National Aeronautics and Space Administration

Human Exploration and Operations Committee Status

Ken Bowersox
Committee Chair
March 30th, 2017

NAC HEO Committee Members

- Ms. Bartell, Shannon
- Mr. Bowersox, Ken, *Chair*
- Ms. Budden, Nancy Ann
- Ms. Caserta Gardner, Ruth G.
- Dr. Chiao, Leroy
- Dr. Condon, Stephen "Pat"
- Mr. Cuzzupoli, Joseph W.
- Mr. Holloway, Tom
- Mr. Lon Levin
- Dr. Longenecker, David E.
- Mr. Lopez-Alegria, Michael
- Mr. Sieck, Robert
- Mr. Smith, Gerald
- Mr. Voss, James

Major Events Since Last NAC Meeting

Launch and return of HTV-6

Launch and return of SPX10

Progress cargo launch failure and reflight

Transfer of Orion European Service Module test article to KSC

Completion of multiple ISS spacewalks including battery servicing

Large amount of ISS science activity with Increment 50 crew

Tornado at Michoud Assembly Facility

Presidential transition and study of adding crew to EM-1 mission

Congressional passage and signature by the president of NASA Authorization Act

NAC HEO Committee Meeting

Tuesday , March 28th, 2017

Human Exploration & Operations - Mr. Bill Gerstenmaier

Exploration Architecture Planning - Mr. Jim Free

ISS and LEO Commercialization - Ms.Robyn Gatens

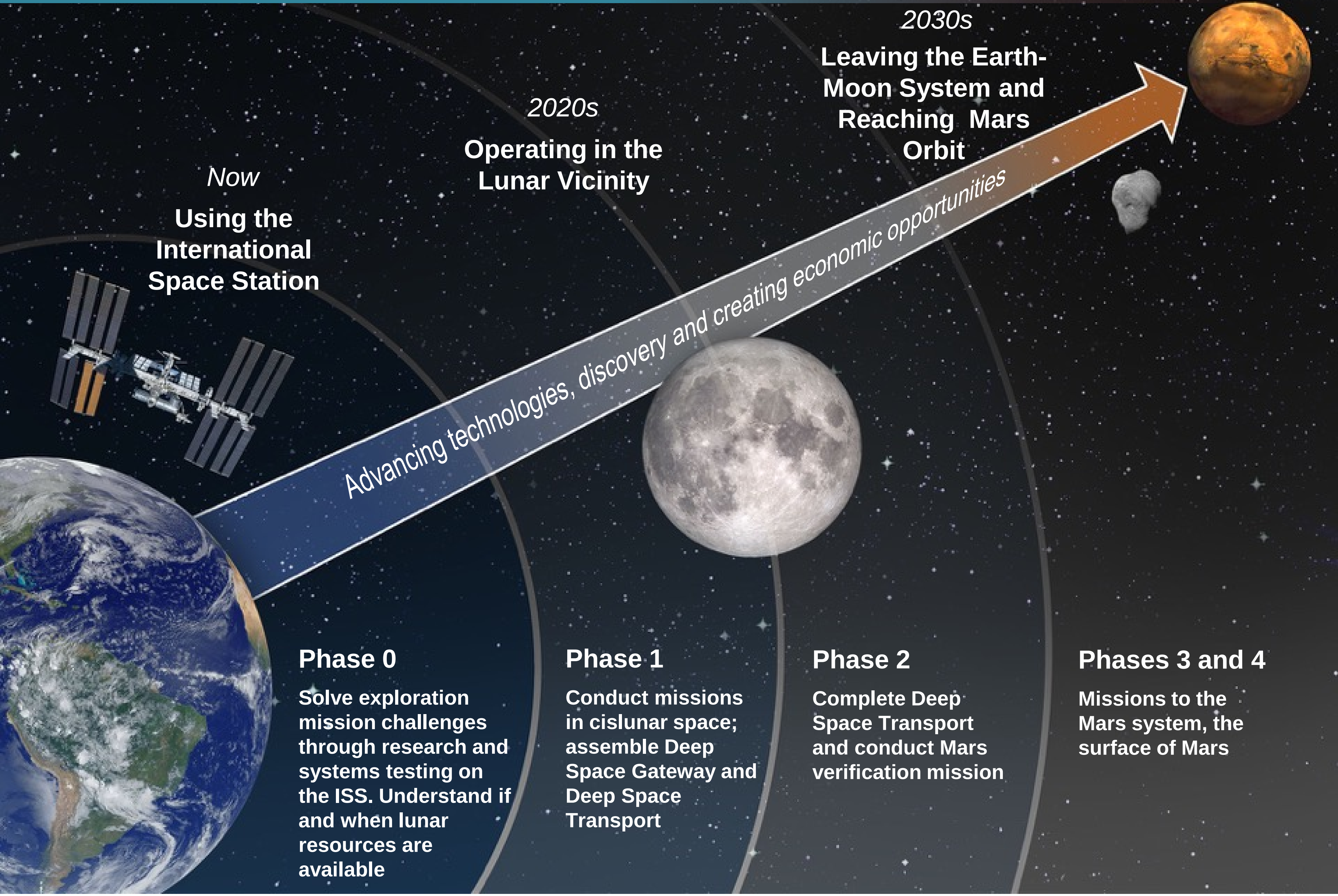
Space Life and Physical Sciences Research and Applications - Dr. Craig Kundrot

Commercial Space Division/Commercial Crew Program - Ms. Kathy Leuders

Wednesday, March 29th, 2017

Exploration Systems Division - Mr. Bill Hill
Cislunar Hab/Environmental Control and Life Support System - Mr. Jason Crusan/Ms. Robyn Gatens
In-space Power/Propulsion – Dr. Michelle Gates

Exploring Space In Partnership



Human Space Exploration Phases From ISS to the Surface of Mars
as of November 2016

