastronautics Roadmap Risks: (SK)**
  - In development for over a decade: involvement of both internal and external experts
  - Currently being vetted by the National Academies/Institute of Medicine
  - Identifies 45 Top Level Risk Categories and multiple questions to be answered to ensure mission success/crew survivability for >180 day ISS, ~90 day lunar, >600 day Mars)

RISK Control: Standards

- **Medical Standards: Chief Health and Medical Officer (SD/CHMO) (HQ: Dr. Rich Williams)**
  - Standards of Medical Care
  - Standards for Crew Selection and Retention
  - **Physiological/Psychological Standards**
- **Human Systems Integration Standard 3000 (HSIS): (SF)**
  - Ensures that the Spacecraft is appropriately designed for the human system
  - Provides for Life Support, Health Care Systems, Food Systems, Habitability and provides for deconditioned Crew Members to levels identified by Standards.

Advisory Guidance:

"Safe Passage, Astronaut Care for Exploration Missions"

Institute of Medicine, IOM

National Academies

Skylab

1973

84d

STS-32

Extended Duration Orbiter (EDO)

1990

11d

ISS

>180d

General Relationships between the Crew Health Medical Standards, Bioastronautics Roadmap for Risk Mitigation and HSIS Spacecraft Design Requirements

What we know about keeping humans healthy

Known Human Medical Standards

Human Spaceflight Research Data and Lessons Learned (1950's – Present)

MEDICAL STANDARDS:

- **Standards of Medical Care**
- **Standards for Crew Selection and Retention**
- **Physiological/Psychological Standards**

Bone Cardiovascular Neurovestibular Behavioral Radiation Immunology Radiation Nutrition Muscle

CHMO

What we know about keeping humans alive, and productive in space

Unknowns…

Human Systems Integration Standard 3000 (HSIS)

Vol VIII CEV includes:

<u>Anthropometry and Human Factors</u>

<u>Human Performance Capabilities</u> (Vision, Auditory, Cardiovascular, Vestibular, Kinesthesia, Workload, Microgravity Deconditioning)

<u>Natural and Induced Environments</u> (Atmosphere, Microgravity, Acceleration, Acoustics, Vibration, Ionizing Radiation, Non-Ionizing Radiation, Thermal, Combined Effects)

<u>Health Management Hardware Systems</u> (Nutrition, Personal Hygiene, Biological Payloads, Sleep, Biological Gravity Countermeasures, Medical Monitoring, Medical Care, Crew Survival)

Bioastronautics Roadmap Risks

•Over a Decade in Development/Review by IOM

•41 Major Risks: Bone, Cardiovascular, Air and Water Contamination, Immune Dysfunction, Muscle, Microbrial Environment, Sensory/Motor, Motion Sickness, Nutrition, Illness and Trauma, Pharmacology, Human Performance, Sleep, Circadium Rythym, Radiation Risks,…

What are the open Risks?

Tasks and Deliverables

Spacecraft Design

Health Care System

Countermeasures

Example: Relationship between the ***Bone Permissible Outcome Limit (POL),*** Bioastronautics Roadmap for Risk Mitigation and HSIS Spacecraft Design Requirements

EXAMPLE: Bone

Known Human Medical Standards (Osteoporosis)

Human Spaceflight Research Data and Lessons Learned (Skylab 84 day, Shuttle/Spacelab, MIR and ISS)

Bone POL*

Maintain Bone Mass at greater than or equal to -1SD at end of space flight (~30% loss for 1000d)

(*Bone and Muscle are interrelated)

CHMO

1/6 g? 1/3g?

Unknowns……

Human Systems Integration Standard 3000 (HSIS)

Vol VIII CEV

5.3.3.3 Impact Accelerations Design Limits

Guidelines for neck injury are based on data from NHTSA automotive injuries modified by Aviation scenarios for healthy men and women.

5.3.3.4 Acceleration Countermeasures

Musculoskeletal System:…In flight resistive exercise

5.3.3.5 Future Research

To ascertain human responses to sustained and impact accelerations following long duration microgravity exposures future …***studies shall be required.***

