National Aeronautics and Space Administration

ECLSS-CHP SCLT

Environmental Control Life Support System (ECLSS)
Crew Health and Performance (CHP)
System Capabilities Leadership Team (SCLT)

CHP Technology Roadmaps
Revision 2023.3
For Public Release
Revised: July 31, 2024

Change History

Version	Date	Description	Roadmaps
Revision 2022.0	October 20, 2022	Annual review and revision	All
Revision 2023.0	November 16, 2023	Annual review and revision	All
Revision 2023.1	November 28, 2023	Mid-year updates	Spacesuit Physiology
Revision 2023.2	April 9, 2024	Mid-year updates	Crew Health Countermeasures
Revision 2023.3	July 31, 2024	Delete ECLSS section; rework CHP section for public release	All

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Purpose and Scope

The Environmental Control and Life Support System (ECLSS) – Crew Health and Performance (CHP) Systems Capability Leadership Team (SCLT) is a community of practice (not a funded program) sponsored by Headquarters to develop, retain, and infuse the ECLSS and CHP capabilities necessary to enable the human exploration of the Moon and Mars through the integration and empowerment of experts across NASA, other government agencies, commercial industry, and academia.

The goals of the SCLT are as follows:

1. Use the Architecture Definition Document use cases and functions to identify gaps in NASA's current technological capabilities to meet Agency objectives and develop strategies and roadmaps for closing such gaps
2. Make technical/strategic recommendations on ECLSS and CHP technology development efforts and investments for PPBE, acquisition strategies, and leveraging NASA's critical capabilities
3. Establish key performance parameters and participate in key program and project reviews
4. Maintain cognizance of relevant ECLSS and CHP national and international technology activities in government, industry, and academia, specifically, emerging innovations and technologies, trends, and opportunities
5. Coordinate with commercial and international partners to identify areas of mutual interest and cooperation
6. Support future mission and system architecture studies for human exploration

This document is intended to be a comprehensive overview of the strategic development plans, or Roadmaps, of key technologies and capabilities identified by the SCLT. Each Roadmap is organized by Capability Gap as the gap name and number appears in STARPort, follows a fiscal year timeline, and displays any additional information on milestones, decision points, or important details on the right-hand side of the page. The Roadmaps should be used to facilitate discussion, decision making, and planning for programs and development projects, but are not expected to accurately depict the details and statuses of the projects and tasks appearing within the plans.

For details and questions, please reach out to a member of our management and support team.

ECLSS-CHP SCLT Lead: James Broyan (JSC-BG040)
HMTA/HHP Representative: Andrew Abercromby (JSC-SA121),
Planning & Integration Team: Meghan Hillis (JSC-SA111)[KBR Wyle Services, LLC]

Definitions (1/3)

Acronyms

A-HoSS	Artemis HERA on Space Station
AMOS	Autonomous Medical Officer Support
ANS	Advanced Neutron Spectrometer
ARD	Active Radiation Dosimeter
ARES	Active Radiation Environment Sensor
ARRT	Advanced Risk Reduction Tool
ASCR	Astronaut Strength Condition Rehabilitation
BAA	Broad Agency Announcement
BHP	Behavioral Health and Performance
BPS	Biological and Physical Sciences
BR CM	Bed Rest Counter Measure
CAD	Crew Active Dosimeter
CCRPP	Civilian Commercialization Readiness Pilot Program
CDISS	Commercial Destination International Space Station
CDR	Critical Design Review
CIF	Center Innovation Fund
CIPHER	Complement of Integrated Protocols for Human Exploration Research
CLD	Commercial LEO Destination
CLPS	Commercial Lunar Payload Services
CM	Counter Measure(s)
CMO	Crew Medical Officer
CNS	Central Nervous System
COTS	Commercial Off The Shelf
CSU	Col State University
CUBES	Center for the Utilization of Biological Engineering in Space
DCM	Display & Control Module
DCS	Decompression Sickness
DDT&E	Design, Development, Test, & Evaluation
DFM	Dual Function Materials
DFRC	Dryden Flight Research Center
DOF	Degrees Of Freedom
Dx	Diagnostics
E4D	European Enhanced Exploration Exercise Device
EES	Exploration Exercise System
EHS	Environmental Health Systems
EIHO	Earth Independent Human Operations
EIMO	Earth Independent Medical Operations
EMR	Electronic Medical Record
EMU	Extravehicular Mobility Unit
EOL	End Of Life
EPSCoR	Established Program to Stimulate Competitive Research
ERM	ESPRIT Refueling Module
ERSA	European Radiation Sensor Array
ESDMD	Exploration Systems Development Mission Directorate
EVA	Extravehicular Activity
FLT	Flight
FNS	Fast Neutron Spectrometer
FOM	Figure Of Merit
FSH	Foundation Surface Habitat
GBVG	Google Based Visual Field
GFE	Government Furnished Equipment
GMO	Genetically Modified Organism
GW	Gateway
HALO	Habitation and Logistics Outpost
HDBR	Head Down Bed Rest
HERA	Hybrid Electronic Radiation Assessor
HERMES	Heliophysics Environmental and Radiation Measurement Experiment Suite

Definitions (2/3)

Acronyms - continued

HITL	Human in the Loop
HLS	Human Landing System
HRP	Human Research Program
HT	Holographic Teleportation
HW	Hardware
IARV	Injury Assessment Reference Value
IDA	Integrated Data Architecture
IHAB	International Habitation Module
IMPALA	Information Management Platform for anALysis and Aggregation
IMS	Inventory Management System
ISRU	In-Situ Resource Utilization
ISS	International Space Station
IVGEN	Intravenous Fluid Generation
JARVIS	Joint Augmented Reality Visual Informatics System
JAXA	Japan Aerospace Exploration Agency
JIT	Just In Time
KPP	Key Performance Parameter
LBNP	Lower Body Negative Pressure
LEA	Launch, Entry, Ascent
LEO	Low-Earth Orbit
LETS	Linear Energy Transfer Spectrometer
LP	Laser Processed
LTV	Lunar Terrain Vehicle
MAVRIIC	Multidisciplinary Analytics, Visualization, and Reporting Interface for Integrated Countermeasures
MCTB	Multipurpose Cargo Transfer Bag
MEDPRAT	Medical Extensible Dynamic Probabilistic Risk Assessment Tool
MISSE	Materials International Space Station Experiment
MS	Mass Spectrometer
MTH	Mars Transit Habitat
NESC	NASA Engineering & Safety Center
OCHMO	Office of the Chief Health and Medical Officer
OCT	Optical Coherence Tomography
OIG	Orthostatic Intolerance Garment
OLTARIS	On-Line Tool for the Assessment of Radiation In Space
OSMA	Office of Safety and Mission Assurance
PB	PreBreathe
PDR	Preliminary Design Review
PEL	Permissible Exposure Limits
PersEIDS	Personalized EVA Informatics & Decision Support
PR	Pressurized Rover
PRC	Plant Research Chamber
PSM	Power Supply Module
RAD	Radiation Assessment Detector
REM	Radiation Environment Monitor
RHS	Reactor Health Sensor
ROSBio	Research Opportunities and Space Biology
RSA	Rotary Separator Accumulator
S/L	Shelf-Life
SAA	Space Act Agreement
SANS	Spaceflight Associated Neuro-ocular Syndrome
SBIR	Small Business Innovative Research
SCLT	Systems Capability Leadership Team
SIA	Suited Injury Avoidance
SM	Sensorimotor
SMD	Science Mission Directorate
SOA	State Of Art
SOMD	Space Operations Mission Directorate

Definitions (3/3)

Acronyms - continued

SPLC	SuitPort Logistics Carrier
SRR	System Requirements Review
STMD	Space Technology Mission Directorate
STRI	Space Technology Research Institutes
STTR	Small Business Technology Transfer Program
SUITS	Suited User Injury Tracking System
SW	Software
T2	Treadmill on ISS
TBD	To Be Determined
TD	Technology Demonstration
TDU	Technology Demonstration Unit
TRISH	Translational Research Institute for Space Health
TTO	Transition to Operations
Tx	Treatment
U/S	Ultrasound
USDA	United States Department of Agriculture
USP	United States Pharmacopoeia
UV	Ultraviolet
VIS	Vibration Isolation System
VR	Virtual Reality
VSM	Vehicle System Manager
VV	Verification and Validation
WPAFB	Wright Patterson Air Force Base
xEHR	Exploration Electronic Health Record
xPWD	Exploration Potable Water Dispenser
XR	X-Ray
XROOTS	Exposed Root On-Orbit Test System
XU	Exploration Unit

Crew Health and Performance (CHP) Systems

Spacesuit Physiology & Performance Capability Area

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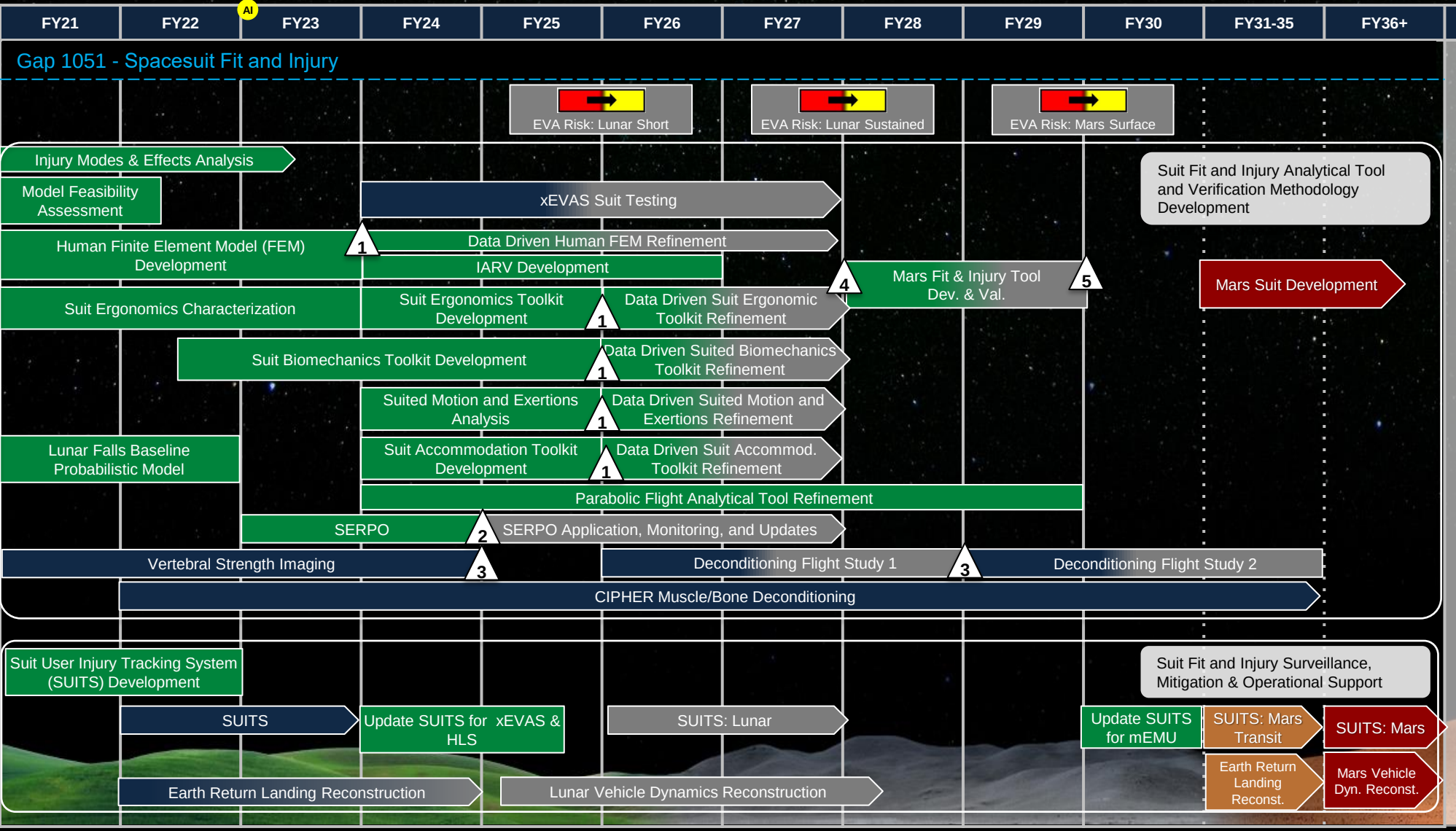
SPACESUIT PHYSIOLOGY & PERFORMANCE (1 of 5)

TIMELINE NOTIONAL



Additional Information

Gap 1051

Deliverables

1. **Baseline suit-independent analytical tool release (decision point, deliverable and infusion point to Artemis for risk characterization and mitigation)**
2. **SERPO final report with recommendations for crew readiness and relevant conOps for Artemis (decision point, deliverable, infusion point)**
3. **Decision points for follow on deconditioning studies**
4. **Updated Release of Suit-Independent Analytical Tools for assessing suit fit and injury risk**
5. **Validated, suit-agnostic fit and injury analytical tools for Mars**