Ends with testing, research and demos complete*

Today

Phase 0: Exploration Systems ***Testing on ISS***

Asteroid Redirect-Crewed Mission Marks Move from Phase 1 to Phase 2

Phase 1: ***Cislunar Flight Testing*** of Exploration Systems

Ends with one year crewed Mars-class shakedown cruise

Phase 2: ***Cislunar Validation*** of Exploration Capability

Phase 3: Crewed Missions Beyond Earth-Moon System

Planning for the details and specific objectives will be needed in ~2020

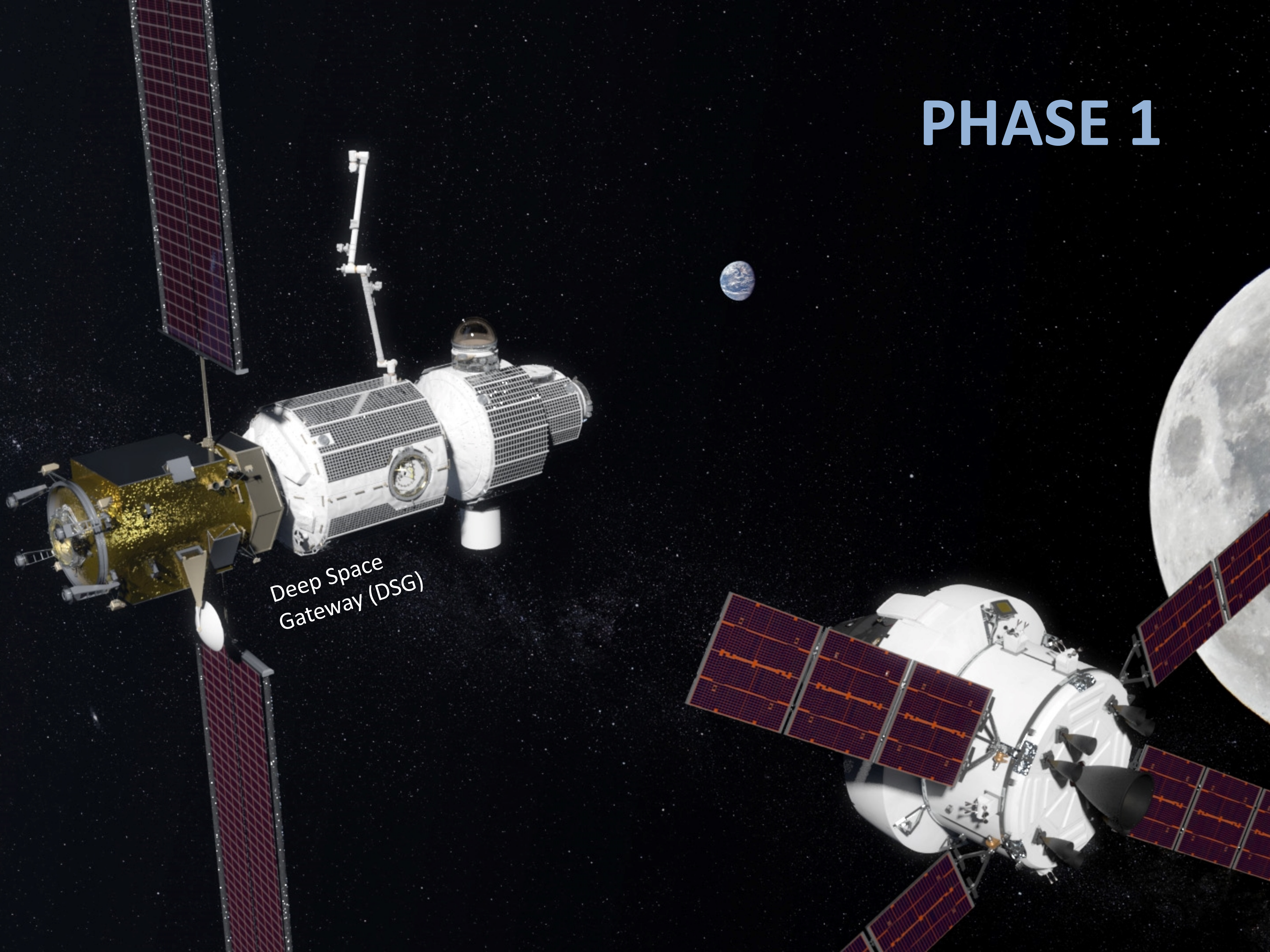
Phase 4a: Development and robotic preparatory missions

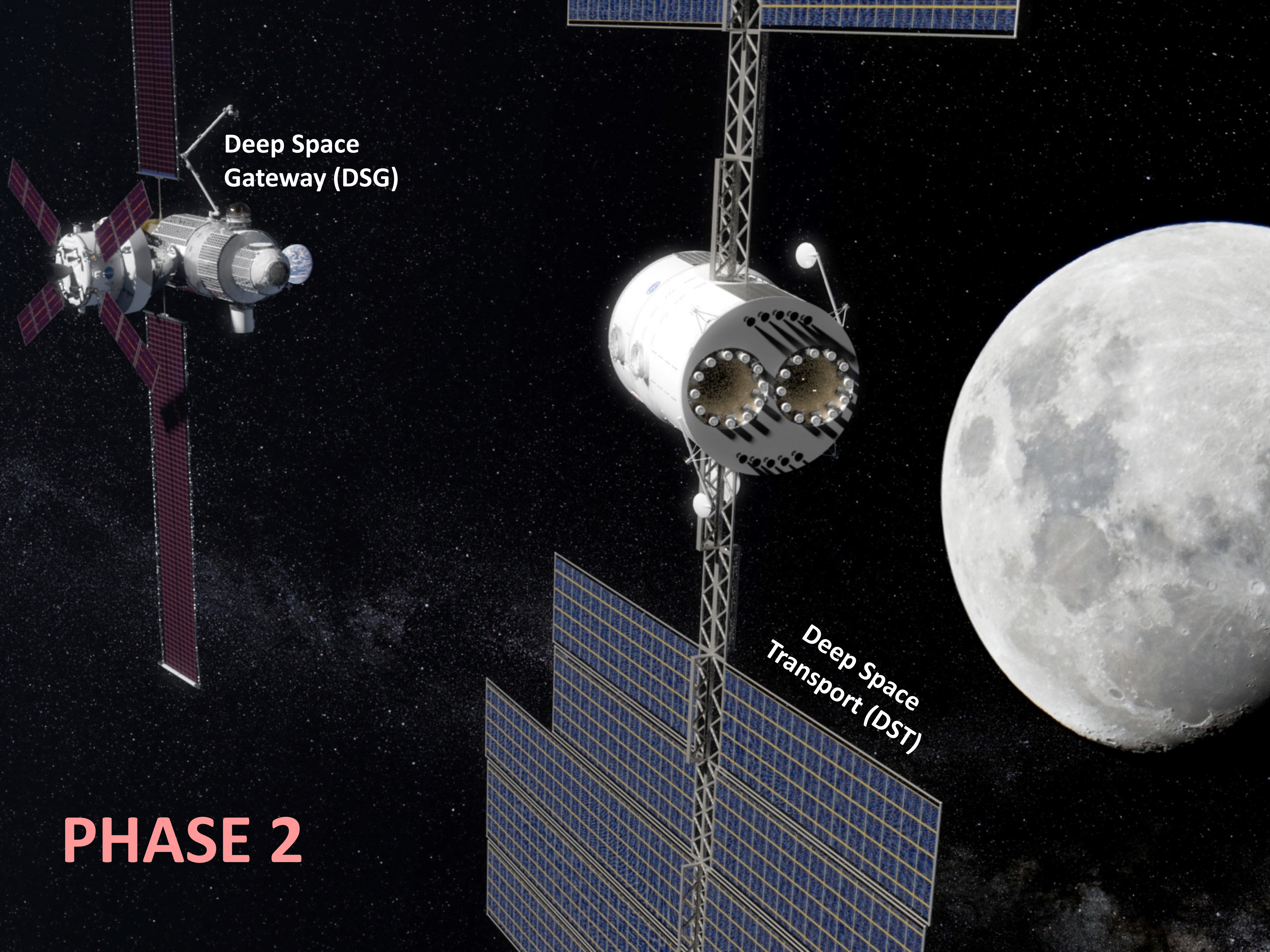
* There are several other considerations for ISS end-of-life

Phase 4b: Mars Human Landing Missions

Mid-2020s

2030


PHASE 1
Deep Space Gateway (DSG)