Bioastronautics Roadmap Risks

01 Accelerated Bone Loss and Fracture Risk

03 Injury to Joints and Intervertebral Structures

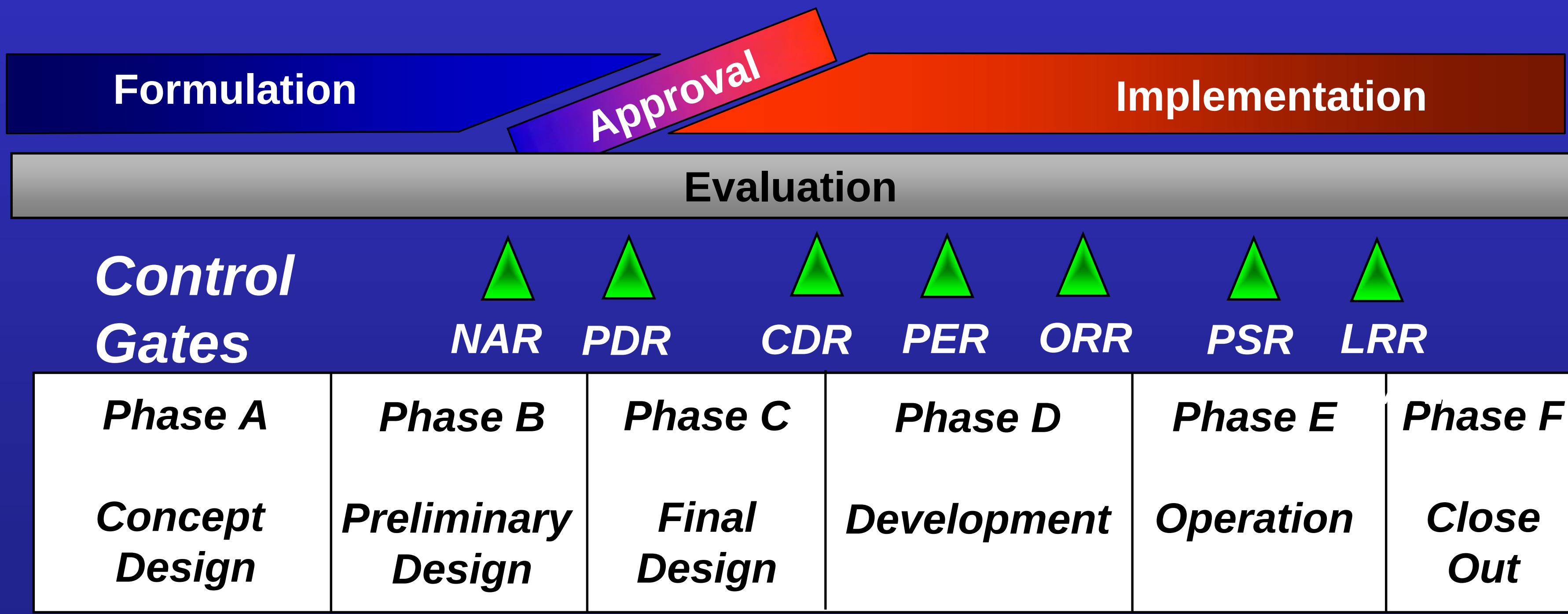
16 Questions and 66 Tasks to Risk Reduction Deliverables

Spacecraft Design

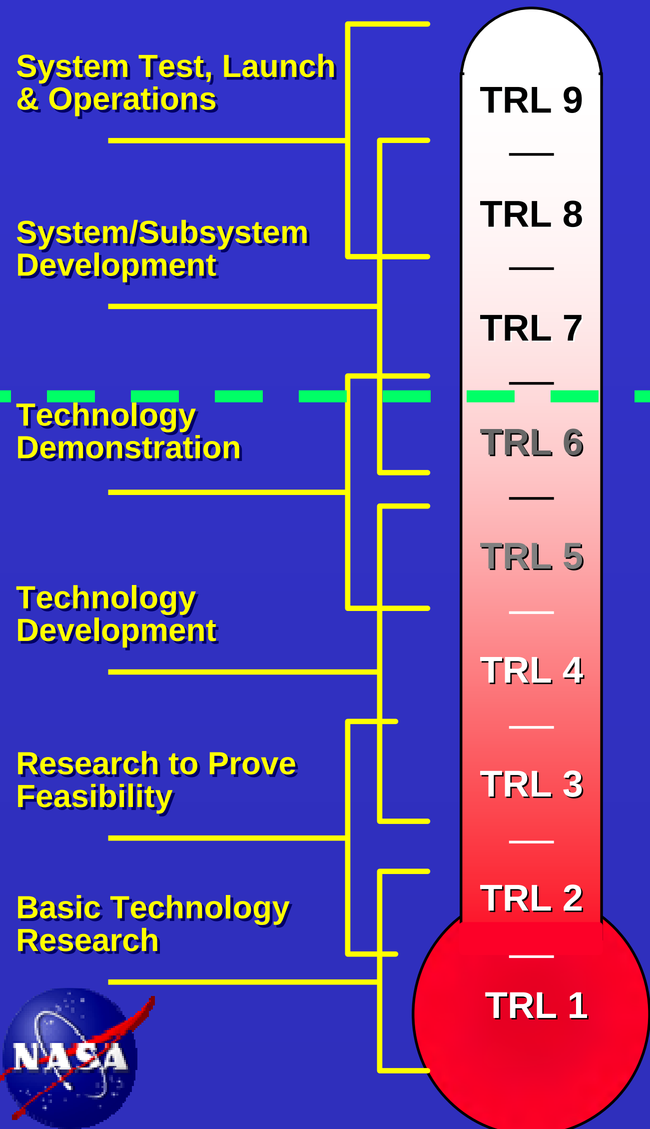
(Acceleration Limits, Force and Torque Limits, Exercise Countermeasure Systems, Nutritional Systems)

Health Care System Countermeasures

WHEN MUST CRITICAL DECISIONS BE MADE?