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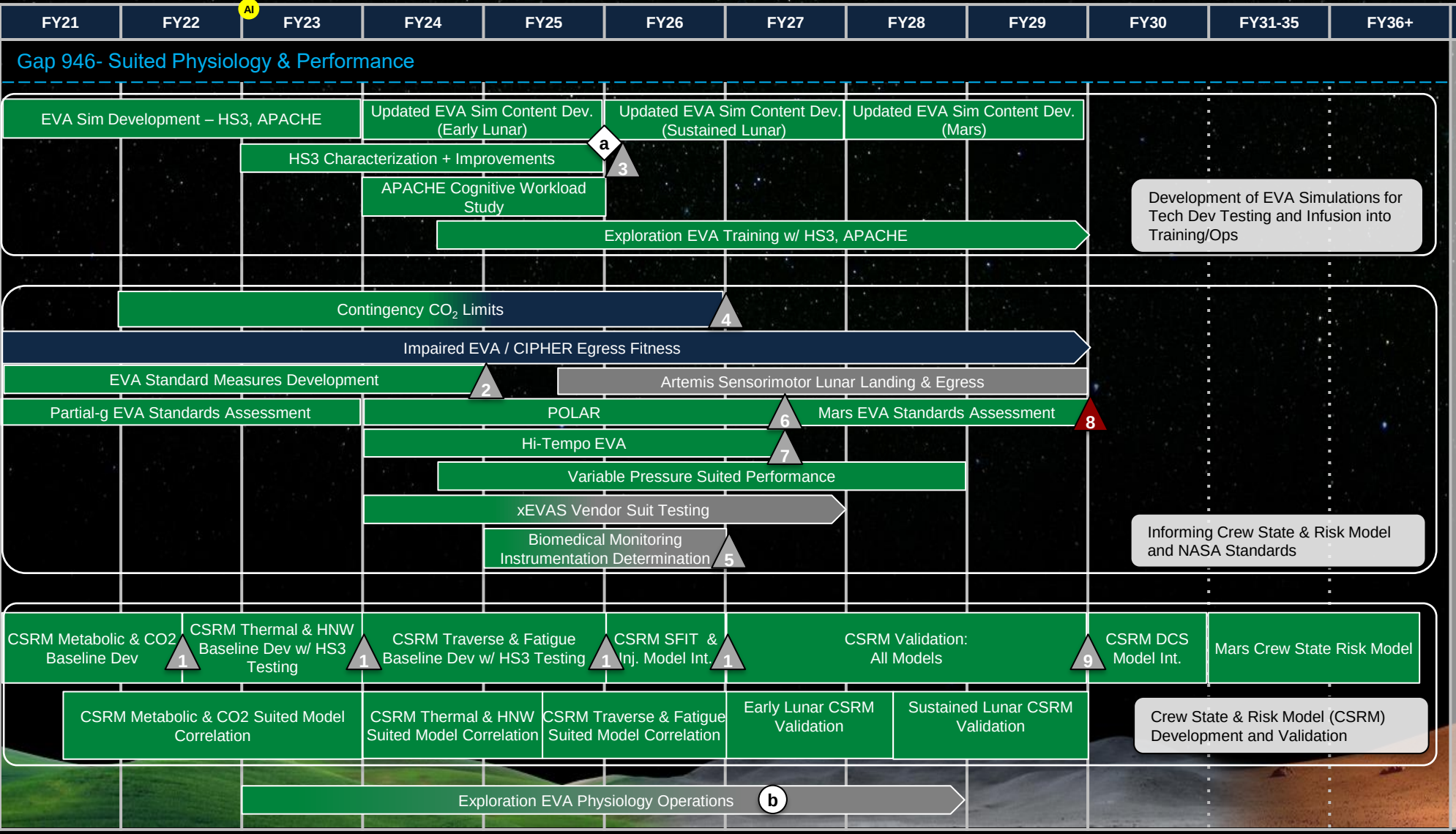
NASA EXTERNAL

SPACESUIT PHYSIOLOGY & PERFORMANCE (2 of 5)

TIMELINE NOTIONAL



Additional Information

Gap 946

Deliverables

1. Initial release of individual crew state models
2. EVA Standard Measures
3. Initial EVA Simulation Capability
4. Contingency Suited CO2 Standard
5. Biomedical Monitoring Instrumentation Needs
6. Lunar EVA Readiness Standards
7. Timeline & Conops constraints: Lunar Initial
8. Mars EVA Readiness Standards
9. Release of integrated multi-model version of CSRM

Decision Points/Comments

a. Initial infusion of EVA simulation content into EVA training operations

b. Exploration EVA Physiology Operations task denotes how the work is infused into Artemis/operations in a time-phased approach as new capabilities are available

Crew State Model is a core component of PersEIDS, see Suited Autonomous Health Monitoring & Decision Support gap for additional information.

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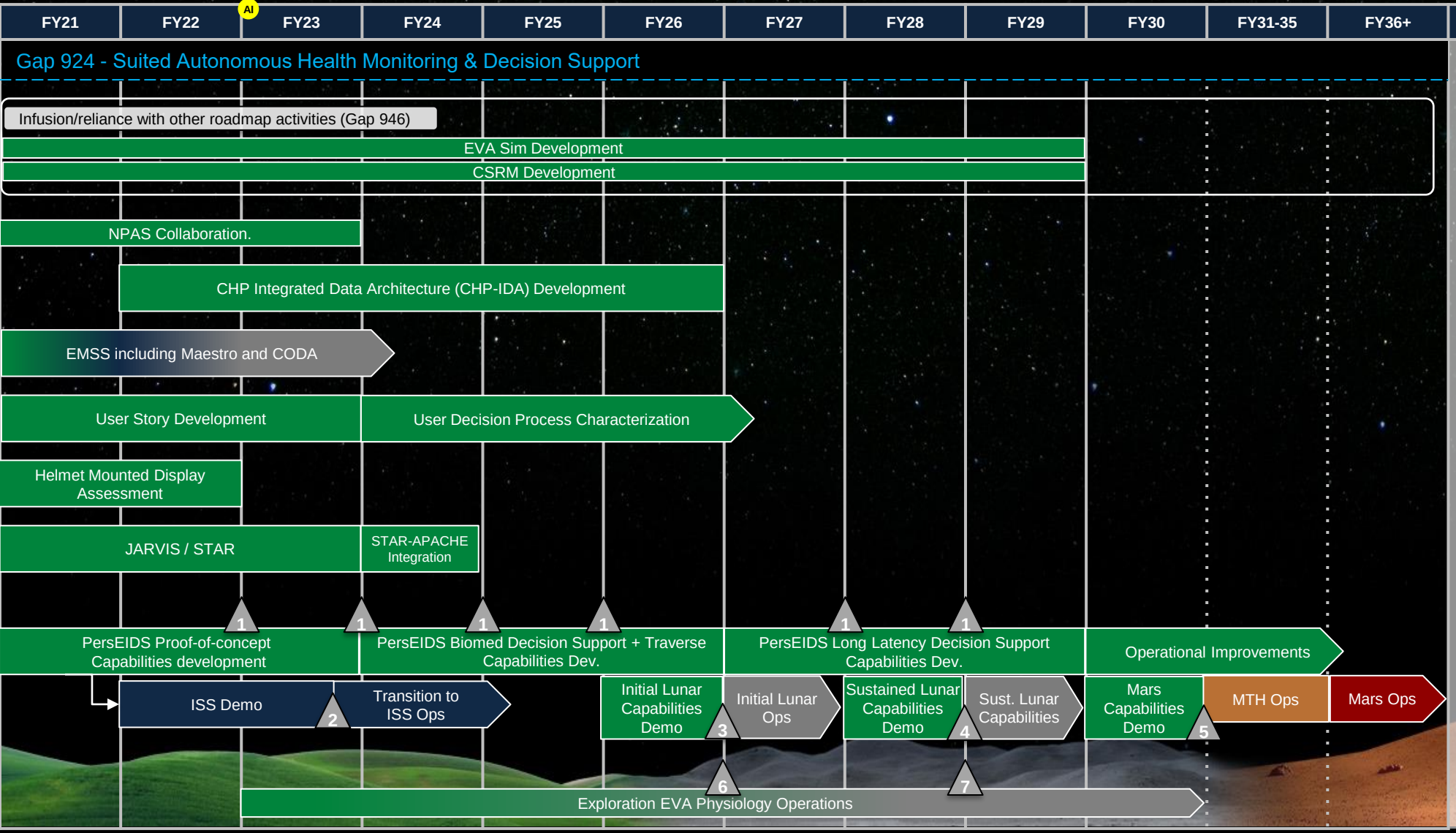
SPACESUIT PHYSIOLOGY & PERFORMANCE (3 of 5)

TIMELINE NOTIONAL



Additional Information

Gap 2941

Deliverables

1. **PersEIDS Capabilities demonstrations**
2. **ISS Real-Time Monitoring Demo**
3. **Initial lunar capabilities demonstration**
4. **Mars-like capabilities for Lunar demo.**
5. **Mars capabilities demonstration**
6. **Infusion point for feeding PersEIDS (Personalized EVA Informatics & Decision Support) capabilities into Initial Artemis operations via Exploration EVA Physiology Operations**
7. **Infusion point for feeding PersEIDS capabilities into sustained Artemis operations via Exploration EVA Physiology Operations**

Please see the Exploration Medical roadmap for additional information on the development of the CHP-IDA and the Suited Physiology and Performance gap for more details on EVA simulation development.

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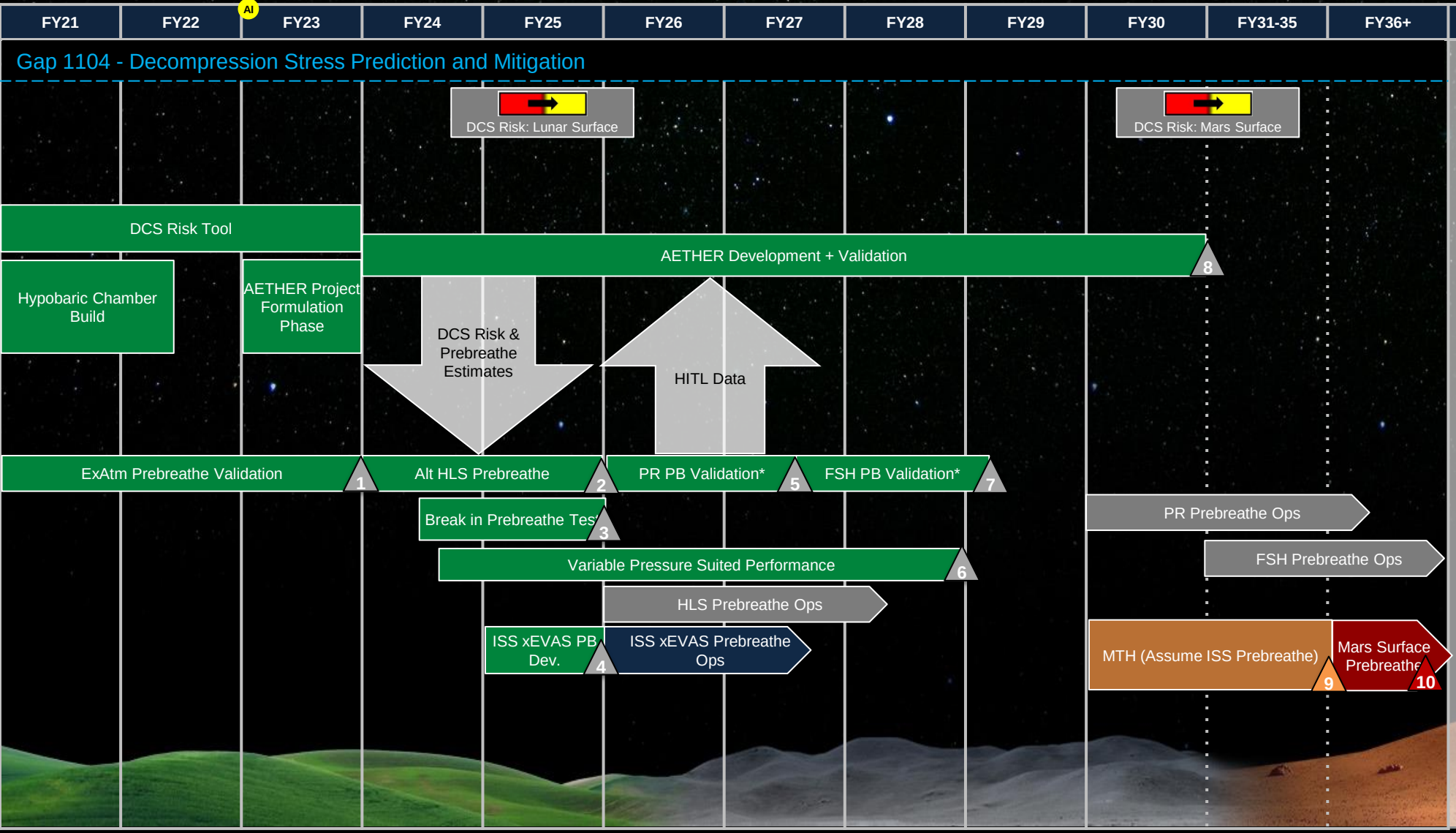

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Additional Information

Gap 1104

Deliverables

1. HLS Prebreathe (PB) Validation
2. HLS Alternate PB Validation
3. Break in PB Flight Rule Update
4. ISS xEVAs PB Flight Rule
5. PR Atmosphere Validation
6. Variable Pressure Suit Capabilities
7. FSH Atmosphere Validation
8. Validated AETHER Model
9. MTH Atmosphere Validation
10. Mars Surface Atmosphere Validation

Please see Suited Physiology and Performance gap for more information on Crew State Risk Model development.