Deep Space Gateway (DSG)
Deep Space Transport (DST)
PHASE 2

HEO Strategic Principles for Sustainable Exploration

- FISCAL REALISM: Implementable in the *near-term with the buying power of current budgets* and in the longer term with budgets commensurate with economic growth*;*
- SCIENTIFIC EXPLORATION*: Exploration enables science and science enables exploration;* leveraging scientific expertise for human exploration of the solar system.
- TECHNOLOGY PULL AND PUSH: Application of high TRL technologies for near term missions, while focusing sustained investments on *technologies and capabilities* to address the challenges of future missions;
- GRADUAL BUILD UP OF CAPABILITY: *Near-term mission opportunities* with a defined cadence of compelling and integrated human and robotic missions, providing for an incremental buildup of capabilities for more complex missions over time;
- ECONOMIC OPPORTUNITY: Opportunities for *U.S. commercial business* to further enhance their experience and business base;
- ARCHITECTURE OPENNESS AND RESILIENCE : Resilient architecture featuring multi-use, evolvable space infrastructure, minimizing unique developments, with each mission leaving something behind to support subsequent missions;
- GLOBAL COLLABORATION AND LEADERSHIP: Substantial *new international and commercial partnerships,* leveraging current International Space Station partnerships and building new cooperative ventures for exploration; and
- CONTINUITY OF HUMAN SPACEFLIGHT*: Uninterrupted expansion of human presence into the solar system* by establishing a regular cadence of crewed missions to cislunar space during ISS lifetime.

HEO Implementation Principles

- Robust international partnerships, among existing and new partners are important
  - Examine utility of building on/adapt/growing partnerships
  - Consider what partners can provide given funding, historic and future interests, and demonstrated commitment to date for hardware development
- Commercial capabilities will be needed in the architecture
  - Preserve an open, competitive environment, and defining and communicating an appropriate risk acceptance posture
- Goal of cislunar is build up and validation of the crewed Mars transit system
  - Shakedown cruise by the end of the 2020s is still the right target
- Humans Mars orbit mission in 2033 (out and back – short stay which may require Venus flyby)
- A minimal, crew-tended gateway remains long-term in cislunar space to facilitate successive crewed Mars missions and sustain mission cadence; this should drive the definition of initial cislunar gateway
  - Stage Mars vicinity missions in cislunar space
  - Could also support lunar surface missions

Commercial Crew Program Progress

CCP has made significant progress over the last quarter, notably:

- **Awarded Post Certification Missions 3 - 6 for both providers in December 2016**
- **Continue to burn down key certification products with the providers**
  - Progress for each provider is included in provider-specific sections of this briefing
- **Eight CCP missions now in process:**
  - For SpaceX:
    - November 2017: Flight to ISS Without Crew (Demo Mission 1)
    - May 2018: Flight to ISS with crew (Demo Mission 2)
    - PCM-1 awarded November 2015; Completed three milestones to date
    - PCM-2 awarded July 2016; Completed one milestone to date
  - For Boeing:
    - June 2018: Orbital Flight Test (unmanned demo)
    - August 2018: Crewed Flight Test (demo)
    - PCM-1 awarded May 2015; Completed five milestones to date
    - PCM-2 awarded in December 2015; Completed four milestones to date

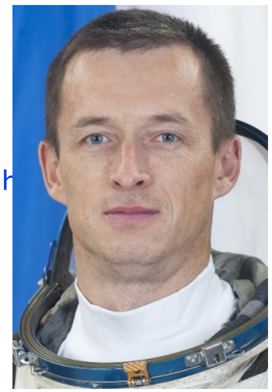
CCP Summary

- **CCiCap partners continue to advance integrated crew transportation system designs**
- **CCtCap partners, Boeing and SpaceX, are meeting contractual milestones and maturing their designs**
  - Actively building and testing hardware to inform design
  - Engaging in meaningful insight with NASA
  - Addressing important design challenges
- **Providers are providing increased insight opportunities for the NASA team**
- **CCP has robust and efficient processes for certification including addressing waivers and deviations**
- **In preparation for flight, there is significant work ahead**

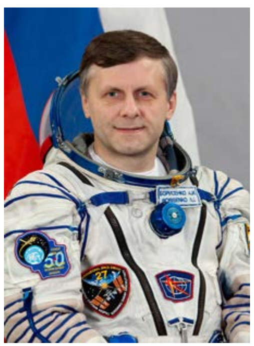
Increment 50 Overview: Crew

48S Dock
10/21/16
48S Undock
4/10/17

Shane Kimbrough
FE (US) – 48S
(*CDR Inc 50*)



Sergey
Ryzhikov
FE (R) – 48S
CDR – 48S



Andrey
Borisenko
FE (R) – 48S

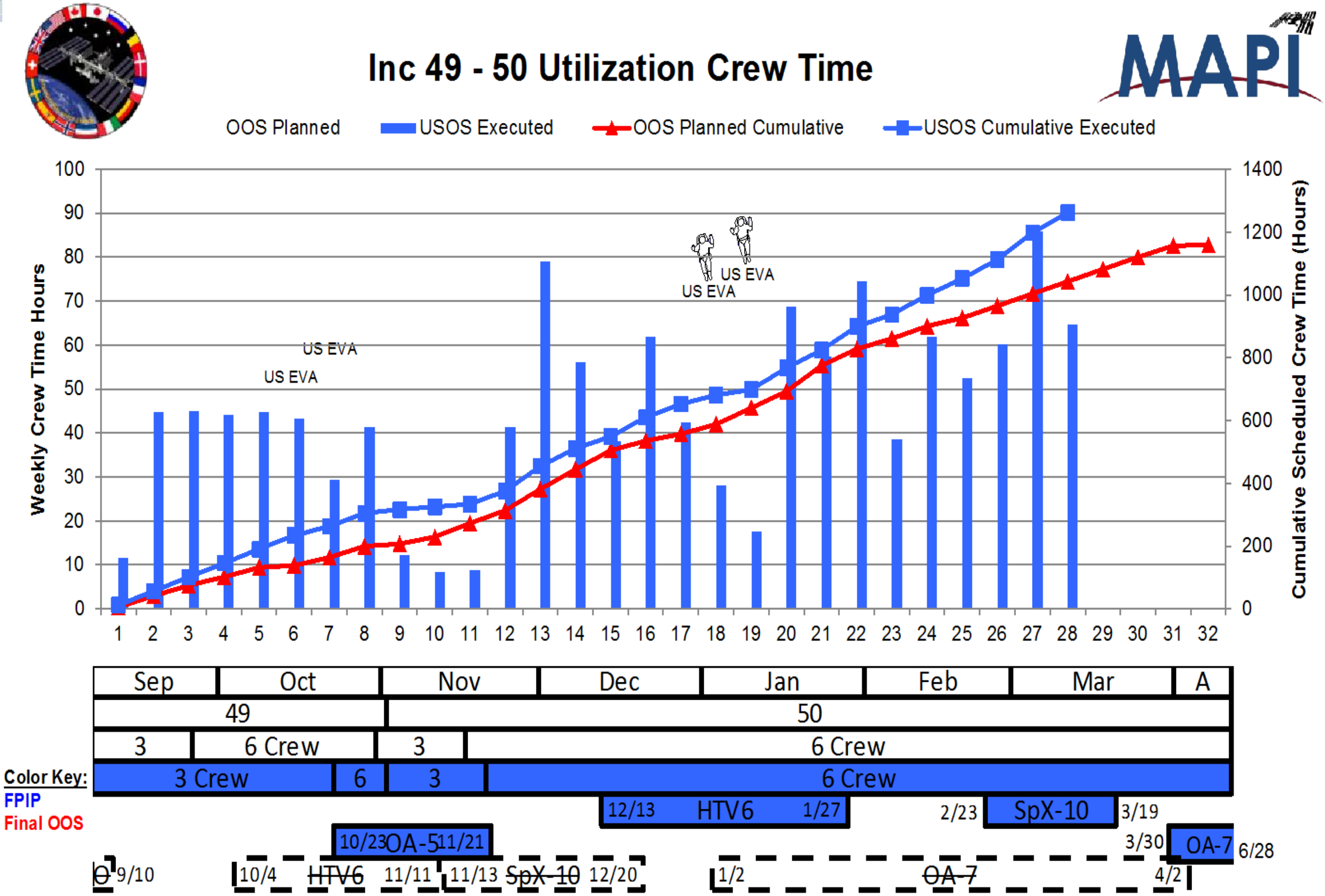
49S Dock
11/19/16
49S Undock
6/2/17

Peggy
Whitson
FE (US) – 49S
(*CDR Inc 51*)