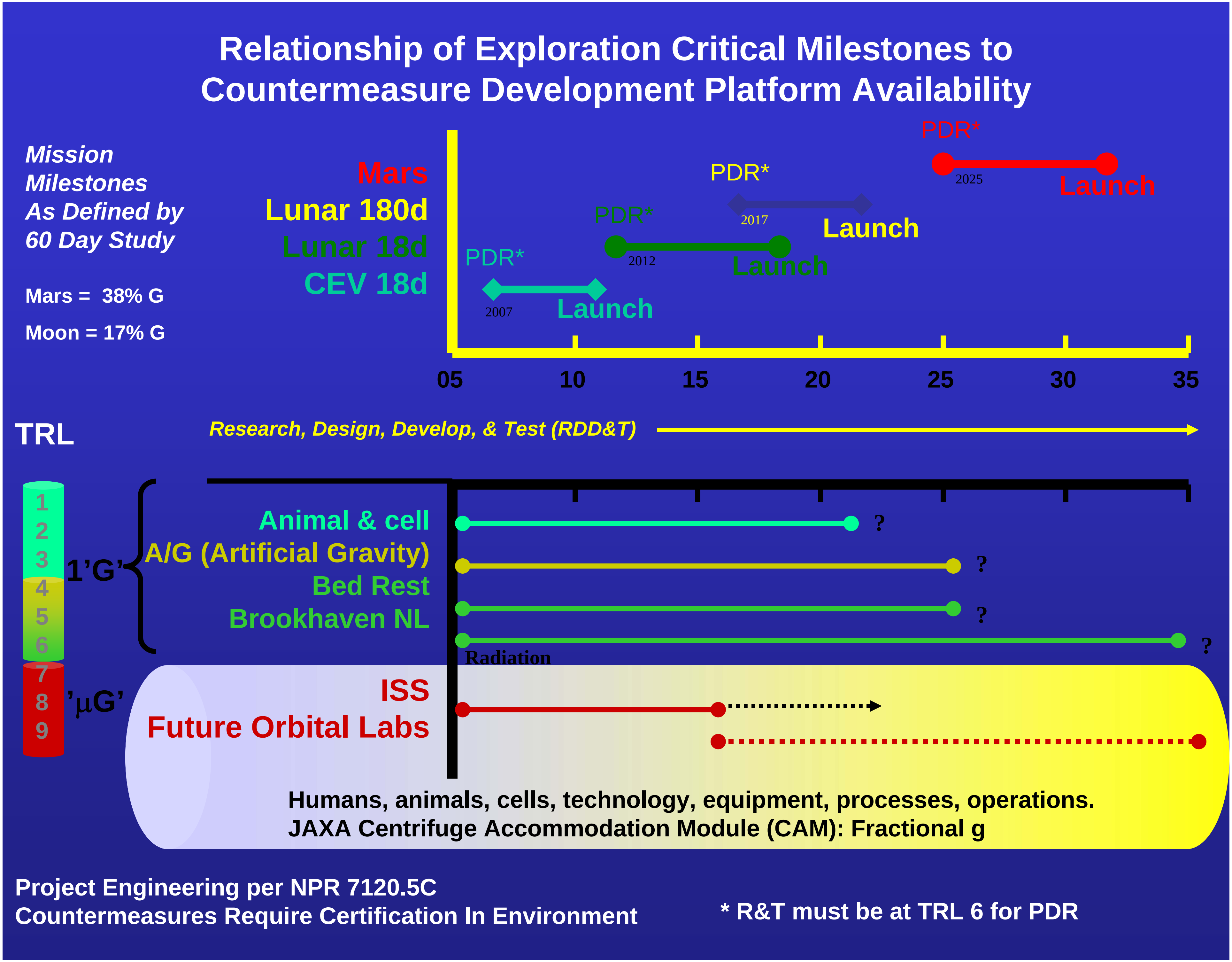
NASA Technology Readiness Levels (TRL)



- TRL 9: Actual system “flight proven” through successful mission operations
- TRL 8: Actual system completed and “flight qualified” through test and demonstration (Ground or Flight)
- TRL 7: System prototype demonstration in a space environment
- TRL 6: System/subsystem model or prototype demonstration in a relevant environment (Ground or Space)
- TRL 5: Component and/or breadboard validation in relevant environment
- TRL 4: Component and/or breadboard validation in laboratory environment
- TRL 3: Analytical and experimental critical function and/or characteristic proof-of-concept
- TRL 2: Technology concept and/or application formulated
- TRL 1: Basic principles observed and reported

Critical Path Milestone Assumptions

- **Exploration Architecture Milestones:**
  - CEV, Lunar and Mars PDRs and Launches currently being proposed by 60 day architecture team (shown on following chart)
  - All Systems must be at Technology Readiness Level (TRL) = 6 (on scale of 9) by PDR: **System/subsystem model or prototype demonstration in a relevant environment (Ground or Space)**
  - TRL =7 is defined as: **System prototype demonstration in a space environment**
- **Astronaut Health Countermeasure Hardware/Software and Medical Care Systems for relevant exploration mission must be at TRL=6 by PDR or Capability Readiness Level (CRL) = 6**
- **The only platforms for proceeding from TRL = 6 to TRL = 7 are the Space Shuttle (>~7 days) through 2010 and International Space Station (ISS) through at least 2016 (CEV powered down while docked)**
- **The only potential for fractional g Lunar and Mars risk mitigation research is with the Centrifuge Accommodation Module (CAM) on ISS, developed by JAXA in Japan.**