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Crew Health and Performance (CHP) Systems Crew Health Countermeasures Capability Area

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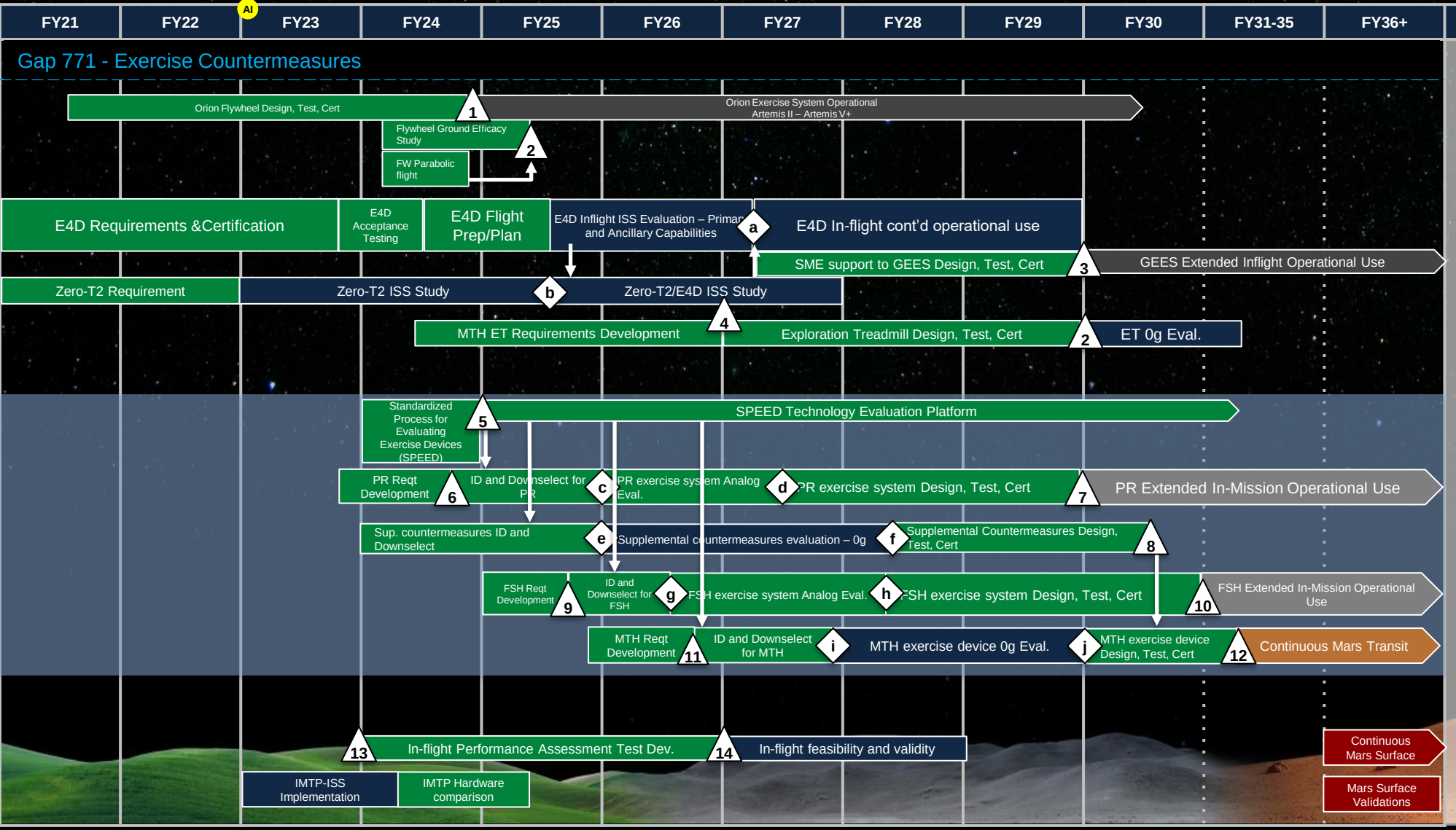
CREW HEALTH COUNTERMEASURES (Slide 1 of 7) *Exercise Countermeasures*

TIMELINE NOTIONAL



Gap 771

Deliverables

1. Orion Flywheel exercise system delivered and certified for A-II
2. Input to Artemis Exercise System Risk Recommendation and Ops products finalization
3. Gateway Exploration Exercise System (GEES) and Ops products delivered
4. Recommendation on need for Exploration Treadmill
5. Documented standardized process w/ updated archive
6. PR Exercise System Requirements delivered
7. PR Exercise System and Ops products delivered
8. Supplemental Exercise Countermeasure and Ops products delivered
9. FSH Exercise System Requirements delivered
10. FSH Exercise System and Ops products delivered
11. MTH Exercise System Requirements delivered
12. MTH Exercise System and Ops products delivered
13. Primary In-flight Strength measures available on ISS
14. Ops products for in-flight validation of Muscle and Aerobic assessment protocols

Decision Points/Comments

a. Refine capability requirements for Gateway Exploration Exercise System
b. Preliminary inputs to MTH requirements from 2/3 study arms
c. Selection of PR Exercise System candidate
d. Refine capability requirements for PR Exercise System
e. Selection of Supplemental Countermeasure to proceed to 0g evaluations
f. Refine capabilities requirements for Supplemental Countermeasures
g. Selection of FSH Exercise System candidate
h. Refine capability requirements for FSH Exercise System
i. Selection of MTH Exercise System candidate
j. Refine capability requirements for MTH Exercise System

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Notes:
*Exercise System 1g and 0g analog evals will be structured to include the assessment of supplemental countermeasure efficacy
**Standardized strength and aerobic (VO2) measures will be included in each exercise system's analog eval for assessment of countermeasure efficacy

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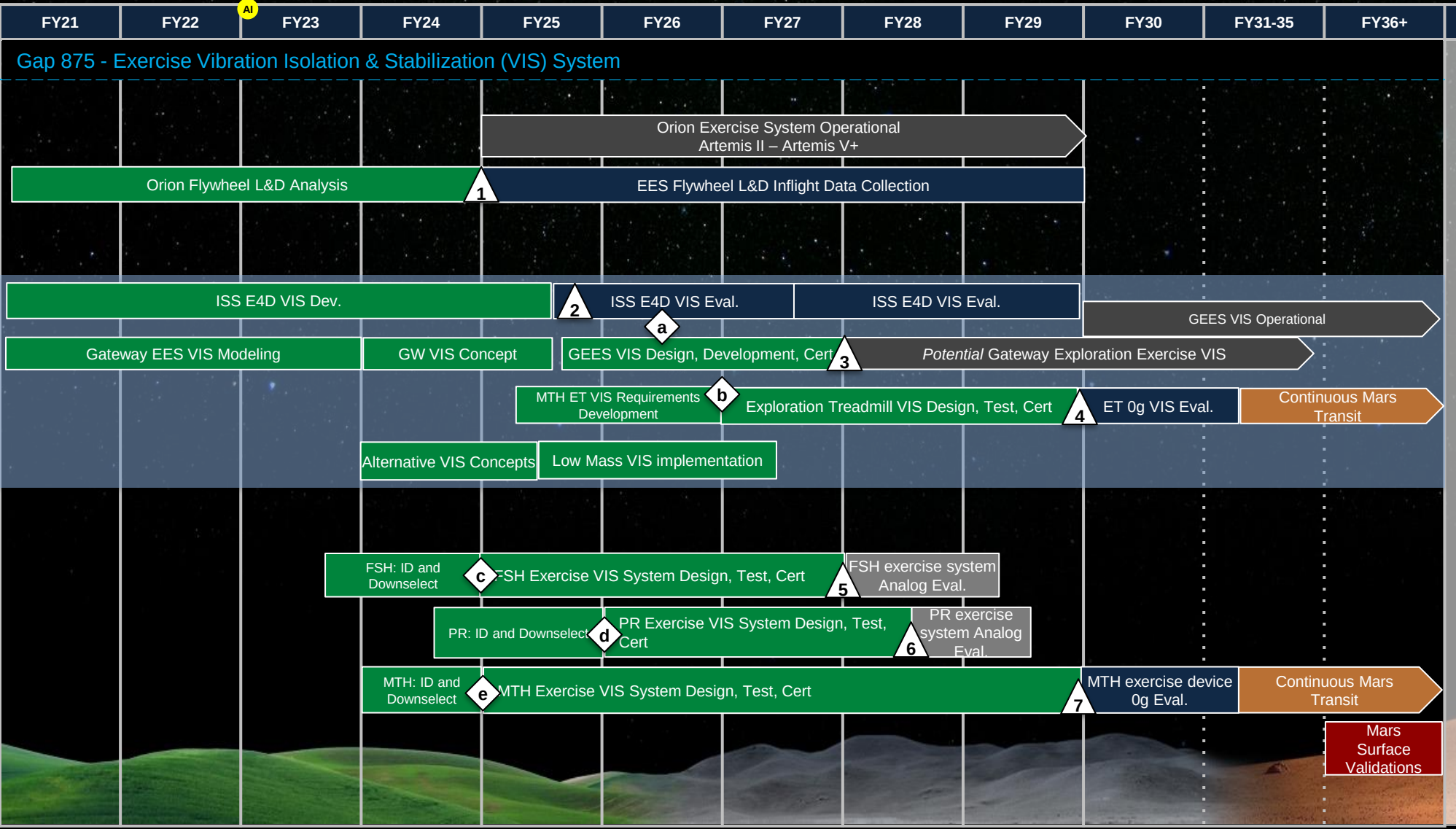
CREW HEALTH COUNTERMEASURES (Slide 2 of 7) *Exercise Vibration Isolation Stabilization (VIS) System*

TIMELINE NOTIONAL



Additional Information

Gap 875

Deliverables

1. Will inform Ops products and Orion Exercise System exercise requirements
2. ISS E4D VIS Flight Hardware
3. Gateway Exercise VIS System and Ops products delivered. Due to the potential upmass issues, Exercise VIS hardware might need to be launched and installed prior to exercise device delivery.
4. Exploration Treadmill (ET) System and Ops products delivered
5. FSH Exercise System and Ops products delivered
6. PR Exercise System and Ops products delivered
7. MTH Exercise System and Ops products delivered

Decision Points/Comments

a. Refine capability requirements for Gateway Exercise System

b. Decision point to proceed with development MTH Exploration Treadmill system

c. Selection of FSH Exercise System candidate

d. Selection of PR Exercise System candidate

e. Selection of MTH Exercise System candidate

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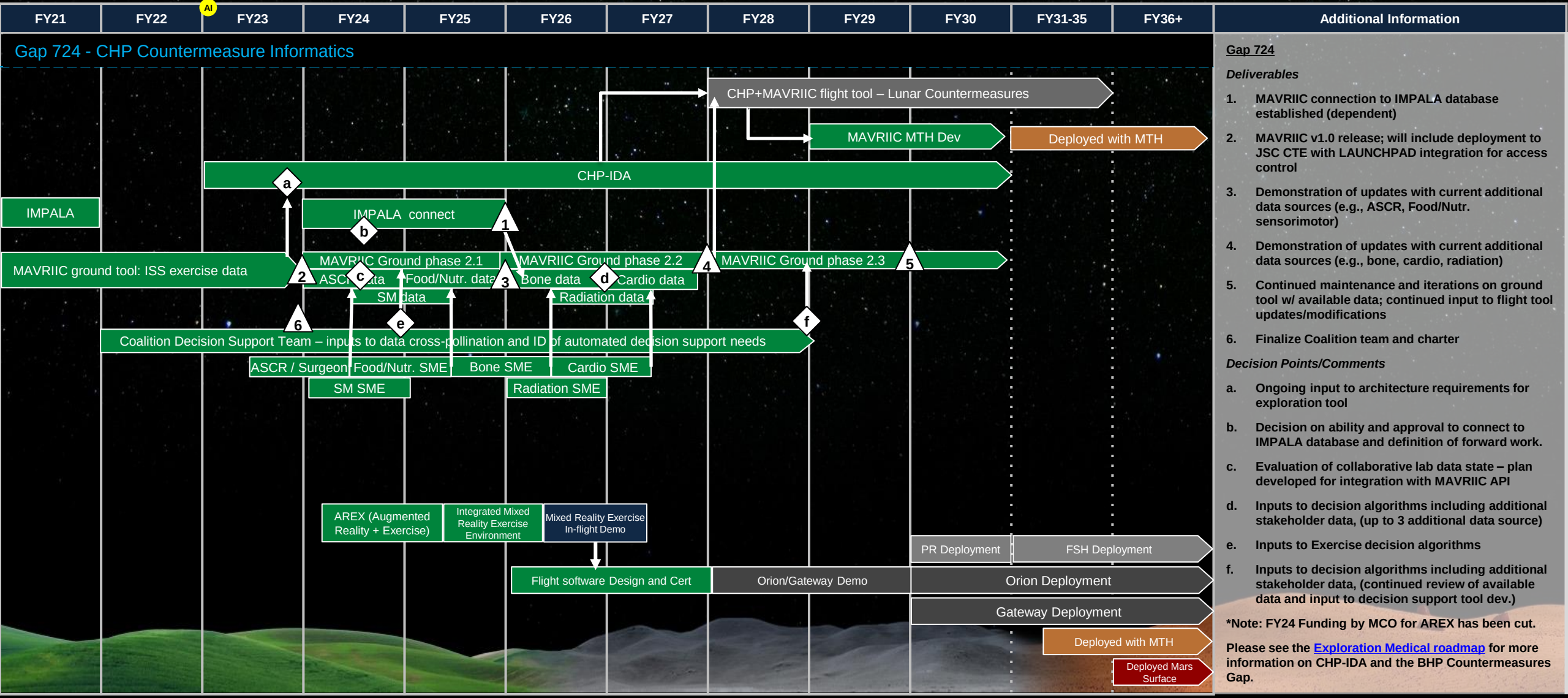
CREW HEALTH COUNTERMEASURES (Slide 3 of 7) *CHP Countermeasure Informatics*

TIMELINE NOTIONAL



Gap 724

Deliverables

1. MAVRIIC connection to IMPALA database established (dependent)
2. MAVRIIC v1.0 release; will include deployment to JSC CTE with LAUNCHPAD integration for access control
3. Demonstration of updates with current additional data sources (e.g., ASCR, Food/Nutr. sensorimotor)
4. Demonstration of updates with current additional data sources (e.g., bone, cardio, radiation)
5. Continued maintenance and iterations on ground tool w/ available data; continued input to flight tool updates/modifications
6. Finalize Coalition team and charter

Decision Points/Comments

a. Ongoing input to architecture requirements for exploration tool

b. Decision on ability and approval to connect to IMPALA database and definition of forward work.

c. Evaluation of collaborative lab data state – plan developed for integration with MAVRIIC API

d. Inputs to decision algorithms including additional stakeholder data, (up to 3 additional data source)

e. Inputs to Exercise decision algorithms

f. Inputs to decision algorithms including additional stakeholder data, (continued review of available data and input to decision support tool dev.)