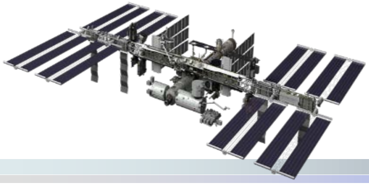
Thomas
Pesquet
FE (US) – 49S

Oleg Novitski
FE (R) – 49S
CDR

Inc 49-50 Utilization Crew Time



Executed through Increment Wk (WLP Week) 28 :	26.4 of 29.6 work weeks	(89.2% Complete)
USOS Actuals:	1262.92 hours -> 47.84 hours/week	
USOS IDRD Allocation:	1,159.00 hours-> 39.16 hours/week	(109.0% Complete)
OOS USOS Planned Total:	1,159.21 hours	(108.9% Complete)
Voluntary Science Totals to Date:	7.17 hours (not included in the above totals or graph)	
RSA/NASA Joint Utilization to Date:	178.00 hours (not included in the above totals or graph)	



Increment 50 EVA Execution

- 2 EVAs
  - EVA 1– 3A battery replace
  - EVA 2– 1A battery replace

S4 Battery R&R – EVA 1 (1/6/17)

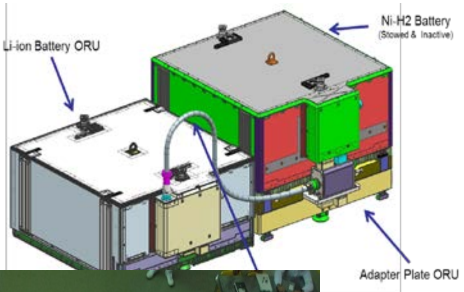
Color key: IEA Worksite | EP Worksite

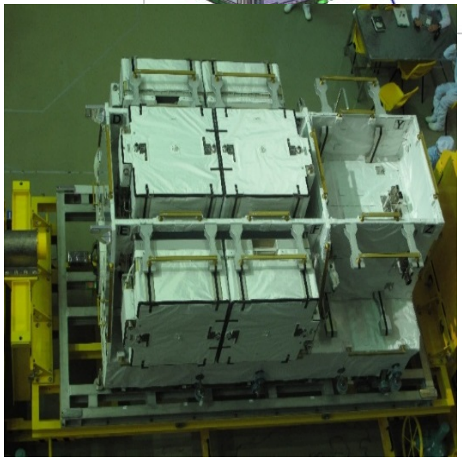
PET: 0:00 · 1:00 · 2:00 · 3:00 · 4:00 · 5:00 · 6:00

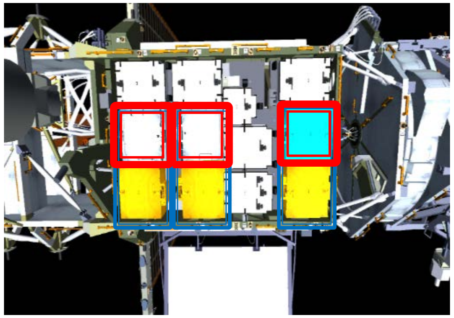
EV1	[1] Egress (0:15)	Worksite Prep (0:55)	Retrieve AP A / AP B (0:35)	Install AP A (0:45)	Relocate Battery 4 (0:35)	Install AP B (0:20)	Relocate Battery 2 (0:45)	Retrieve/Install AP C (1:00)	1A Battery Prep/Cleanup (0:40)	Ingress (0:30)	[12]
EV2	[1] Egress (0:15)	Worksite Prep (0:55)	Retrieve AP A / AP B (0:35)	Install AP A (0:45)	Relocate Battery 4 (0:35)	Install AP B (0:20)	Relocate Battery 2 (0:45)	Retrieve/Install AP C (1:00)	1A Battery Prep/Cleanup (0:40)	Ingress (0:30)	[12]

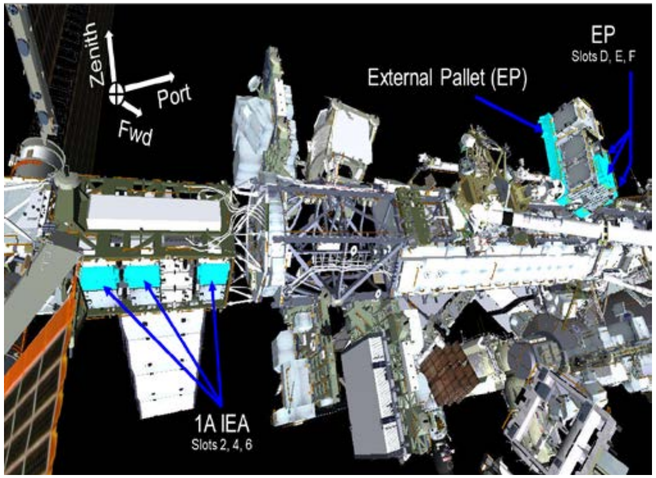
EV1: [1] Post Depress (0:05) [12] Pre Repress (0:05)

EV2: [1] Post Depress (0:05) [12] Pre Repress (0:05)

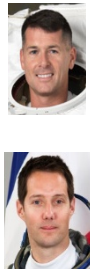








S4 Battery R&R – EVA 2 (1/13/17)



Color key: IEA Worksite | EP Worksite

PET: 0:00 · 1:00 · 2:00 · 3:00 · 4:00 · 5:00 · 6:00

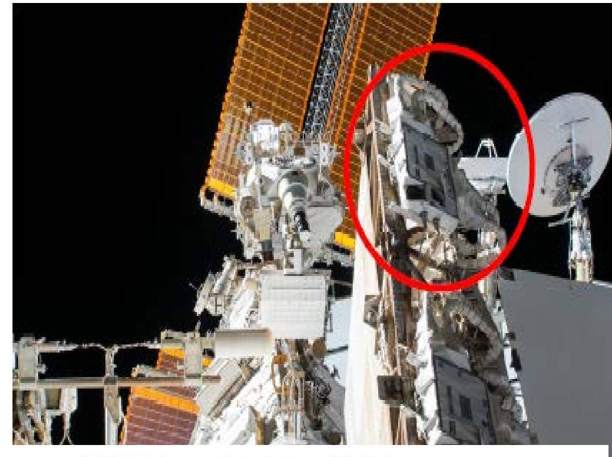
EV1	[1] Egress (0:15)	Worksite Prep (0:55)	Retrieve AP E / AP F (0:35)	Install AP F (0:45)	Relocate Battery 4 (0:35)	Install AP E (0:20)	Retrieve/Install AP D (1:00)	Cleanup (0:40)	Get Ahead (0:45)	Ingress (0:30)	[12]
EV2	[1] Egress (0:15)	Worksite Prep (0:55)	Retrieve AP E / AP F (0:35)	Install AP F (0:45)	Relocate Battery 4 (0:35)	Install AP E (0:20)	Retrieve/Install AP D (1:00)	Cleanup (0:40)	Get Ahead (0:45)	Ingress (0:30)	[12]