Relationship of Exploration Critical Milestones to Countermeasure Development Platform Availability
Mission Milestones As Defined by 60 Day Study
Mars = 38% G
Moon = 17% G
Mars
Lunar 180d
Lunar 18d
CEV 18d
PDR*
2007
Launch
PDR*
2012
Launch
PDR*
2017
Launch
PDR*
2025
Launch
05
10
15
20
25
30
35
TRL
Research, Design, Develop, & Test (RDD&T)
1
2
3
4
5
6
7
8
9
1'G'
'µG'
Animal & cell
A/G (Artificial Gravity)
Bed Rest
Brookhaven NL
?
?
?
?
Radiation
ISS
Future Orbital Labs
Humans, animals, cells, technology, equipment, processes, operations.
JAXA Centrifuge Accommodation Module (CAM): Fractional g
Project Engineering per NPR 7120.5C
Countermeasures Require Certification In Environment
* R&T must be at TRL 6 for PDR

Critical Path Schedule Observations and Issues

- CEV PDR: 2006
  - Astronaut Health Countermeasures and Design Data for Radiation Protection must be at TRL = 6 in 2006. Limited by budget
  - Data is not yet available for Vehicle Radiation Protection.
  - Vehicle not sufficiently designed to determine medical care capability

- Short Lunar PDR: 2012
  - Astronaut Health Countermeasures and Design Data for 18 day Lunar Mission must be at TRL = 6 in 2012. Access to ISS is not available until 2010
  - Current and Projected SLSD Out year budgets will not support RDD&T on this schedule

- Long Lunar PDR: 2016
  - Astronaut Health Countermeasures for 180 day Lunar Surface Stay must be at TRL-6 by 2016:
  - Limited upmass access on Space Shuttle through 2010 (All Shuttle upmass devoted to ISS completion through 2010)
  - Current Access Window on CEV or ATV to ISS for TRL 7+ development for all exploration scenarios is generally from 2010 to ~2016. Six year window will require significant TRL=7+ certification and verification data, more astronaut medical subjects (6 crew), and more crew operational time.
  - Access to downmass uncertain (biomedical specimens, hardware upgrades)
  - If current declining out year budgets are maintained, SLSD will not be in a posture to support RDD&T ramp up at 2010:
    - Loss of Research Scientists (Civil Servants and cancelled NRA's)
    - Loss of Contractor Expertise (instruments, scientists)
    - Loss of Corporate Memory
    - Loss of Core Capability Facilities.

What Role Does the ISS Play for Human Health and Systems Design?

ISS: Only Human Rated Long Duration Microgravity Platform

- **WHY ISS**
  - Skylab Flight in 1973 (84d) Considered the gold standard for collecting biomedical data for long duration spaceflight (9 Crewmembers dedicated to Life Sciences Research)
  - Much Human Health Data has been systematically collected on 113 Space Shuttle Flights, including 13 dedicated Spacelab flights but they have been limited to 17 days.
  - ISS only Platform Since Skylab and MIR available to evaluate long duration integrated physiological effects.
  - ISS is the only orbiting microgravity platform to evaluate environmental effects and to design/test the instrumentation for measuring those effects
  - ISS is the only platform available for TRL = 7+ certification of hardware/software and human interface systems “in environment” in preparation for Exploration.
    - What is “reliable on the ground in 1 g” is not always reliable in space
    - Reliability coupled with redundancy will be required for long duration missions outside of LEO

- **MAJOR ISSUES:**
  - Space Life Sciences has always had more demand that the ISS has been able to provide with 2-3 crewmembers.
  - Coupling the Life Sciences Research hardware to the ISS Program budget since 1993 has left risk mitigation research vulnerable to ISSP budget reductions
  - Loss of ISS upmass since 2003 and as part of RTF—coupled with decision to limit Shuttle to ISS completion through 2010-- will jeopardize ability to meet the Exploration milestones. Compounded by loss of downmass

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Research to pave the way for human exploration of space

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NSBRI research seeks solutions to health concerns facing astronauts on long missions. Patients on Earth suffering from similar conditions will benefit from these advances.

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Bone Loss

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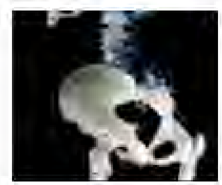
Research Summary

Studies on space flights lasting more than 12 months have shown that, due to microgravity, astronauts on long missions may lose as much as 20 percent of their bone mass. Since it is believed that bone loss continues throughout the mission, estimates lead to worrying conclusions about osteoporosis, the risk of fracture and the possibility of renal stone formation due to calcium mobilization. The Bone Loss Team is studying the mechanisms involved in microgravity-induced bone loss, wheth er microgravity impairs fracture healing, and if radiation exposure impacts bone health. The Team's focus is on developing countermeasures to prevent excess bone loss during missions and devising inflight methods to monitor bone and assess fracture risk.