*Note: FY24 Funding by MCO for AREX has been cut.

Please see the Exploration Medical roadmap for more information on CHP-IDA and the BHP Countermeasures Gap.

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CREW HEALTH COUNTERMEASURES (Slide 4 of 7) *Sensorimotor*

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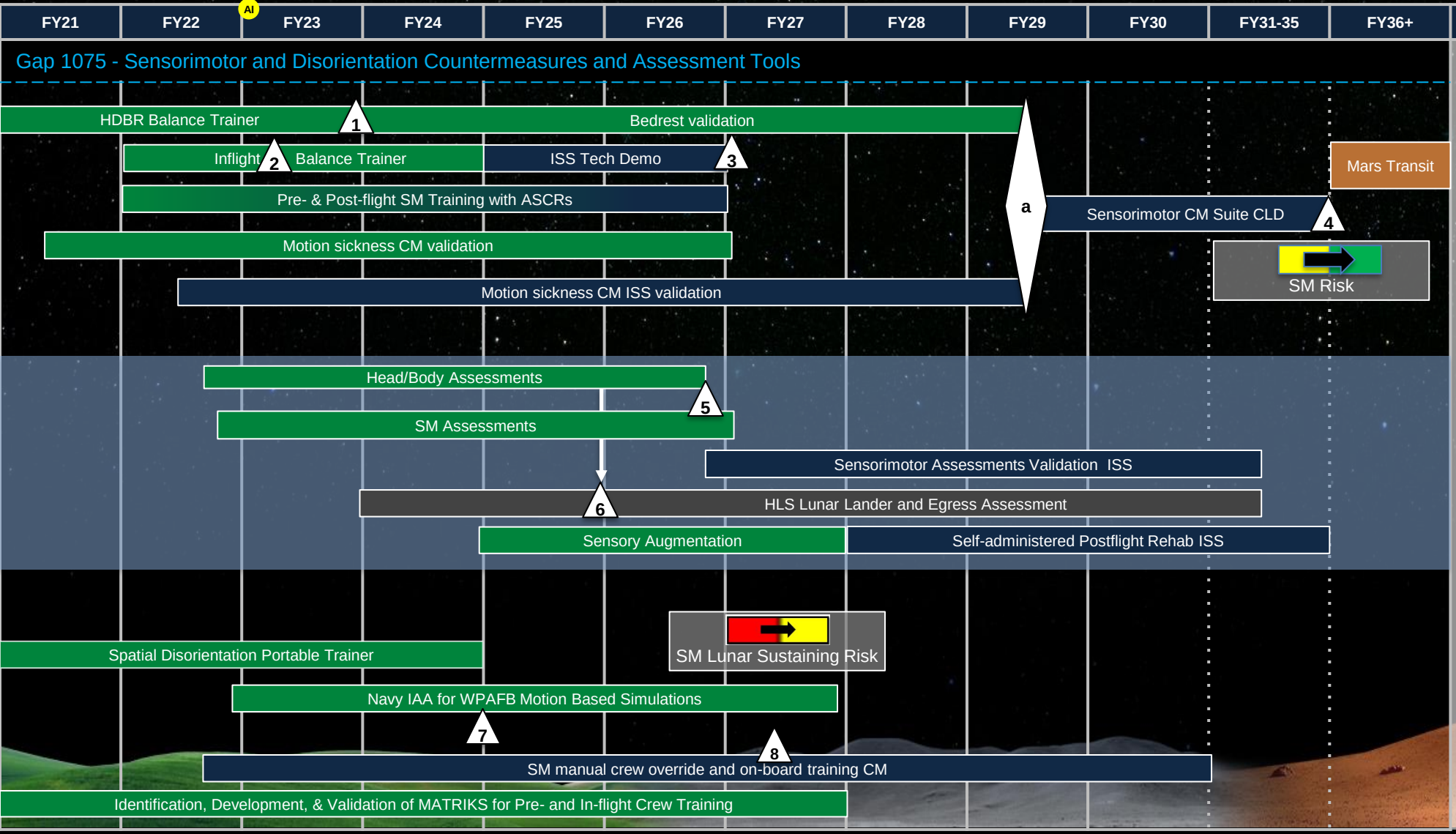

Additional Information

Gap 1075

Deliverables

1. Delivery of balance trainer system at TRL 6 for head-down bedrest (HDBR) validation
2. Delivery of Parabolic flight tech demonstration trainer at TRL 6
3. Complete ISS Tech Demo of balance trainer for Mars Transit Habitat PDR & ISS CM validation
4. Delivery of SM Countermeasure Suite Validation at TRL 8 for Mars Transit Habitat Operations
5. Delivery of markerless motion capture suite for ISS Validation of SM assessments and FSH PDR
6. HRP delivery of SM assessments to HMTA for lunar EVA surface ops based on available analog and post-ISS evidence
7. Delivery of preliminary Design Reference Vehicle lunar landing motion simulation for Artemis FOD skills training evaluation and CM research
8. Proposed risk reduction for lunar landing risk based on ISS study (short duration PAM) and demonstration of on-board trainer at Kraken facility

Decision Points/Comments

a. Decision Point/Gate (a) supports down-select of SM countermeasure suite based on available ground and analog evidence

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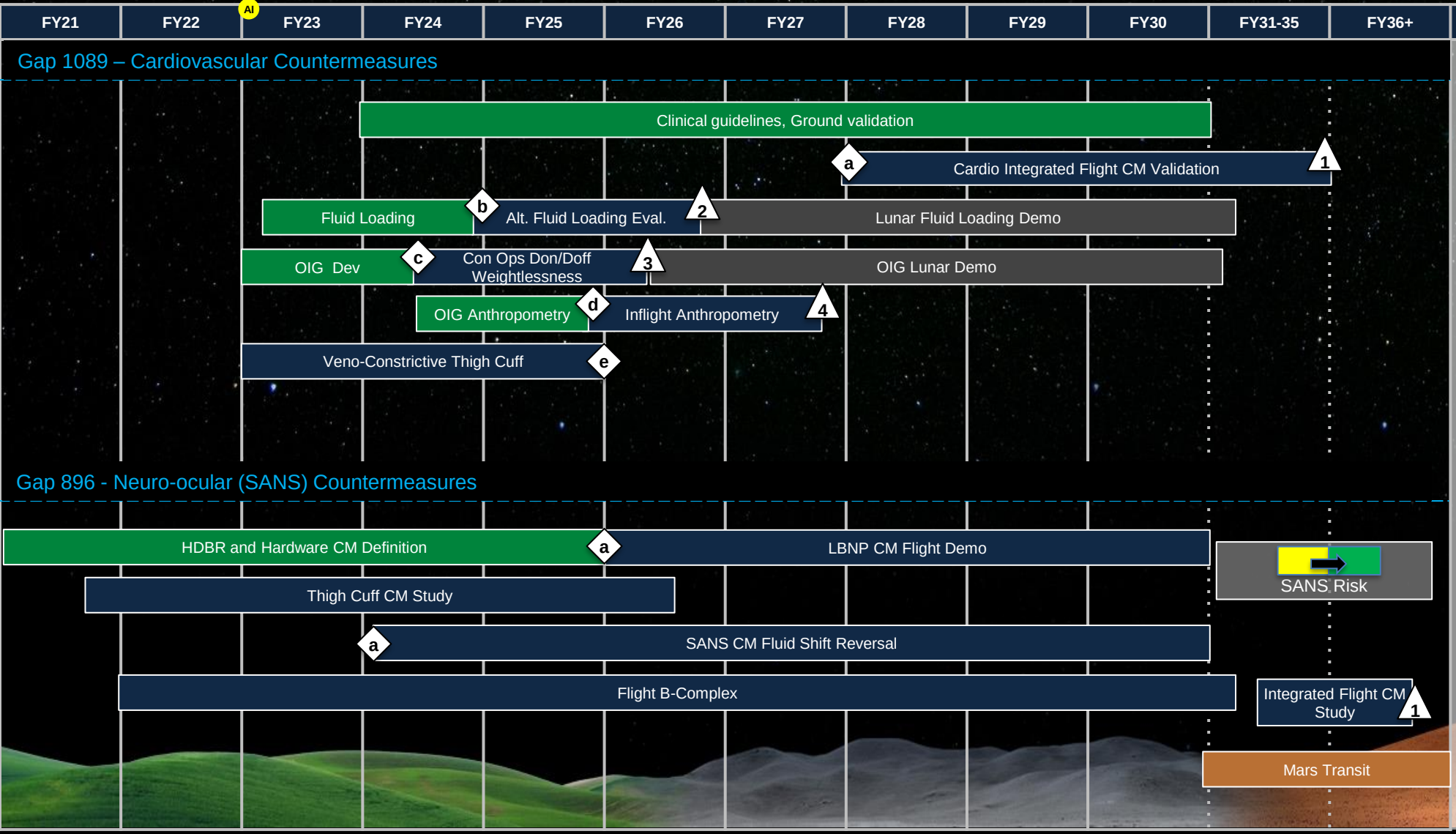
CREW HEALTH COUNTERMEASURES (Slide 5 of 7) *Cardiovascular, Neuro-ocular (SANS)*

TIMELINE NOTIONAL



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Gap 1089

Deliverables

1. HRP delivery of Cardiovascular Assessment and CM based on Spaceflight Effects to SCLT/HMTA (YtG color change)
2. Delivery of alternate fluid loading for lunar flight demo
3. Delivery of Orthostatic Intolerance (compression) Garment (OIG) for lunar flight demo
4. Delivery of inflight anthropometry measurement capability

Decision Points/Comments

a. Decision Point/Gate on starting ISS flight CM study

b. Decision Point/Gate on starting ISS tech evaluation

c. Decision Point/Gate on starting ISS/PAM/Parabolic tech evaluation

d. Decision Point/Gate on starting ISS tech evaluation

e. Decision Point/Gate on delivery to CCP/Artemis/MCO

Gap 896

Deliverables

1. HRP delivery of SANS CM to Artemis/MCO (YtG color change)

Decision Points/Comments

a. Decision Point/Gate on starting CLD CM evaluation study

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CREW HEALTH COUNTERMEASURES (Slide 6 of 7) *Bone, Immune, Micro Host*

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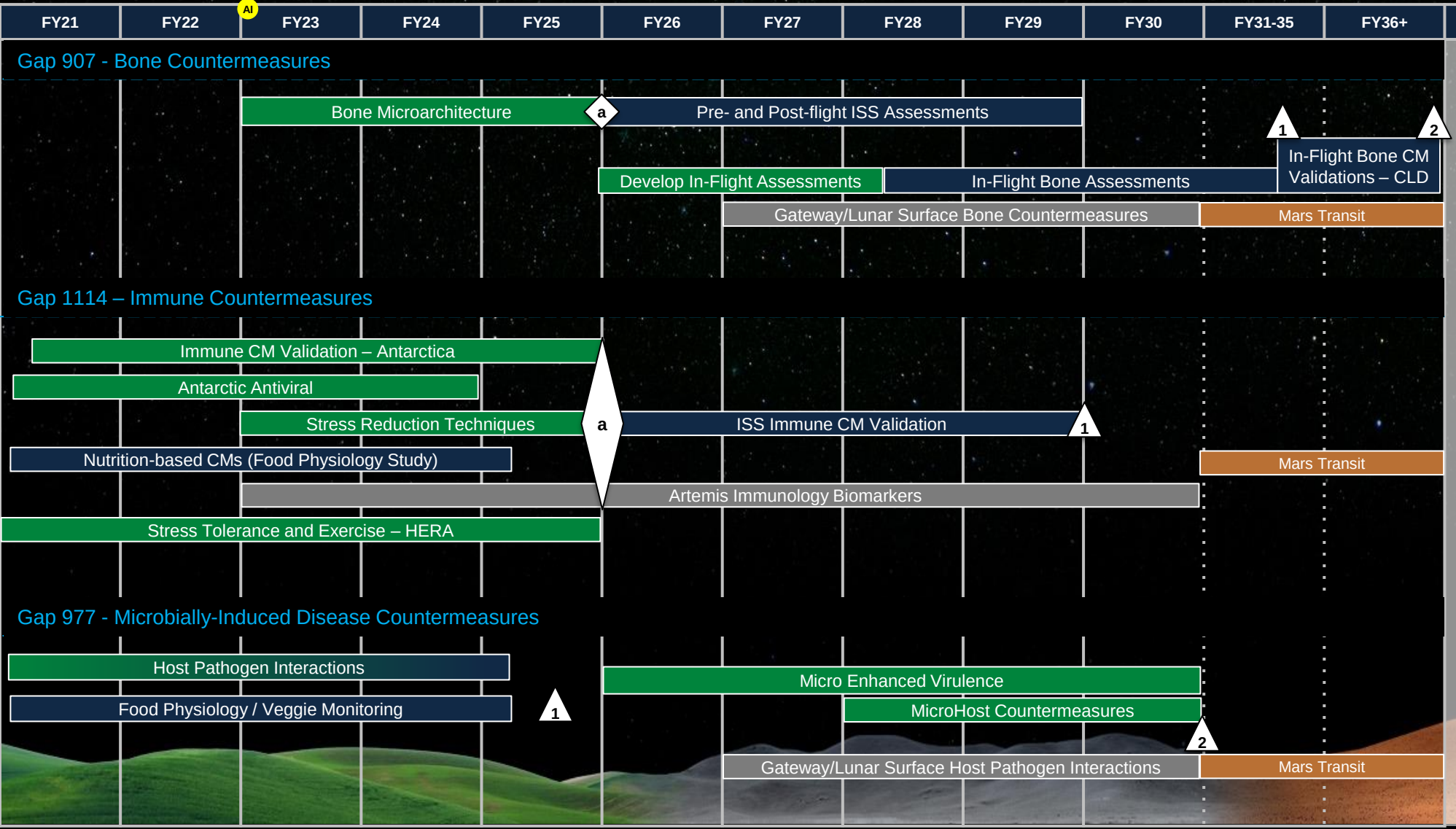