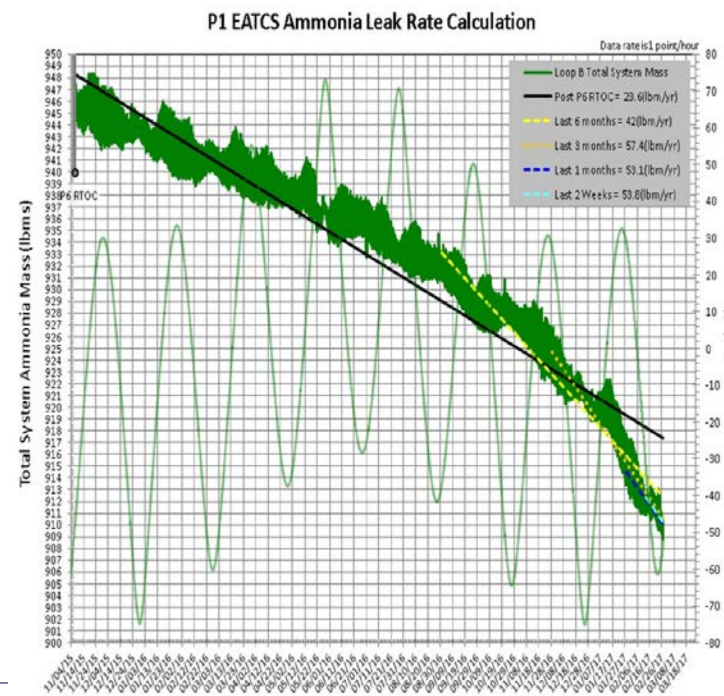
EV1: [1] Post Depress (0:05) [12] Pre Repress (0:05)

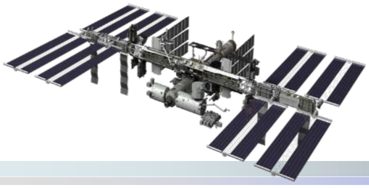
EV2: [1] Post Depress (0:05) [12] Pre Repress (0:05)

EATCS Loop B Leak

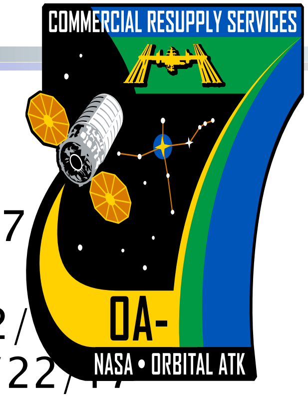
- External Active Thermal Control System (EATCS) Loop B has had a trending leak since ~2013
- Current leak rate is in the range of 42 – 57 lbs/year NH3,
  - While current rate is still small, the rate has been accelerating *(particularly in last 3 months)*
  - Similar leak profile of PVTCS P6 2B loop accelerated, then opened up in May 2013 requiring contingency EVA for ORU replacement
- Radiator flex line region around RBVM P1-3-2 hardware appear to have ammonia leakage.
  - Robotic External Leak Locator (RELL) operations in November 2016 indicated elevated ppNH3 in vicinity of P1-3-2 and February 2017 operations indicated elevated ppNH3 in vicinity of radiator jumpers from P1-3-2 RBVM.
  - Imagery of RBVM P1-3-2 performed in February by the crew from the Cupola currently under review.
  - Tasks in planning during the Inc 50 EPIC SPDM Lube EVA to perform close up inspections of the suspect RBVM hardware in this area for evidence of ammonia.
    - Includes manipulation of the MLI surrounding suspect hardware (RBVM and Junction Box QD, flex hoses, system rigid lines) in the area and additional close in imagery.
  - Looking at options to isolate or fix
    - Team assessing impact for further increased rate
    - There are two spare ATAs onboard and two spare ATAs on the ground.







OA-7 Mission Status



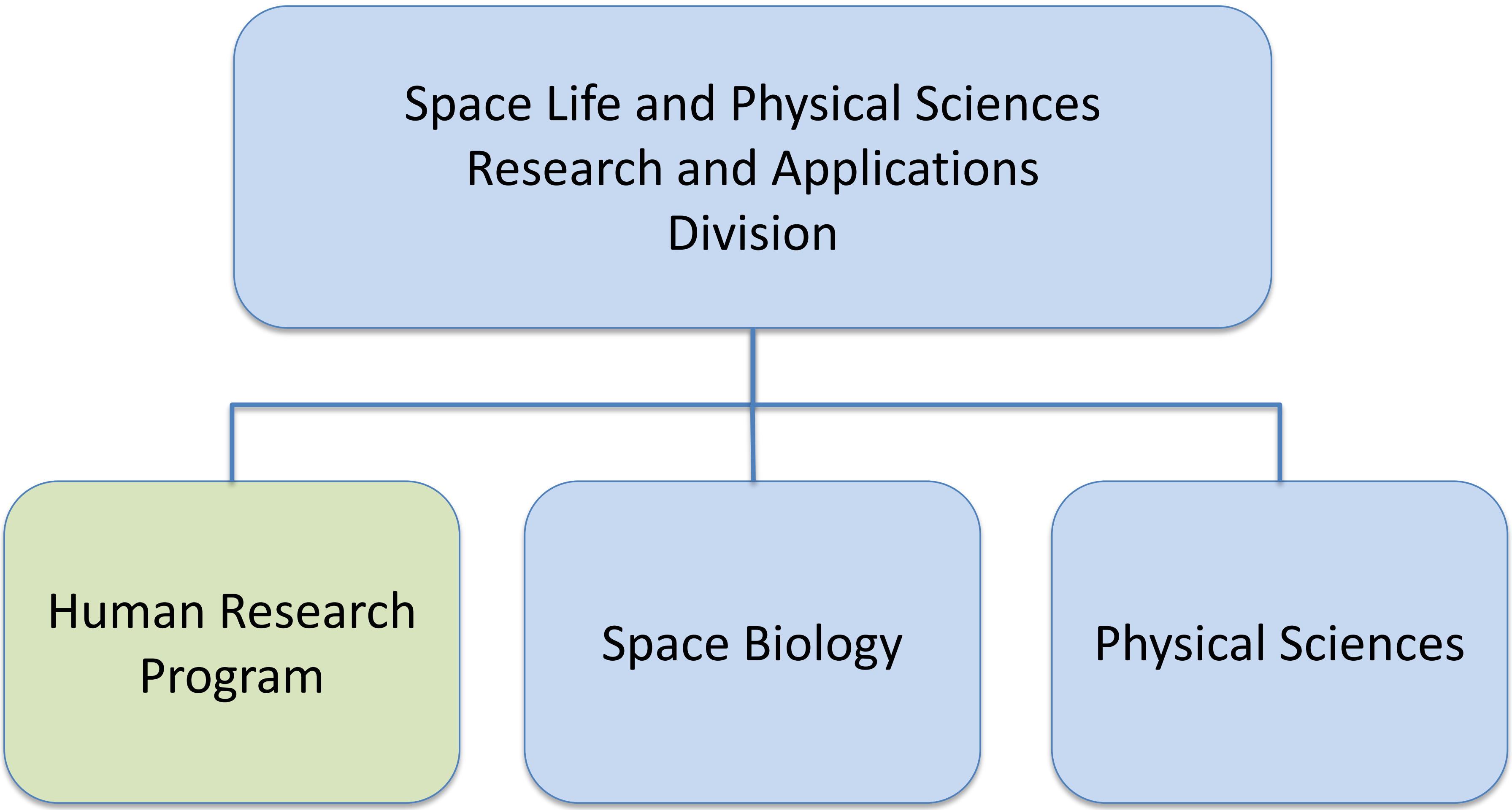
- Mission Planning
  - Mission Readiness Review (MRR) was completed on 1/12/17
  - Joint Multi Segment Training (JMST) #2 was completed on 2/3/17
  - Post Qualification Review (PQR) was completed on 2/9/17
  - Flight Readiness Certification Review (FRCR) was completed on 2/
  - Stage Operations Readiness Review (SORR) was completed on 2/22/17
- Pressurized Cargo – 3371 kg planned; 1802 kg disposal estimated
  - Saffire #3 payload installation was completed on 2/3/17
  - RED-Data 2 experiment and 4 Polars are planned for this mission
  - Initial cargo load was completed on 2/11/17
  - Late cargo load was completed on 3/4/17
  - Final cargo load was completed on 3/6/17
- Unpressurized Cargo
  - NanoRacks CubeSat Deploy (NRCSD) for deploy above post unberth; installation was completed on 2/28/17
- Cygnus Status
  - Cygnus is fueled. Fairing encapsulation completed
- Atlas Status
  - Investigating anomaly in booster hydraulic system discovered 3/22