Bone Loss Team Publication List (PDF)

Bone Loss Team Strategic Plan (PDF)

Team Leader:
Peter Cavanagh, Ph.D., D.Sc. (Med.)
The Cleveland Clinic Foundation

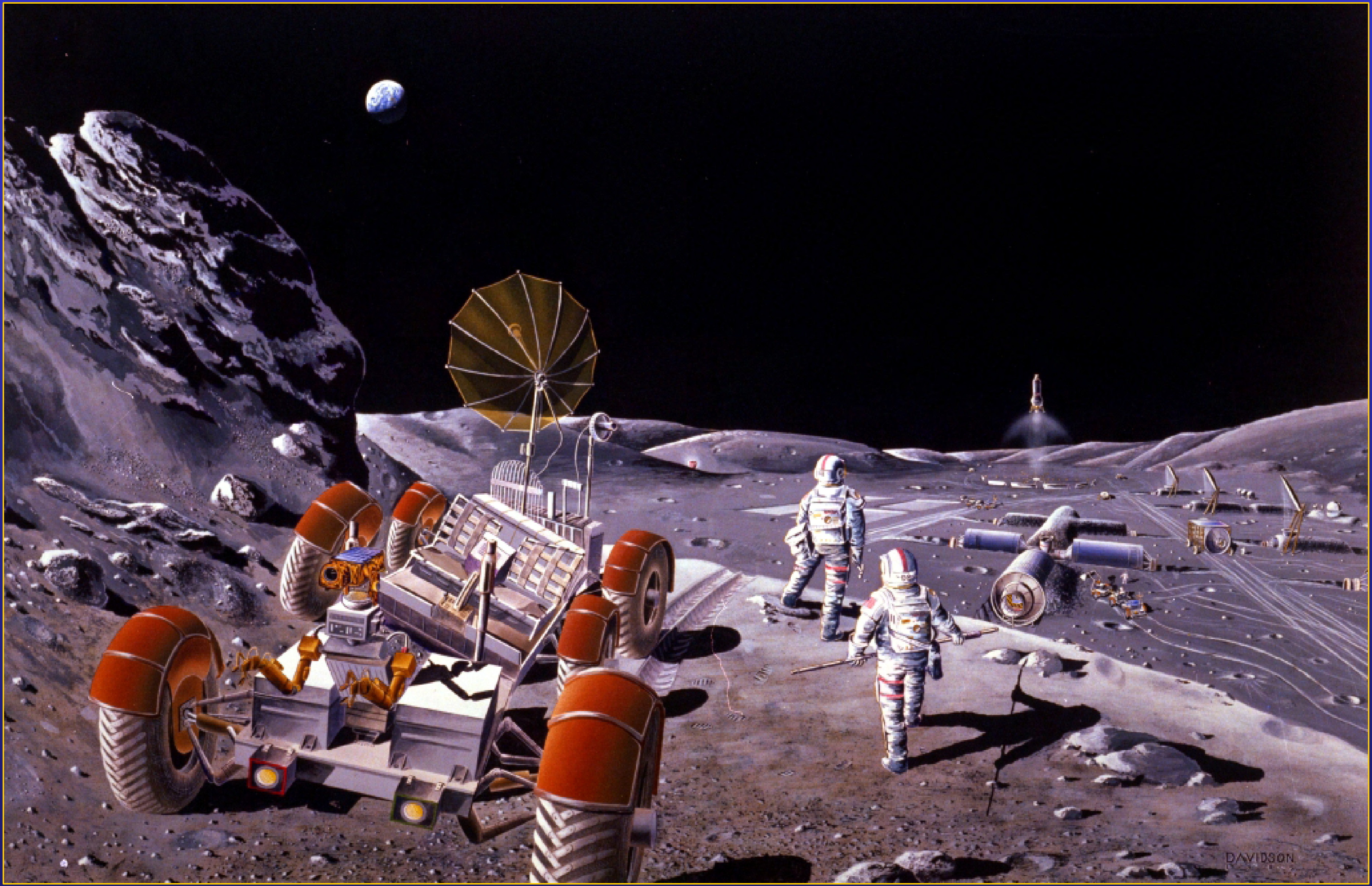
Earth Benefit: Osteoporosis and Other Bone Disorders