Additional Information

Gap 907

Deliverables

1. Delivery of Bone Microarchitecture Assessment to HMTA , risk color change (Red to Yellow)
2. Delivery of Bone CM to HMTA, risk color change (Yellow to Green)

Decision Points/Comments

a. Decision Point/Gate (a) supports inflight monitoring requirements for CM intervention

Gap 1114

Deliverables

1. HRP delivery of Immune Countermeasure to SCLT/HMTA, risk color change (Yellow to Green)

Decision Points/Comments

a. Decision Point/Gate (a) supports selection of immune CMs for inflight validation

Gap 977

Deliverables

1. HRP delivery of Micro standards to OCHMO
2. HRP delivery of Microhost CM to SCLT/HMTA, risk color change (Yellow to Green)

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Crew Health and Performance (CHP) Systems

Radiation Protection Capability Area

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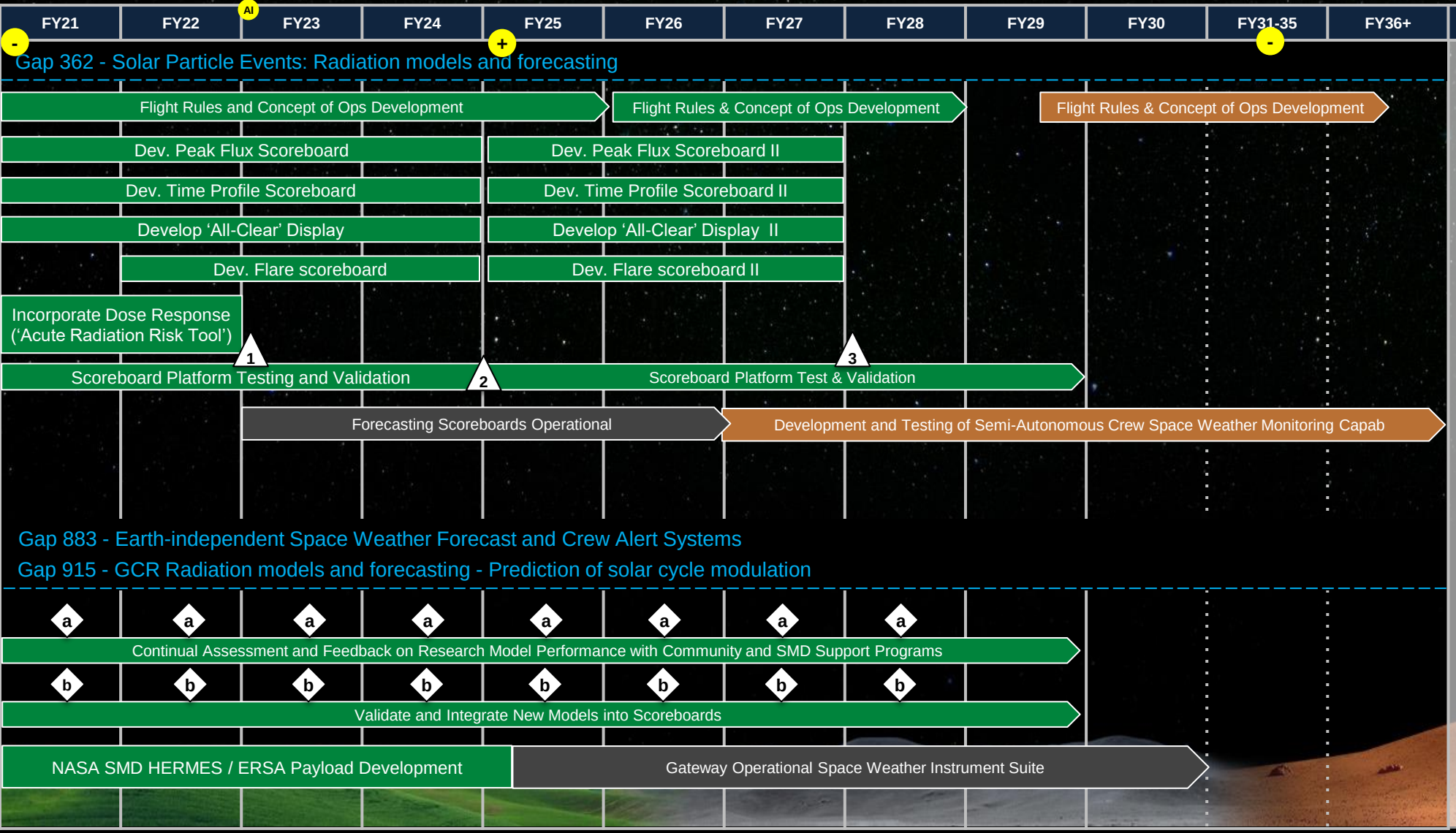
Radiation Protection (Slide 1 of 5) *Space Weather Forecasting*

TIMELINE NOTIONAL



Additional Information

Gap 362

Deliverables

1. **[RAD.DEL.1] Scoreboards delivered for testing on Artemis I. [TRL 6/7] Q4FY22**
2. **[RAD.DEL.2] Scoreboards delivered for usage on Artemis II & II.I [TRL 8] Q4FY24**
3. **[NEW] Scoreboards delivered for usage on Artemis IV & V. Q4FY27**

Gaps 883 & 915

Decision Points/ Comments

a. **[RAD.DEC.1] Assessment of Space Weather Research and Scoreboard progress – Annual Review**

b. **[RAD.DEC.2] Assess Model Performance and integrated scoreboard platform – Annual Review**

+ Solar Maximum

- Solar Minimum

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Radiation Protection (Slide 2 of 5) *Radiation Monitoring*

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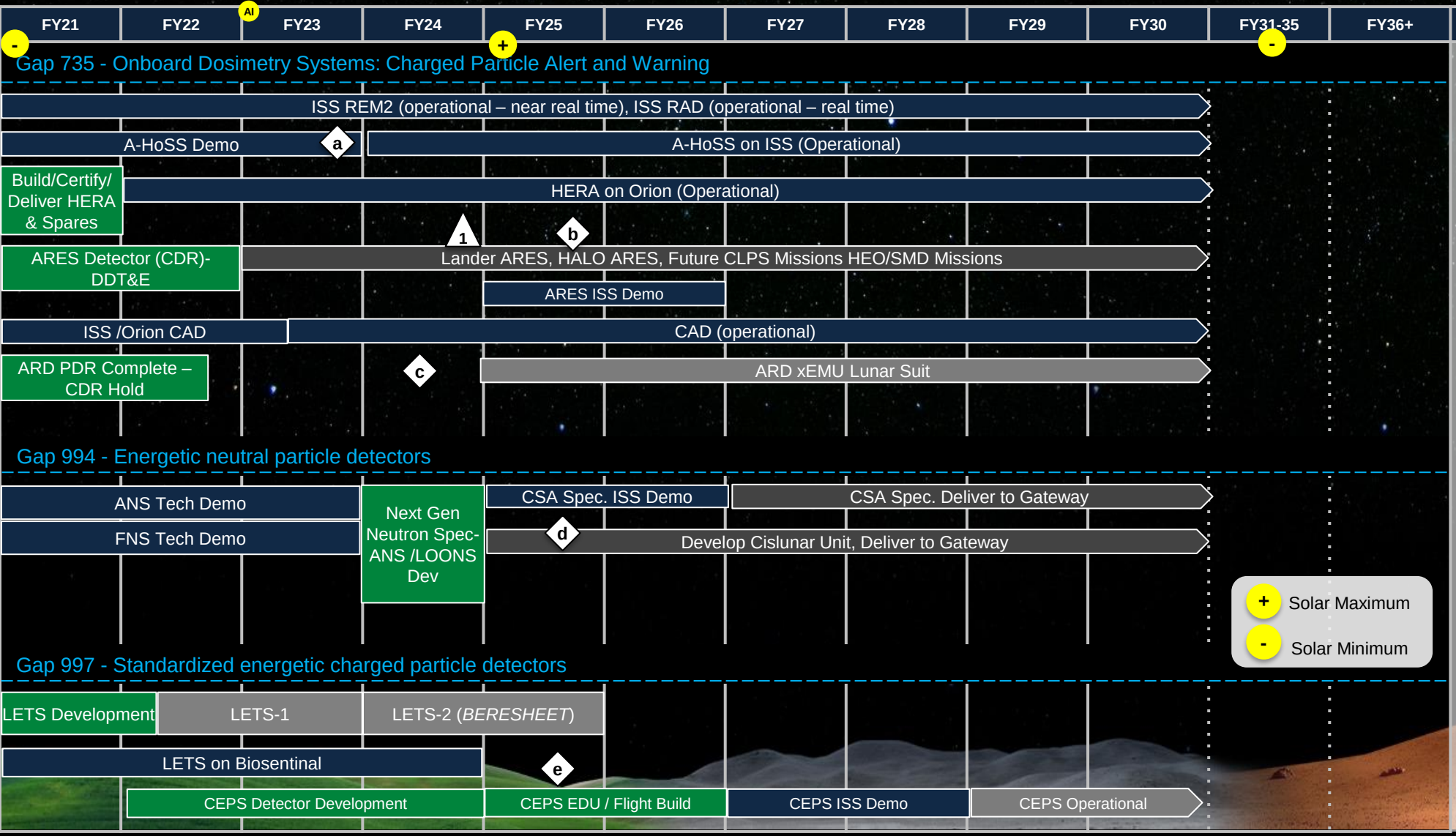

Additional Information

Gap 735

Deliverables

1. **[RAD.DEL.3] Delivery of flight units to Gateway(HALO) and HLS (AR3 and AR4) Q4FY22**

Decision Points

a. **[RAD.DEC.3] Decision point to make A-HoSS operational in FY 2024. Q2FY23 YES**

b. **[RAD.DEC.4] HLS-ARES and Gateway-ARES SAAR. Q3FY25**

c. **[RAD.DEC.5] Decision Point for xEVAS vendor to pick up ARD for suit radiation monitoring for Lunar Suit (and possibly ISS Demo Suit). Q2FY24**

Gap 994

Decision Points

d. **[RAD.DEC.6] Neutron Detector decision – Downselect between ANS, LOONS, or CSA neutron spectrometer for cis-lunar development & delivery to Gateway. Q2FY25**

Gap 997

Decision Points

e. **[RAD.DEC.7] CEPS SRR. Q2FY25**

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Radiation Protection (Slide 3 of 5) *Effective Shielding*

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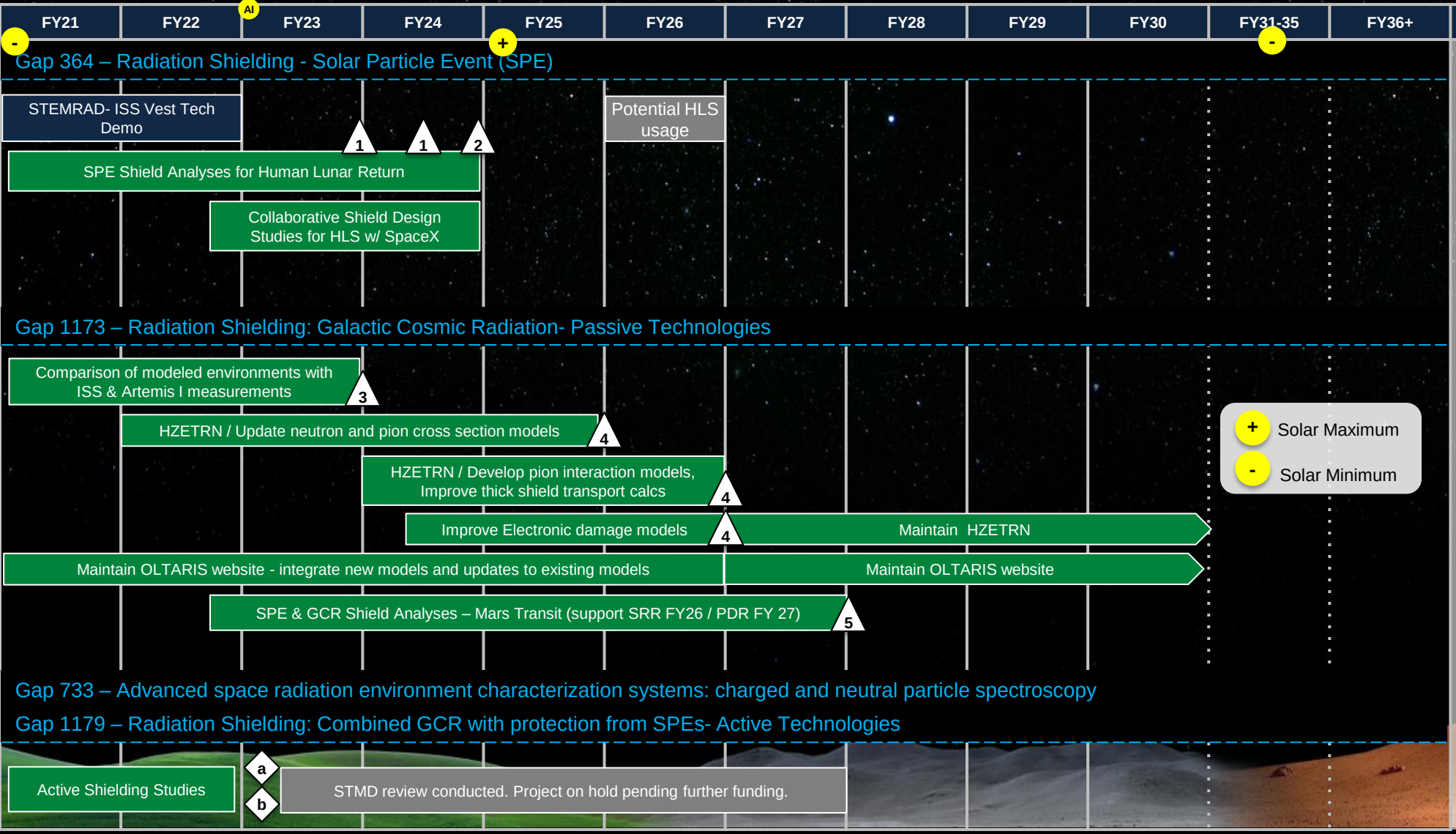