Commercial Resupply Services CRS-2 Status

- CRS-2 Contract award was announced on January 14, 2016
  - Awardees are Orbital-ATK Inc. (OA), Sierra Nevada Corporation (SNC) and SpaceX (SpX)
  - ISS Integration work has been ordered for each provider as of 6/3/16; there are seven integration milestones required to be completed prior to first vehicle launch
  - A minimum of six missions will be ordered from each provider
- ISS Integration Milestones – #1 Kickoff and #2 System Requirements Review for all three contracts were successfully completed
- ISS Integration Milestone – #3 Preliminary Design level review
  - OA IR #3 was conducted on 10/26/16
  - SpX IR #3 was conducted on 11/15/16
  - SNC IR #3 was conducted on 2/27/17 – 3/1/17
- ISS Integration Milestone – #4 Critical Design level reviews are scheduled to begin in the Fall 2017
- CRS-2 missions are planned for launch beginning in 2019

LEO Commercialization Update

- Assessing next steps in Port RFI
- Evaluating the REMIS responses from industry; expect to award in early summer
  - Research, Engineering, Mission Integration Services
- NASA has initiated a study activity to define long term research and utilization requirements in LEO
  - Across NASA including SMD, STMD and HEOMD with input from CASIS
- CASIS and AAS are making very good progress in finalizing the plans for the ISS Research and Development Conference
  - July 17-20 at the Omni Shoreham at Woodley Park in DC


Space Life and Physical Sciences Research and Applications Division
Human Research Program
Space Biology
Physical Sciences

Research Portfolio Guided by Decadal Survey

Research that enables space exploration:

scientific research in the life and physical sciences that is needed to develop advanced exploration technologies and processes, particularly those that are profoundly affected by operation in a space environment.

Research enabled by access to space:

scientific research in the life and physical sciences that takes advantage of unique aspects of the space environment to significantly advance fundamental scientific understanding

Capitalizing on resources in LEO and below

- **Space Stations**
  - International Space Station
  - International partner space station(s)?
  - Commercial space station(s)?
- **Free Fliers**
  - Other government agencies
  - Commercial
  - International partners
- **Sub-orbital**
  - Crewed flights
  - Sounding rockets
  - Balloons
  - Parabolic aircraft
- **Ground research**

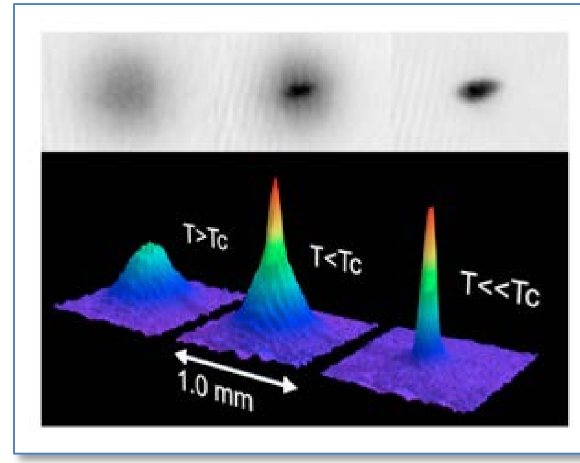
Enabling Exploration

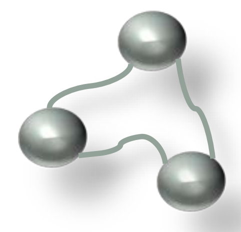
Pioneering Scientific Discovery

- Other government agencies
- Commercial
- International partners

Cold Atom Laboratory (CAL)

- Bose Einstein condensation (BEC) occurs at $T = 10^{-8}$ K atoms share the same wave function
  - Many body physics
  - Test Einstein Equivalence Principle
  - Search for dark matter, dark energy
- Microgravity enables
  - Reduced temperature ($T = 10^{-12}$ K)
  - Increased interaction time (10 s)
  - Bias free symmetric trap
- High and low resolution imaging allow scientists to view atom clouds from 2 directions
- 7 funded awards
  - Universities, government labs, and NASA
  - Includes 3 Nobel Laureates
- Launch 2017
- Follow on research planned
  - National Science Foundation
  - DLR

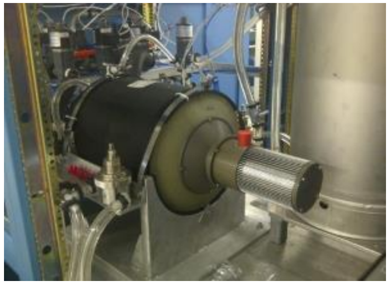




Deep Space Habitation Systems

Bigelow Expandable Activity Module (BEAM): Test of inflatable module structures on ISS (JSC).

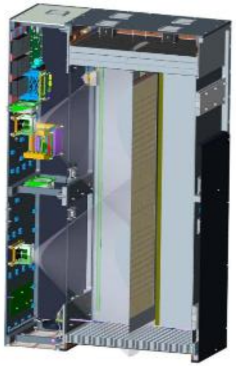
Atmosphere Resource Recovery & Environmental Monitoring: Integrated ground testing of ISS-derived life support system components (MSFC).



Water Recovery: Development of processes and systems for recycling wastewater (JSC).

Radiation Protection: Development and testing of radiation sensors and shielding (JSC).