Internet

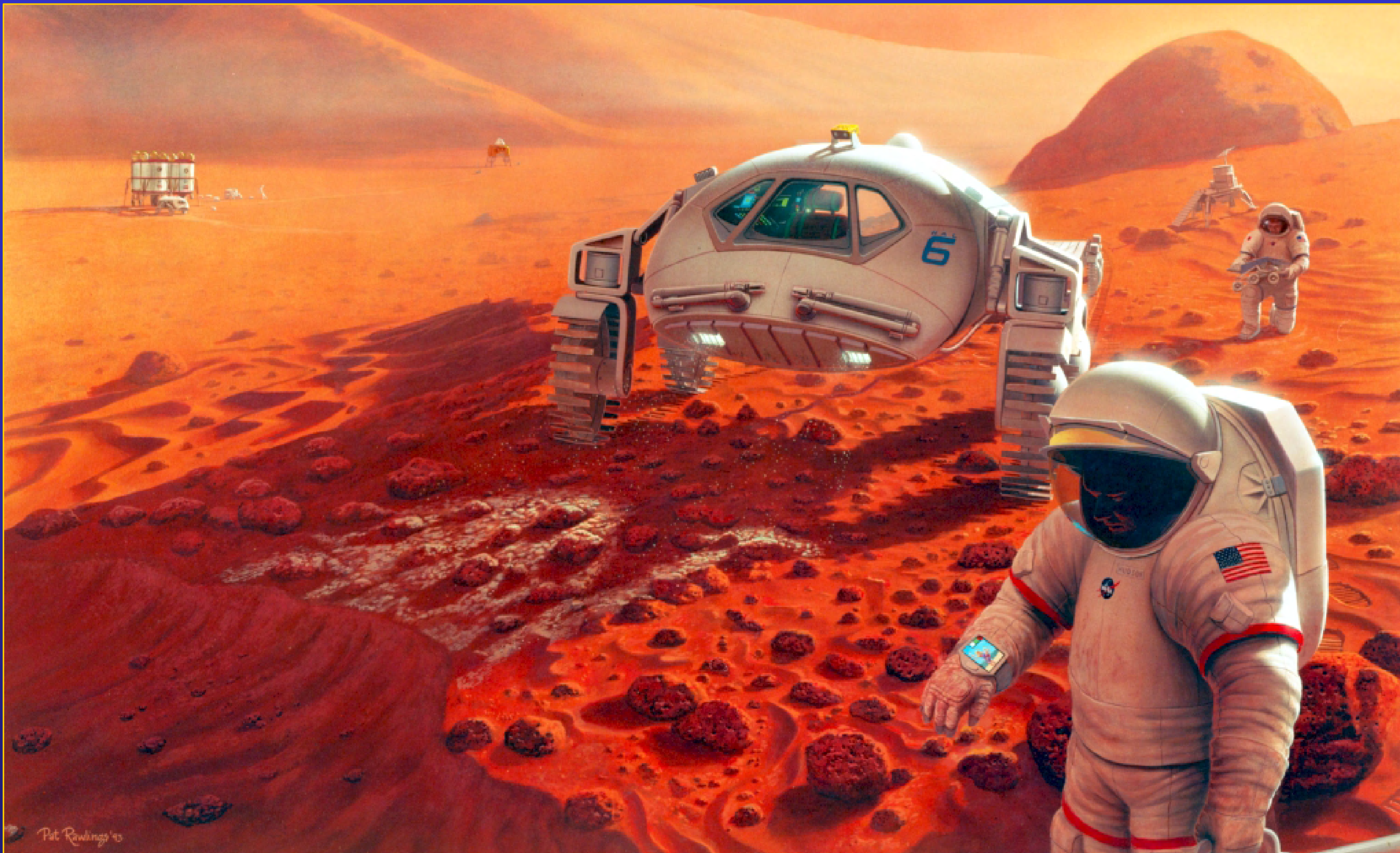
Observations, Recommendations and Conclusions:

- Despite having been to the Moon and Long Duration stays on MIR/ISS, we have not yet quantified nor mitigated all risks to the human which could compromise current and future missions.
- Human Systems Research on ISS is required to mitigate Risk: avoid using the crew as “canaries”
- Research must be conducted at the cell, animal and human levels, in 1 g, microgravity and fractional gravity
- Use the Lessons Learned from Mercury, Gemini, Apollo, Skylab, Shuttle, Spacelab, Spacehab, MIR and ISS

Lunar Base



Martian Base

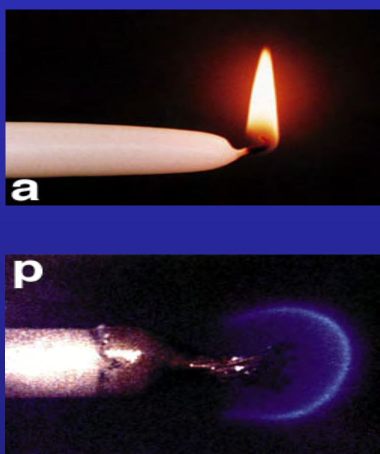


BACKUP

Spaceflight and "micro" gravity – How Do Things Work?

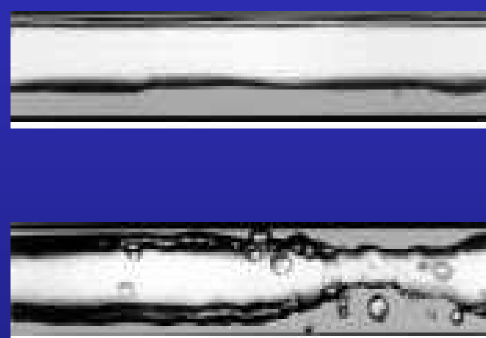
In microgravity, there is no…..

Convection



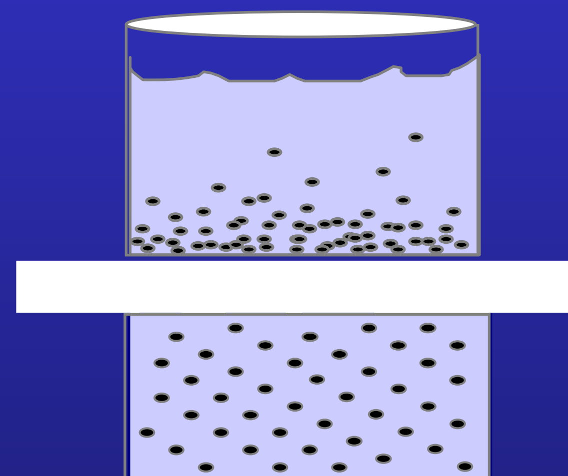
A candle burns on Earth (top) & in microgravity (bottom).