Additional Information

Gap 364

Deliverables

1. **[RAD.DEL.4] Verify shelter requirements for Artemis I and Artemis II (Orion). Funding OR. Q4FY23, Q2FY24**
2. **[RAD.DEL.5] Perform SPE shield analysis for Gateway Iterative Analysis Cycle 10 (IAC 10) – Funding GW. Q4FY24**

Gap 1173

Deliverables

3. **[RAD.DEL.6] Update validation of HZETRN. Q4FY23**
4. **[RAD.DEL.7] Integrate into OLTARIS and make models available to community Q4FY25, Q4FY25**
5. **[RAD.DEL.8] Optimized Mars Transit Shield Design for PDR Q4FY27.**

Gaps 733 & 1179

Decision Points

a. **[RAD.DEC.7] Proceed with Tech Development –Q4FY22 - NO**

b. **[RAD.DEC.8] Perform System Level Trade Study – Q4FY22, On-hold**

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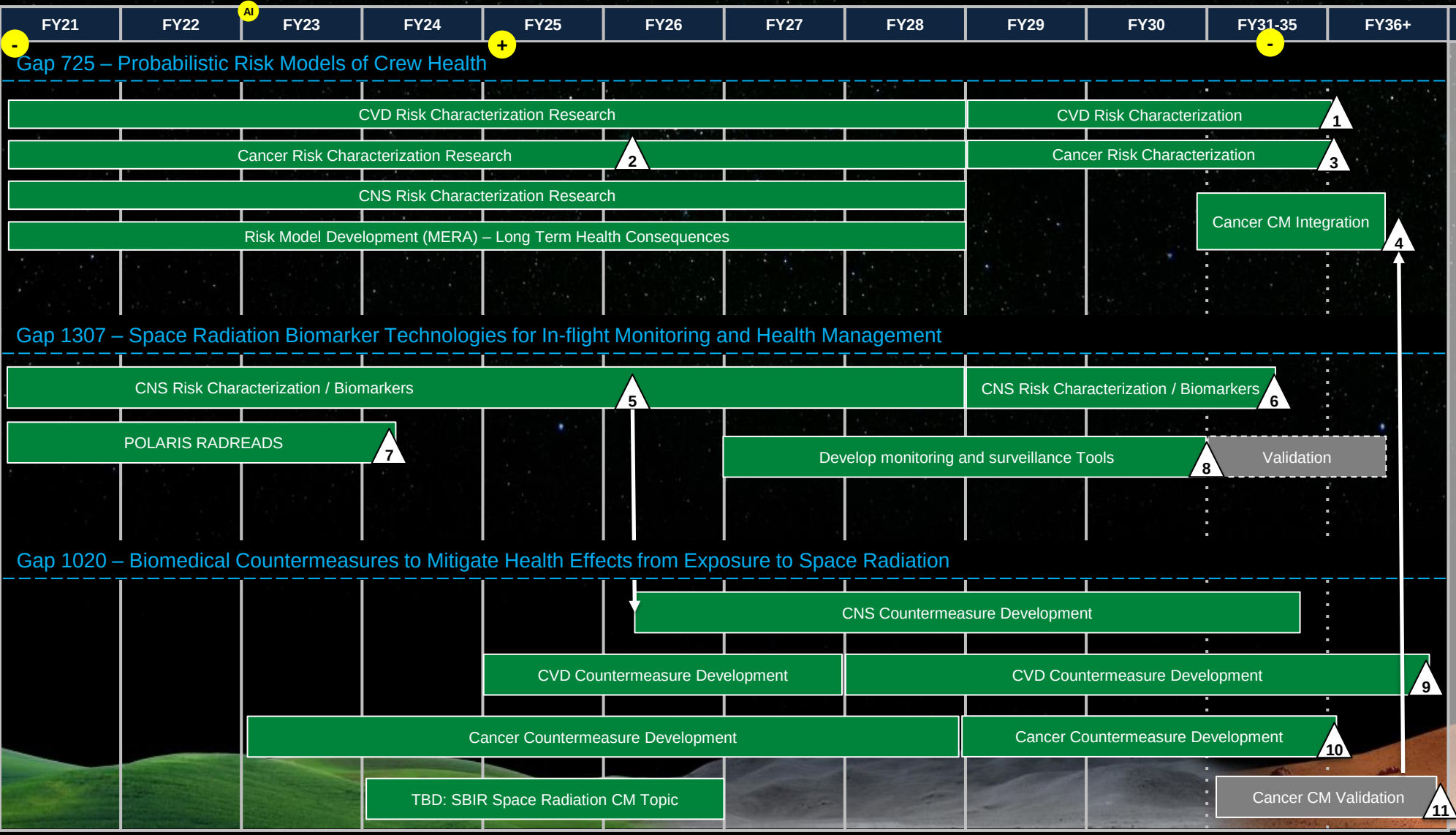
ECLSS-CHP SCLT ROADMAP – REVISION 2023.3

NASA EXTERNAL

Radiation Protection (Slide 4 of 5) *Biological Mitigation*

TIMELINE NOTIONAL



Additional Information

Gap 725

Deliverables

1. [RAD.DEL.12]: CVD Standards Combined Effects to OCHMO 9/28/35
2. [RAD.DEL..9]: Baseline NPR 8900.1B guidance 4/30/26
3. [RAD.DEL.10]: Cancer Artemis NPR 8900.1B Guidance 9/28/35
4. [RAD.DEL.11]: Recommendations for Clinical Practice Guidelines and the Integrated CM Toolkit in the assessment of the radiation exposure standard 11/4/38

Gap 1307

Deliverables

5. [RAD.DEL.16]: BMed Study Results for Inputs to Biomarker Thresholds linked to performance to HSRB. 12/31/25
6. [RAD.DEL.17]: BMed Standards for clinical guidelines for biomarker thresholds linked to performance to OCHMO 8/24/34
7. [RAD.DEL.18] POLARIS - Radiation Assessment DuRing Exposure And long-Duration Spaceflight. Final report. NCE Mar 2024. TRL 4-5
8. [RAD.DEL.19]: Recommendations for Clinical Practice Guidelines - Cancer (Surveillance, early detection) 9/20/30

Gap 1020

Deliverables

9. [RAD.DEL.15]: CVD CM Combined Effects to SCLT/HMTA. 8/31/39
10. [RAD.DEL.13] Cancer Countermeasure Identification 9/18/36
11. [RAD.DEL.14] Integrated CM Toolkit 9/8/38

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Crew Health and Performance (CHP) Systems

Exploration Medical Capability Area

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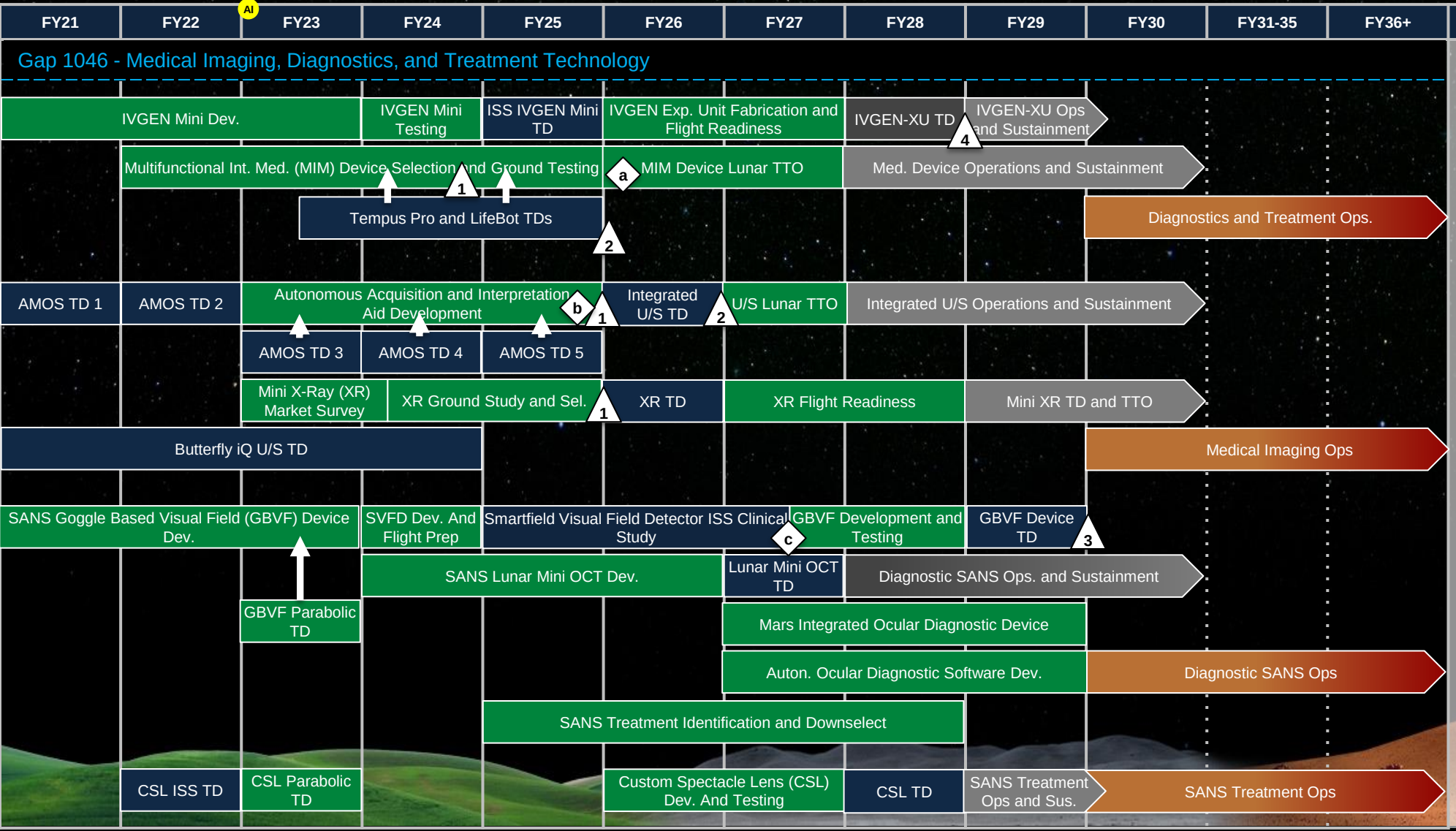
EXPLORATION MEDICAL (XM) (Slide 1 of 6)

TIMELINE NOTIONAL



Gap 1046

Deliverables

1. To be included in integrated ground testing with the Crew Health and Performance Integrated Data Architecture (CHP-IDA).
2. Candidate for ISS4Mars Mars Analog Earth Independent Medical Research Use Case
3. The GBVF Device TD is to support Diagnostic SANS Ops and Sustainment.
4. Successful IVGen Mini TDs will enable IVGen-XU (Exploration Unit) TTO on lunar surface.

Decision Points/Comments

a. Successful MIM Device ISS TDs, including Tempus Pro TD, will enable device down select and TTO for lunar surface operations. ISS TTO is TBD.

b. The Butterfly iQ TD and AMOS TD are testing state-of-the-art ultrasound and image acquisition/interpretation aids. These TDs will inform a technology investigation for and TD of an integrated ultrasound TD.

c. Decide if visual field device 7is needed for exploration missions based on Smartfield study findings.