Logistics Reduction: Waste processing to reduce logistics mass (JSC).



Spacecraft Fire Safety: Flight experiment on Cygnus to investigate how large-scale fires propagate in microgravity (GRC).

NextSTEP Habitation Overview

NextSTEP Phase 1: 2015-2016

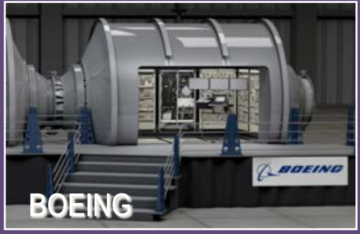
Cislunar habitation concepts that leverage commercialization plans for LEO

FOUR SIGNIFICANTLY DIFFERENT CONCEPTS RECEIVED

Partners develop required deliverables, including concept descriptions with concept of operations, NextSTEP Phase 2 proposals, and statements of work.

NextSTEP Phase 2: 2016-2018

FIVE GROUND PROTOTYPES BY 2018



- Partners refine concepts and develop ground prototypes.
- NASA leads standards and common interfaces development.

ONE CONCEPT STUDY

Initial discussions with international partners

Define reference habitat architecture in preparation for Phase 3.

Phase 3: 2018+

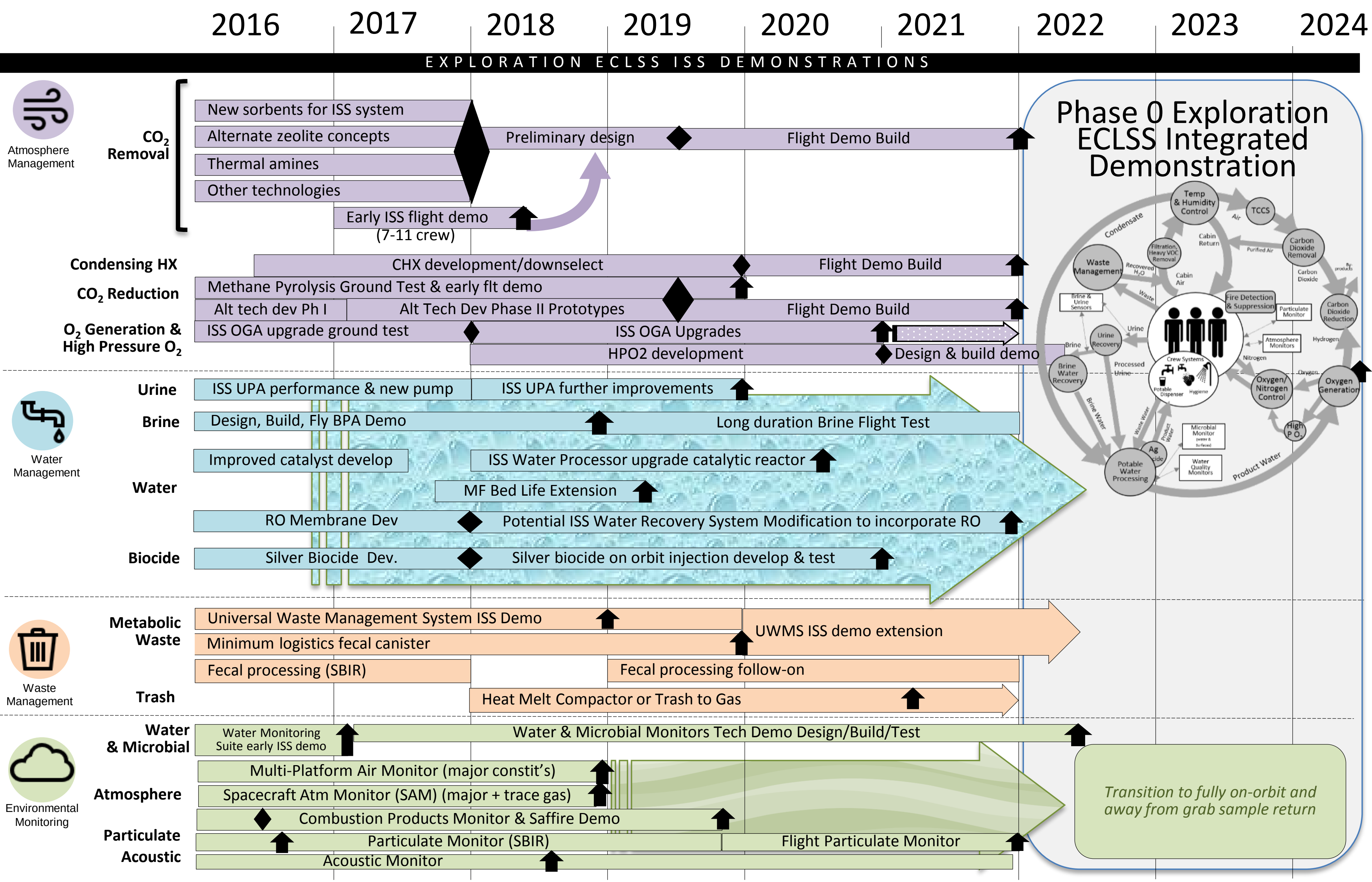
- Partnership and Acquisition approach, leveraging domestic and international capabilities
- Development of deep space habitation capabilities
- Deliverables: flight unit(s)

ECLSS & Environmental Monitoring Capability Gaps

Gap Criticality:
5 = high
1 = low

Function	Capability Gaps	Gap criticality as applicable to μg transit Hab	Orion Need
CO_2 Removal	Bed and valve reliability; $ppCO_2$ <2 mmHg	5	
O_2 recovery from CO_2	Recover >75% O_2 from CO_2	5	
Urine brine processing	Water recovery from urine brine >85%	5	
Metabolic solid waste collection	Low-mass, universal waste collection	5	X
Trace Contaminant Control	Replace obsolete sorbents w/ higher capacity; siloxane removal	4	X
Condensing Heat Exchanger	Durable, chemically-inert hydrophilic surfaces with antimicrobial properties	4	
Water microbial control	Common silver biocide with on-orbit redosing	4	
Contingency urine collection	Backup, no moving parts urine separator	4	X
Urine processing	Reliability, 85% water from urine, dormancy survival	4	
Atmosphere monitoring	Small, reliable atmosphere monitor for major constituents, trace gases, targeted gases	4	X
Water monitoring	In-flight identification & quantification of species in water	4	
Microbial monitoring	Non-culture based in-flight monitor with species identification & quantification	4	
O_2 generation	Smaller, reduced complexity, alternate H_2 sensor	3	
High pressure O_2	High pressure (3000 psi) O_2 for EVA/on-demand O_2 supply for contingency medical	3	
Wastewater processing (WPA)	Reliability (ambient temp, reduced pressure catalyst), reduced expendables, dormancy survival	3	
Non-metabolic solid waste	Volume reduction, stabilization, resource recovery	3	
Particulate monitoring	On-board measurement of particulate hazards	3	
Particulate Filtration	Surface dust pre-filter; regen filter	2	
Atmosphere circulation	Quiet fans	2	
Logistics Reduction	10:1 volume reduction logistical and clothing	2	
Metabolic solid waste treatment	Useful products from metabolic waste	1	