Buoyancy



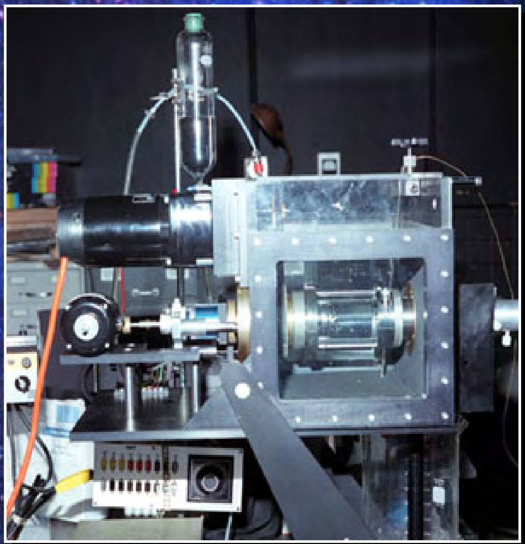
Fluid flows through a pipe in Earth's gravity (top) and in microgravity (bottom).

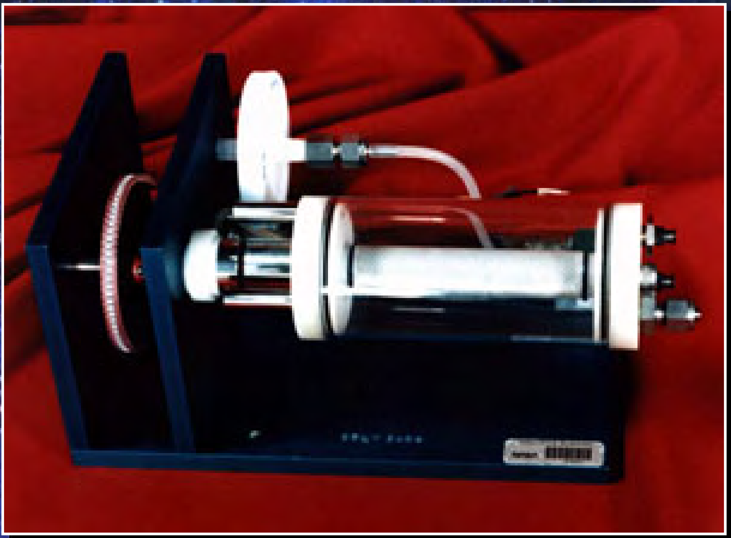
Sedimentation



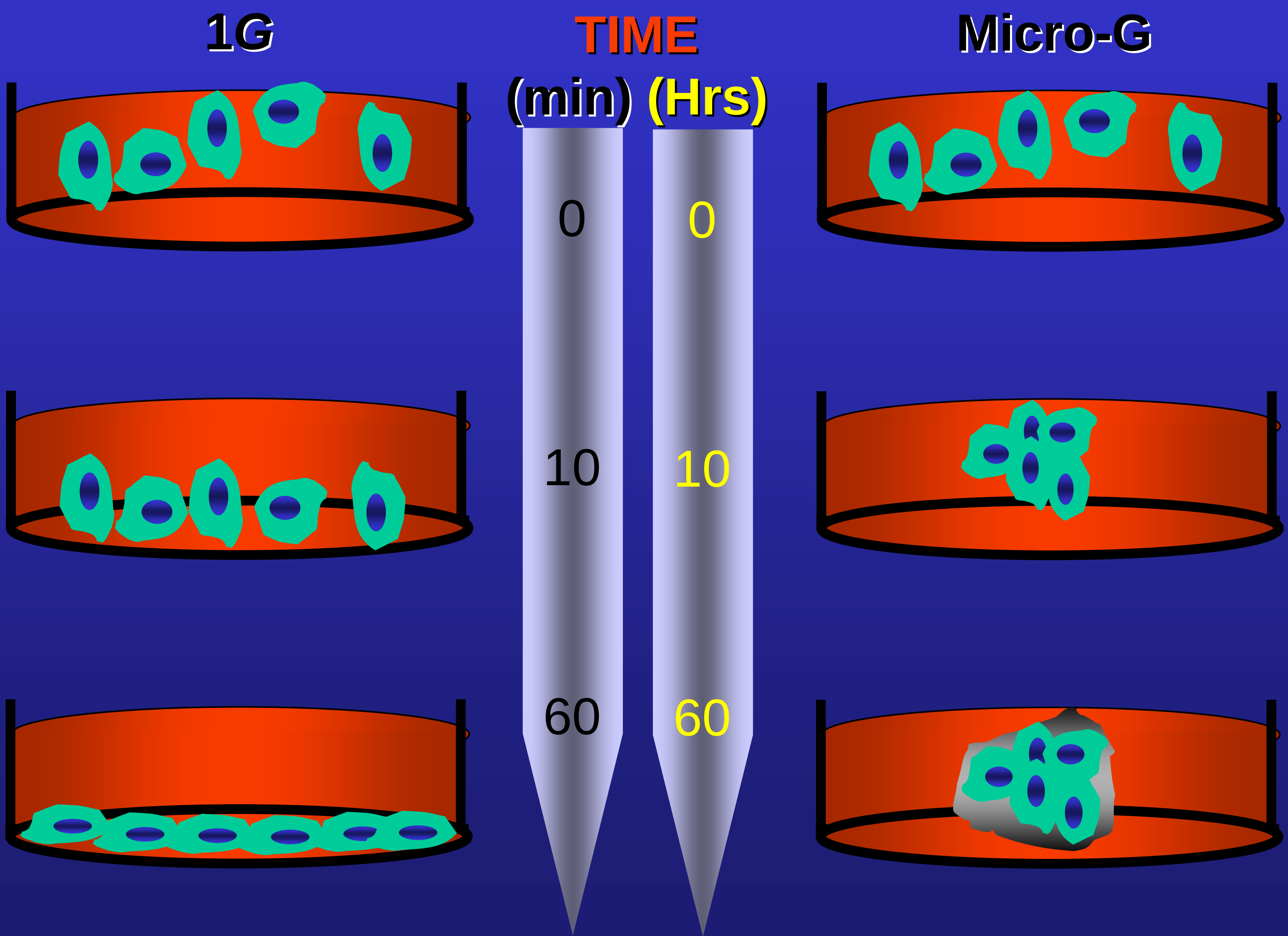
On Earth, particulates settle out of a liquid (top), but in space, particulates are suspended evenly (bottom).