Please see the Crew Health Countermeasures roadmap for information regarding High Pressure O_2

Please see the Crew Health Countermeasures roadmap for additional information regarding SANS

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ECLSS-CHP SCLT ROADMAP – REVISION 2023.3

NASA EXTERNAL

EXPLORATION MEDICAL (XM) (Slide 2 of 6)

TIMELINE NOTIONAL

Additional Information

Gap 853

Deliverables

1. To be included in integrated ground testing with the Crew Health and Performance Integrated Data Architecture (CHP-IDA).
2. Candidate for ISS4Mars Mars Analog Earth Independent Medical Research Use Case
3. Successful AMIS TD will enable TTO and infusion into lunar platforms. Lunar operations will inform technology development for Mars DRMs.
4. Successful xEHR lunar TD will enable TTO and infusion into lunar platforms. Lunar operations will inform technology development for Mars DRMs.
5. SBIR Tracking:
   - Autonomous Medical Response Agent (AMRA) – autonomous clinical decision support (FY21-FY23)
   - Intelligent Medical Crew Assistant (IMCA) – real-time autonomous medical decision making (FY21-FY23)
   - Space medicine GPT – Large language model trained with medical information (Awarded FY23)
   - Amalgamated Vision – Enhanced procedural, technical, and training guidance (Awarded FY23)

Gap 1178

Deliverables

1. Medical risk model and trade space analysis tools will inform development of medical system requirements for Artemis missions and Mars DRMs.
2. HRP Deliverable: IMPACT versions 1.0 and 2.0
3. The risk modeling KPP progresses with the release of each IMPACT Trade space analysis tool version.

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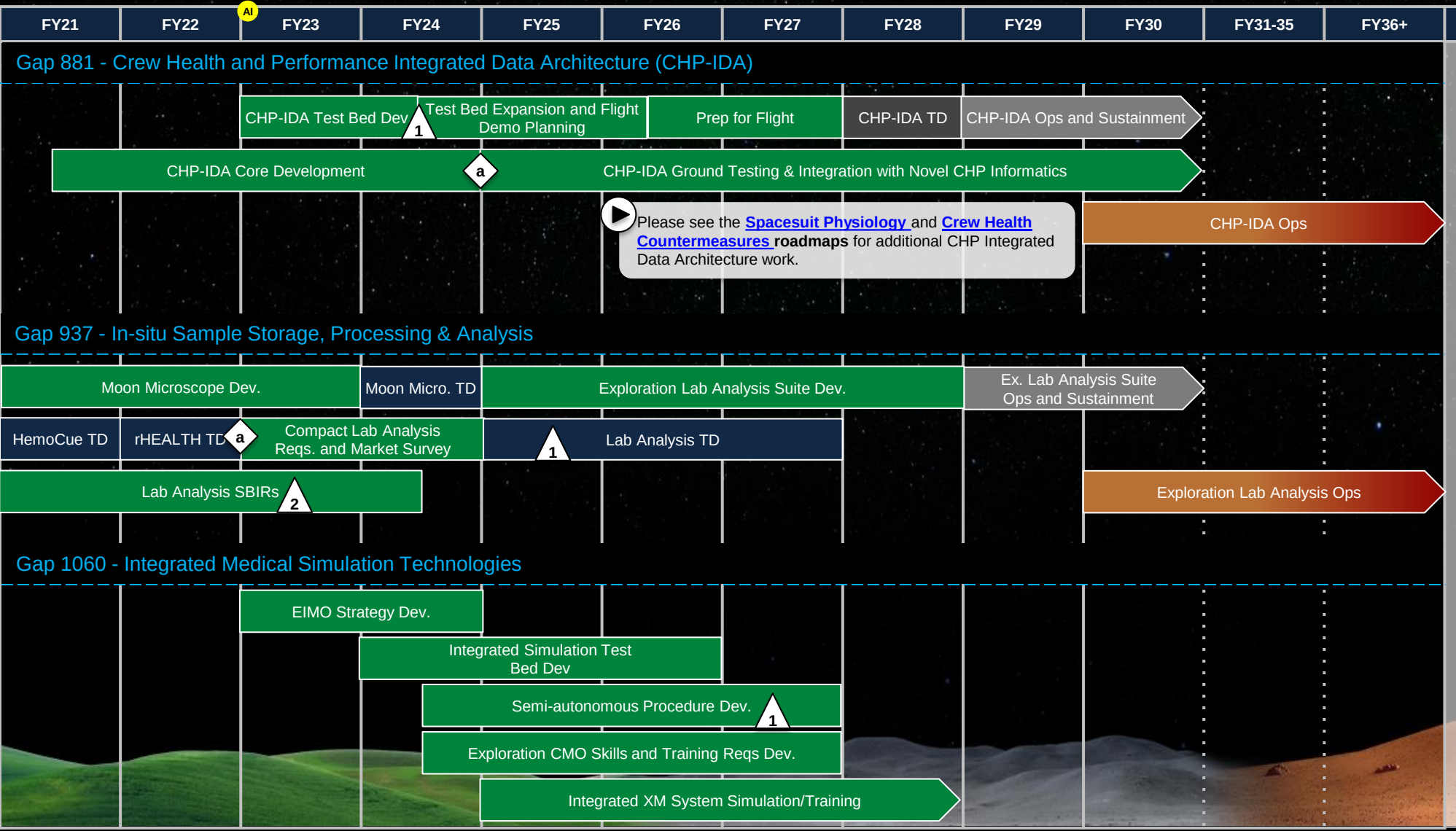
NASA EXTERNAL

EXPLORATION MEDICAL (XM) (Slide 3 of 6)

TIMELINE NOTIONAL



Additional Information

Gap 881

Deliverables

1. **Candidate for ISS4Mars Mars Analog Earth Independent Medical Research Use Case**

Decision Points/Comments

a. **The 1 from other slides represent integrated ground testing of that application or data source with the CHP-IDA. [With each integrated ground test, the KPP (percent of applications and data sources captured in data architecture inflight) increases.]**

Gap 937

Deliverables

1. **Lab analysis and Mini Micro TDs will inform down select of lab analysis suite for exploration. Requirements for the exploration unit will incorporate inputs from the research and medical operations community.**
2. **SBIRs Tracking:**
   - **Remote Experimentation and Analysis Laboratory in Space (FY21-FY23)**
   - **Photonics integrated circuit enabled miniature on chip urine test (FY21-FY24)**
   - **Ultra compact calcium measurement device (FY22-FY23)**

Decision Points/Comments

a. **The HemoCue and rHealth ISS TDs are testing state-of-the-art compact lab analysis devices. These TDs will inform a subsequent market survey and down select for an ISS TD of an exploration lab analysis tool.**

Gap 1060

Deliverables

1. **Earth Independent Medical Operations (EIMO) strategy will inform development of semiautonomous procedures and Crew Medical Officer (CMO) skills and training.**

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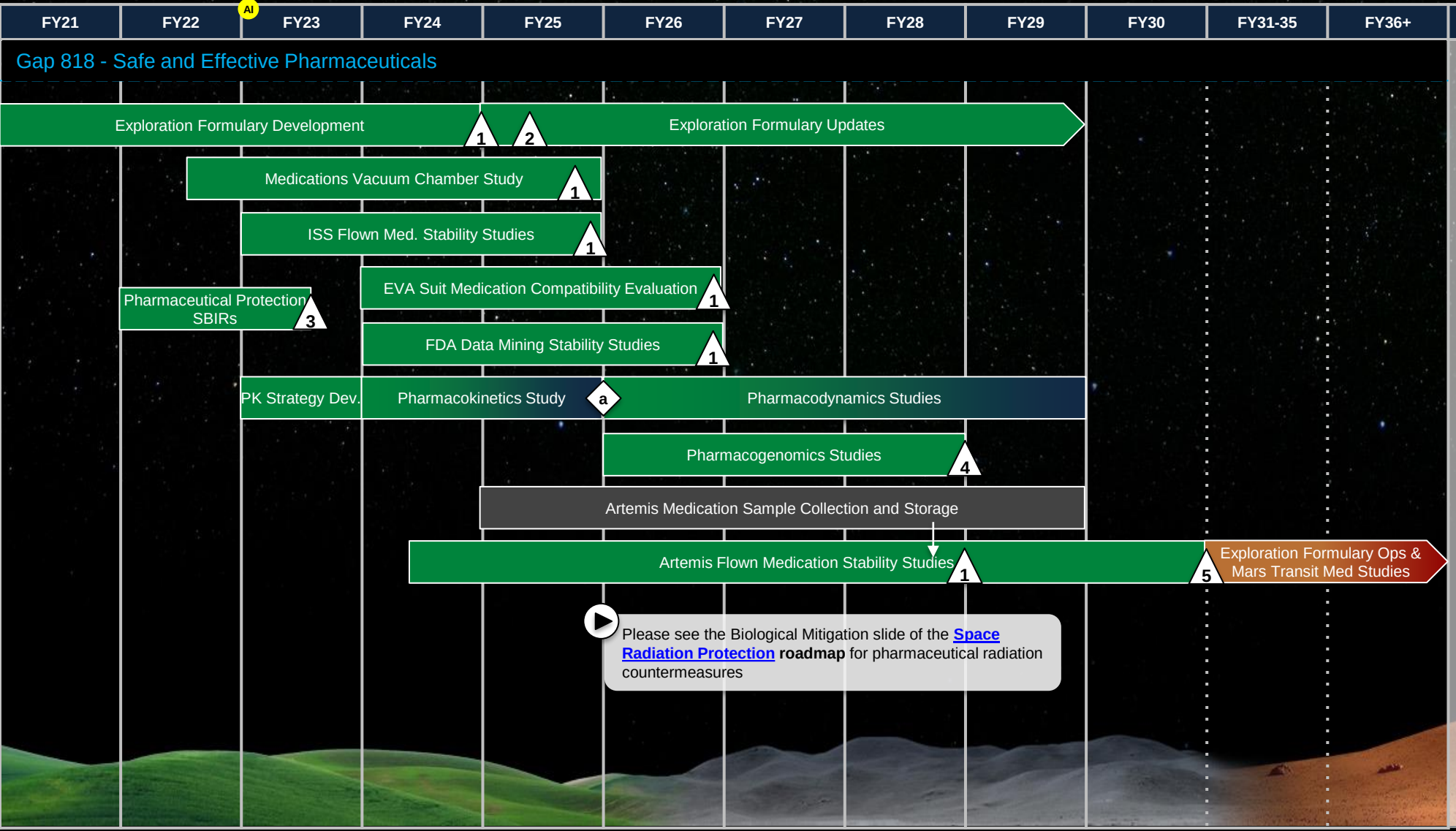
EXPLORATION MEDICAL (XM) (Slide 4 of 6)

TIMELINE NOTIONAL



Additional Information

Gap 818

Deliverables

1. Swim lanes represent data collection activities required to characterize medication stability and efficacy during spaceflight-relevant exposures (LEO IV, Lunar IV, Vacuum, and EVA suit).
2. HRP Deliverable: Exploration Formulary v3.0
3. SBIR Tracking:
   - DoseShield packaging for improved pharmaceutical protection in space (FY22-FY23)
   - Rubber shielding for space pharmaceutical packaging (FY22-FY23)
4. Additionally, there is a need for terrestrial data on shelf-life extension, pharmacokinetics, and pharmacogenomics.
5. Data collected from these studies will inform development of an Exploration Formulary and Ops & Mars Transit Medication Studies. [Each activity will contribute to increasing SOA and gap closure.]

Decision Point

a. Pharmacokinetics study data will determine if pharmacodynamics studies are necessary

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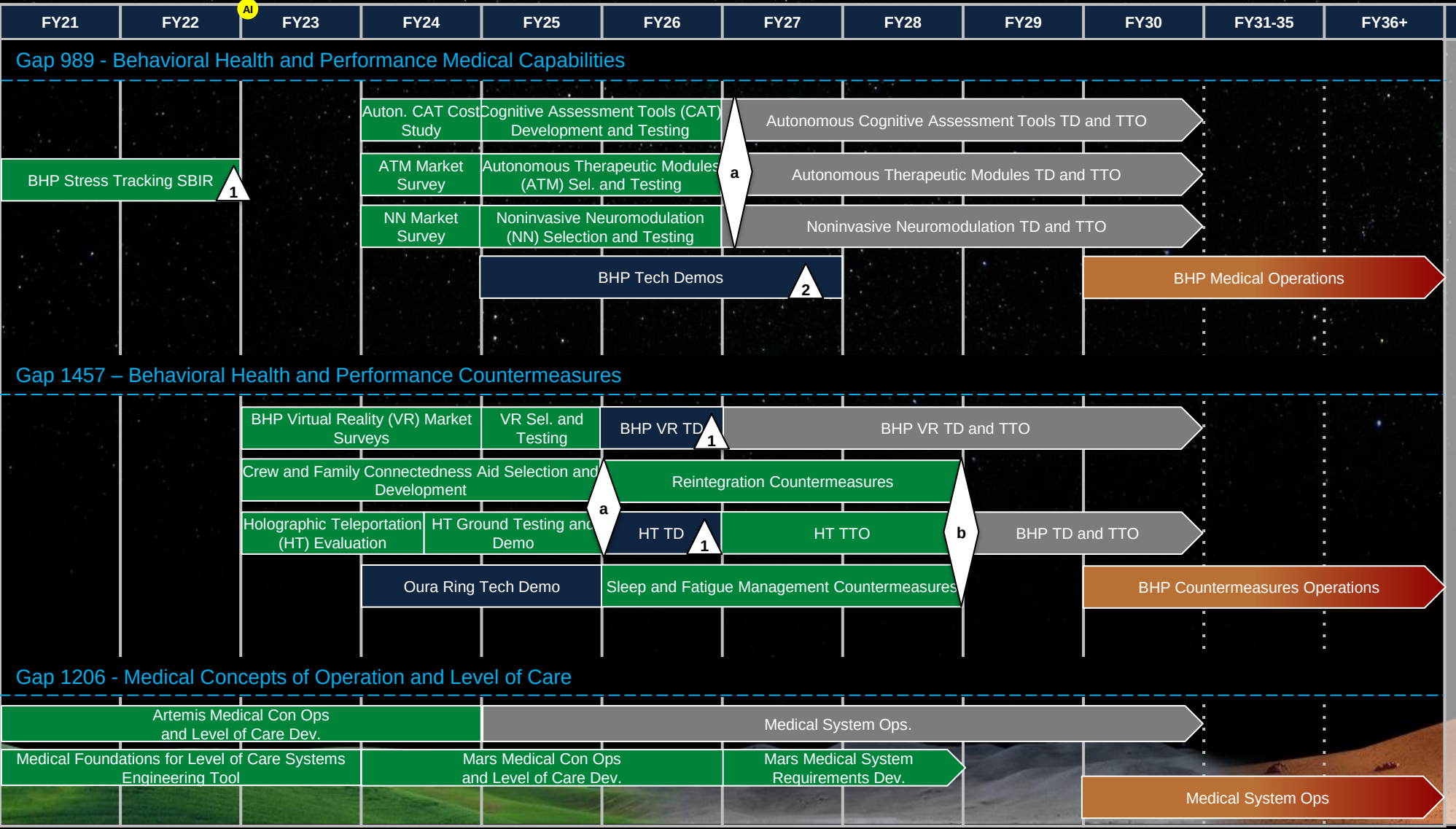
EXPLORATION MEDICAL (XM) (Slide 5 of 6)