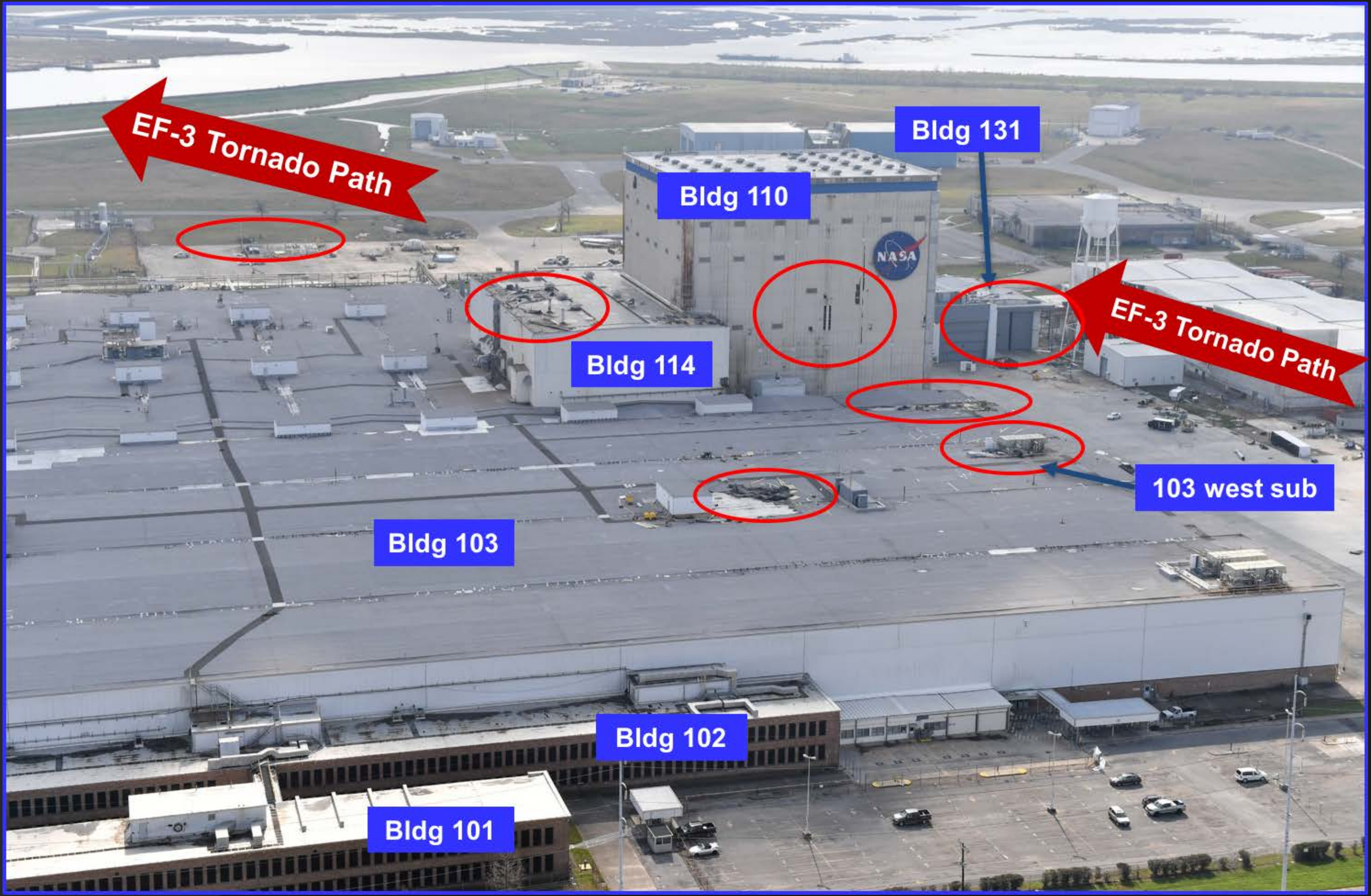
Exploration ECLSS Roadmap



Next Steps

- **Team is currently refining budget estimates and detailed plans**
- **Working with International Partners through the I-SMT**
  - ECLSS Interoperability standards (e.g. atmosphere quality, water quality)
  - Following partner activities and planned ECLSS ISS demonstrations
- **Continue to execute Exploration ECLSS plan!**

MAF Tornado Path Damage



EF-3 = Enhanced Fujita 3: The Enhanced F-scale is a set of tornado wind estimates (not measurements) based on damage. Wind speed estimates are representative of a three second gust. An EF-3 has estimated 3 second gusts of 136 to 165 mph.

Discussion Areas

- Communication of exploration plans
- Advisory group interaction with Commercial Crew Program
- Optimal approaches for NAC and HEO Committee to work with NASA
- Systems engineering and integration for SLS, Orion and Ground Systems
- Latest details of exploration plans and decision time frame
- Budgetary impacts on future plans

HEO Committee Observations

- The current transition to a new presidential administration and a new congress seems to be going well. The HEO Committee commends the NASA team for their good work in preparation for the transition. The recent congressional approval signature by the president of NASA's latest Authorization is an important step toward successful completion of NASA's HEO programs.

- NASA continues to add detail to plans for exploration in cis-lunar space and beyond. The HEO Committee was pleased to see the amount of additional detail in exploration mission planning that was evident at this session and concurs with the HEO Associate Administrator that the time is right to make decisions that will focus the development effort for the planned series of cis-lunar exploration missions.

- If NASA decides to put crew on EM-1, it is important to ensure that the benefit warrants the risk level. It is also critical that the mission receive adequate funding and schedule flexibility to complete critical test activity prior to carrying crew aboard SLS and Orion, as well as eliminating impacts to the content and scheduled dates of later missions.

- The Journey to Mars document was a valuable attempt to communicate the rationale for NASA's future plans to move from Earth orbit, to cis-lunar space and then on to Mars. It would be helpful to replace this document with one that describes current plans for missions in cis-lunar space and beyond. The most recent NASA Authorization Act has a requirement for an exploration road map to be completed by December 1 of 2017 that could be a good candidate for replacement of the Journey to Mars publication.

- ISS is a critical test bed for development of systems that will be used for deep space exploration. While projections show that the work should be complete by 2024, the committee believes that it is likely that exploration development work on ISS will need to be continued until 2028 or later.

HEO Committee Concerns

- Budget uncertainty and lack of flexibility in use of funds continues, and now has greater potential for program disruption as SLS and Orion get closer to launch.
- The Deep Space Gateway could be capable of other deep space missions, in addition to its prime mission as a node for development and staging of the Deep Space Transport. The committee is concerned that requirements for the Gateway may grow excessively during the development phase, and encourages the HEO team to maintain focus on the prime mission when developing the Gateway's system requirements.
- Bureaucratic processes that NASA imposes on itself do not always add value to balance their load on the organization and are a threat to the accomplishment of NASA's exploration mission.
- The number and intensity of current reviews of the HEO programs are not helpful and use too many precious resources.
- Low SLS and Orion Launch rate pose future risks for proficiency of the operations team and reduce program resilience in the event of mission failure

Special Topics at Future HEO Committee Meetings

- Future Special Topics:
  - International Participation in future human exploration
  - ISS after 2024 and ISS commercialization efforts
  - Launch readiness process for commercial crew
  - ASAP insight to the Commercial Crew Program
  - Systems Engineering and Integration for Exploration Systems
  - Deep space telescopes and possible servicing missions
  - Planetary protection

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