Cellular Biotechnology

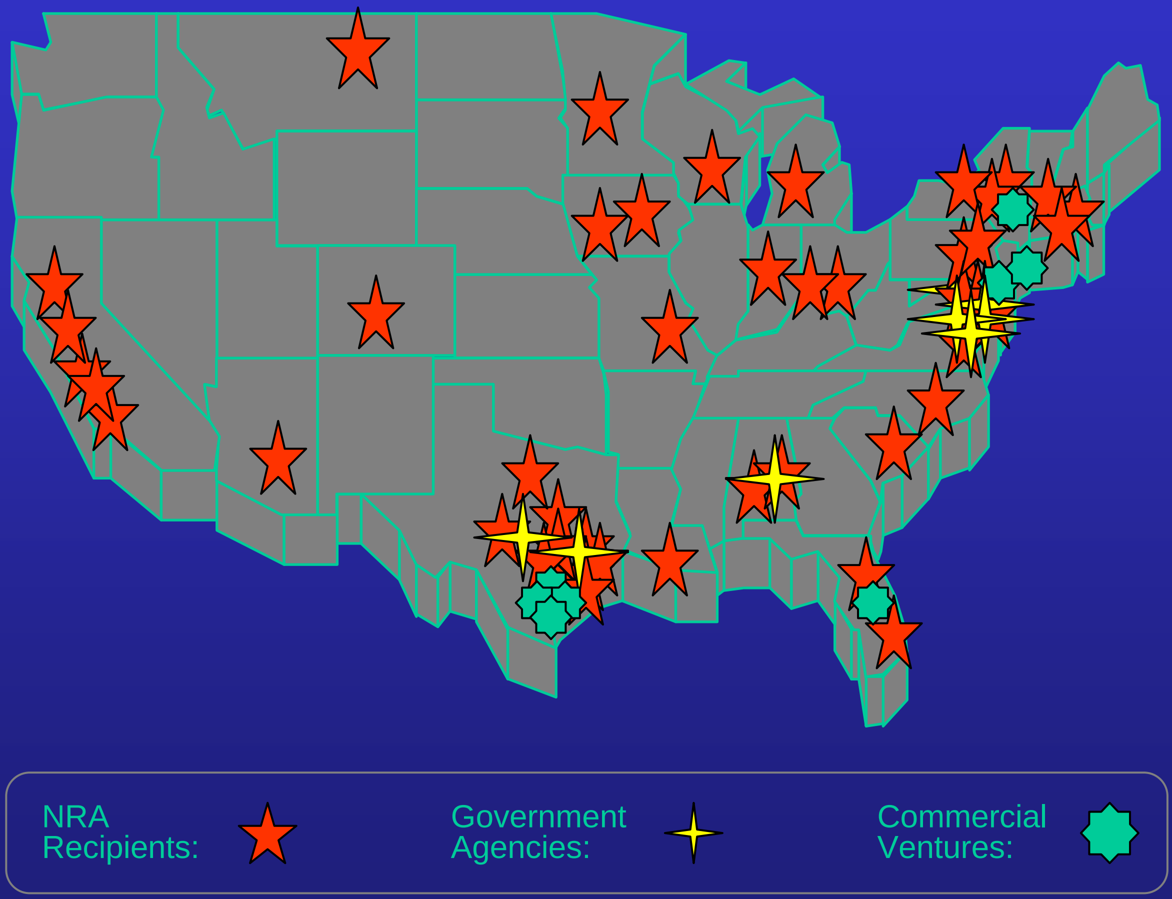




Microgravity Cell Culture



Investigators
Demographics and Expertise



Disciplines represented

- Bacteriology
- Virology
- Cancer Biology
- Cellular and Molecular Biology
- Developmental Biology
- Radiation Biology
- Stem Cell Biology
- Endocrinology
- Hematology
- Immunology
- Medical Oncology
- Metabolism and Nutrition
- Cardiovascular Physiology
- Gastrointestinal Physiology
- Musculoskeletal Physiology
- Pulmonary Physiology
- Neurophysiology
- Plant Physiology/Botany
- Pharmacology
- Transplantation
- Bioreactor Development
- Gene Transfer
- Sensors

Flight Research Program

Missions Supported

- Proved productivity in Shuttle environment
  - STS-120
  - STS-111
  - STS-106
  - STS-90
  - STS-85
  - STS-70
  - STS-63
  - STS-56
  - STS-54
  - STS-44
- Transitioned to long-duration Mir operations
  - Mir 7
  - STS 86-89/Mir 6
  - STS 79-81/Mir 3
- Paved the way for ISS research