TIMELINE NOTIONAL



Additional Information

Gap 989

Decision Point

a. **BHP medical capabilities will be evaluated through testing and tech demos to determine their utility on exploration missions**

Deliverables

1. **SBIR Tracking**
   - **The Individualized, Noninvasive Speech Indicators for Tracking Elevations in Stress (INSITES) SBIR is in phase II of funding. Results will inform BHP technology development. (FY20-FY22)**
2. **Candidate for ISS4Mars Mars Analog Earth Independent Medical Research Use Case**

Gap 1457

Decision Point

a. **Holographic Teleportation will be evaluated against current communication methods, and testing will be performed to determine if HT meets the previously stated technical and communication requirements.**

b. **Countermeasure technology lunar demo down select**

Deliverables

1. **Candidate for ISS4Mars Mars Analog Earth Independent Medical Research Use Case**

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Funding Codes: MCO - ESDMD Mars Campaign Office HRP - SOMD HRP ESA - European Space Agency DoD - Department of Defense

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Crew Health and Performance (CHP) Systems

Food Systems Capability Area

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FOOD SYSTEMS (1 of 12) *Prepackaged (1/2): Development and Evaluation of Food and Hardware*

TIMELINE NOTIONAL

FY21	FY22	FY23	FY24	FY25	FY26	FY27	FY28	FY29	FY30	FY31-35	FY36+	Additional Information

AI

Prepackaged Food: Primary Gap 800 – Safe, Acceptable, and Nutritious Food System; Secondary Gaps: 1013 – Food Resources Requirements and Efficiency; 1171 - Low-Hydration Food for Exploration Missions

- HLS Food System Dev/Mass Reduction
- xEVA Nutrition
- xEVA Development
- Food Stabilization Study
- Scoping: Food Hydration % (a)
- Food Hydration % Dev. (b)
- Hurdle Approach Study - Formulation/Processing/Packaging/Storage Temp. Combo Evals (c, c) (d)
- Hurdle Approach Tech Validation
- Lunar Orbit/Surface Storage Validation (1)

Prepackaged Food Hardware: Primary Gap 1013 – Food Resources Requirements and Efficiency; Secondary Gap: 1036 - Thermal refrigerated long term stowage chamber for food preservation in deep space (passive and/or active approaches)

- Mini-PWD (2)
- M-PWD-ver
- Gateway Full Water Dispenser
- Lunar Orbit/Surface Operations
- Mars Water Dispenser
- Mars Transit Operations
- Exploration Water Dispenser
- Exploration Water Dispenser Tech Demo (2)
- Mars Food Warmer
- Mars Transit Operations
- Gateway Food Warmer
- Lunar Orbit/Surface Operations
- Passive Refrig. Concept Dev. – University – Space Grant Con (c)
- Trade Study (e)
- Development of MTH Cold Storage Unit (1)
- Mars Transit Operations
- Cold Storage Development
- Cold Storage Development
- Cold Storage TD
- Development of Cargo Cold Storage Unit (1)
- Mars Cargo Operations
- Packaging Configuration

Gaps 800, 1013

Deliverables

1. **Exploration Food System delivered**
2. **Flight Unit delivered**

Decision Point/Comments

- a. **Require improved/increased facility capacity**
- b. **Decision on feasibility of reduced food hydration/move to analog testing**
- c. **Early insight into shortfalls of the current pre-packaged food system and temperature needed to start informing mass/volume requirements**
- d. **Decision on food cold storage mass and volume requirements for Mars missions**
- e. **Active vs passive refrigeration trade study**

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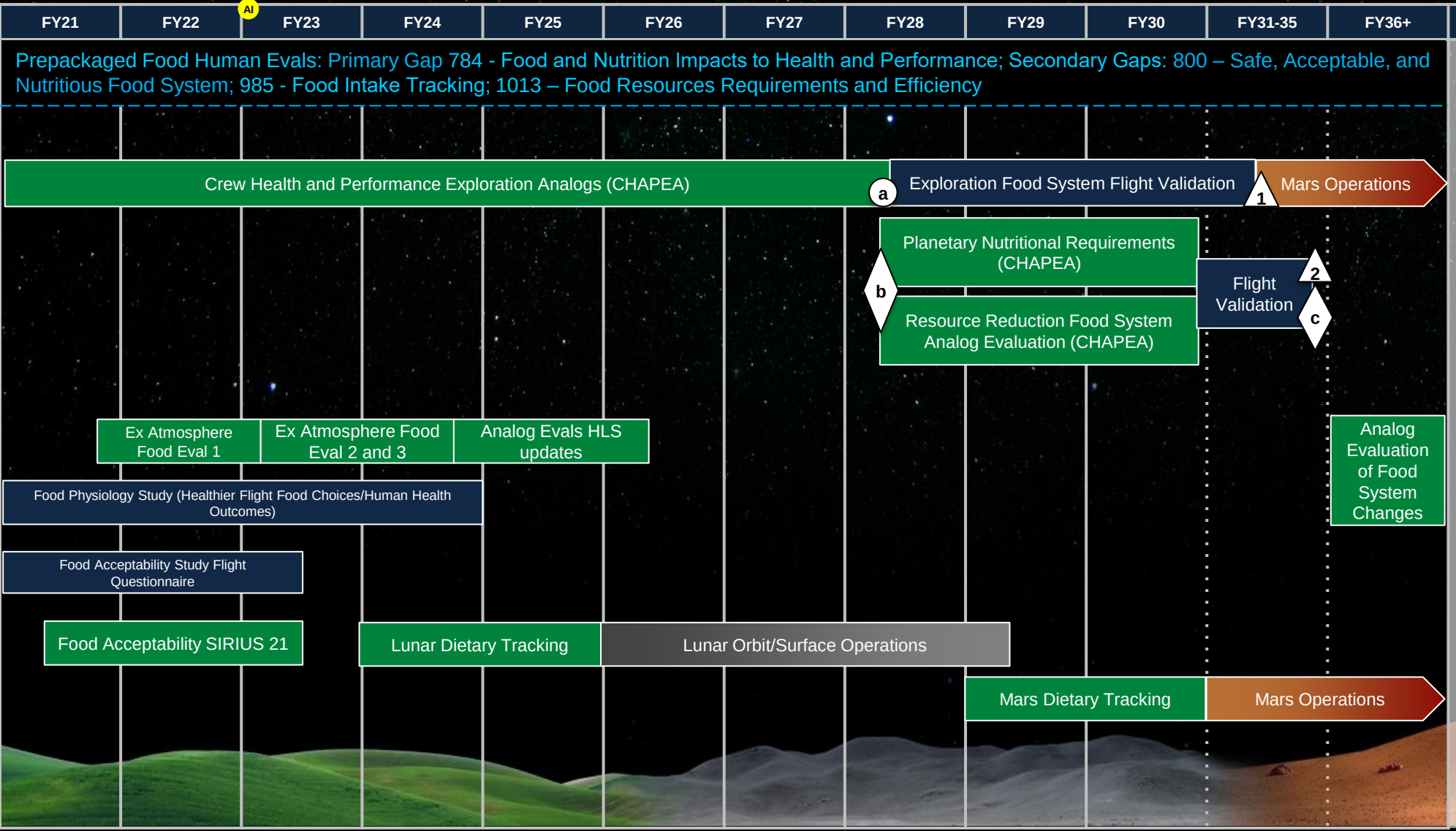
FOOD SYSTEMS (2 of 12) *Prepackaged (2/2): Analogs/Flights - Impacts of Food & Nutrition on Human Health & Performance*

TIMELINE NOTIONAL



Additional Information

Gap 784

Deliverables

1. Exploration Food System delivered
2. Informs food resources for Mars mission

Decision Points/Comments

a. Inform food resources for Mars mission

b. Confirm nutritional requirements for exploration (analog) OR further test trade between resource reduction options and human health/performance risk (analog).

c. Best date we could define the feasibility of the reduced food hydration % that is acceptable without improved facility

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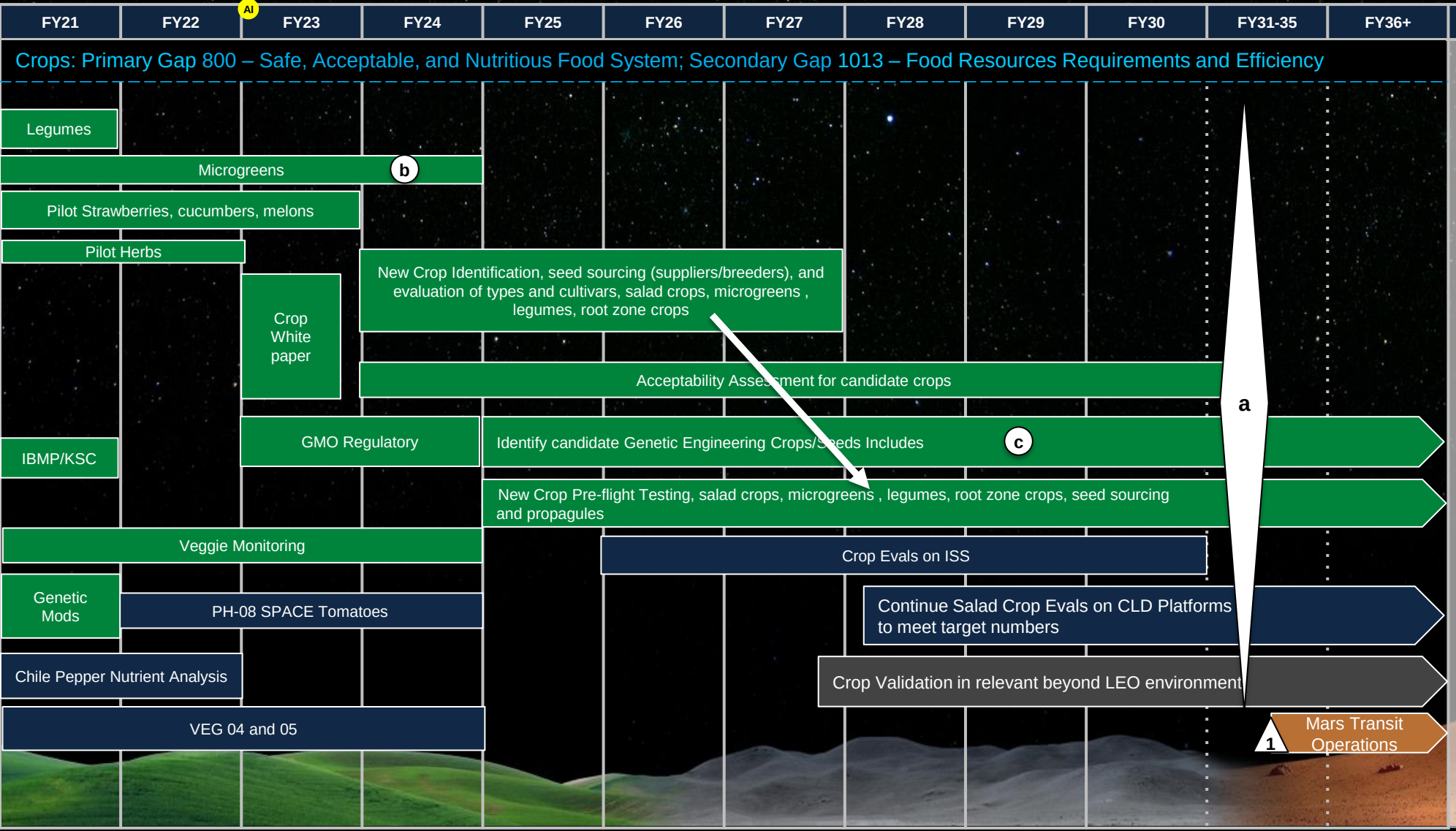
FOOD SYSTEMS (3 of 12) *Crops (1/4): Development and Evaluation of Crops and Hardware*

TIMELINE NOTIONAL



Additional Information

Gap 800

Deliverables

1. **Exploration Food System delivered. First crops to support early Mars missions selected/validated**

Decision Points/Comments

a. **Determine which salad crops will serve as initial candidates for Beyond Low Earth Orbit and Mars transit missions. First evals in Veggie and APH, later evals in OHALO III. Goal is to have minimum of approximately 30 crops selected. (See KSC Space Crop Production team white paper sponsored by HRP for details)**

b. **Hardware to support microgreens flight operations is required and will be identified on the crop hardware page**

c. **Includes collaboration with the Australian Center of Excellence on Plants for Space (P4S) which will start Jan. 2024 and run thru Jan 2031**

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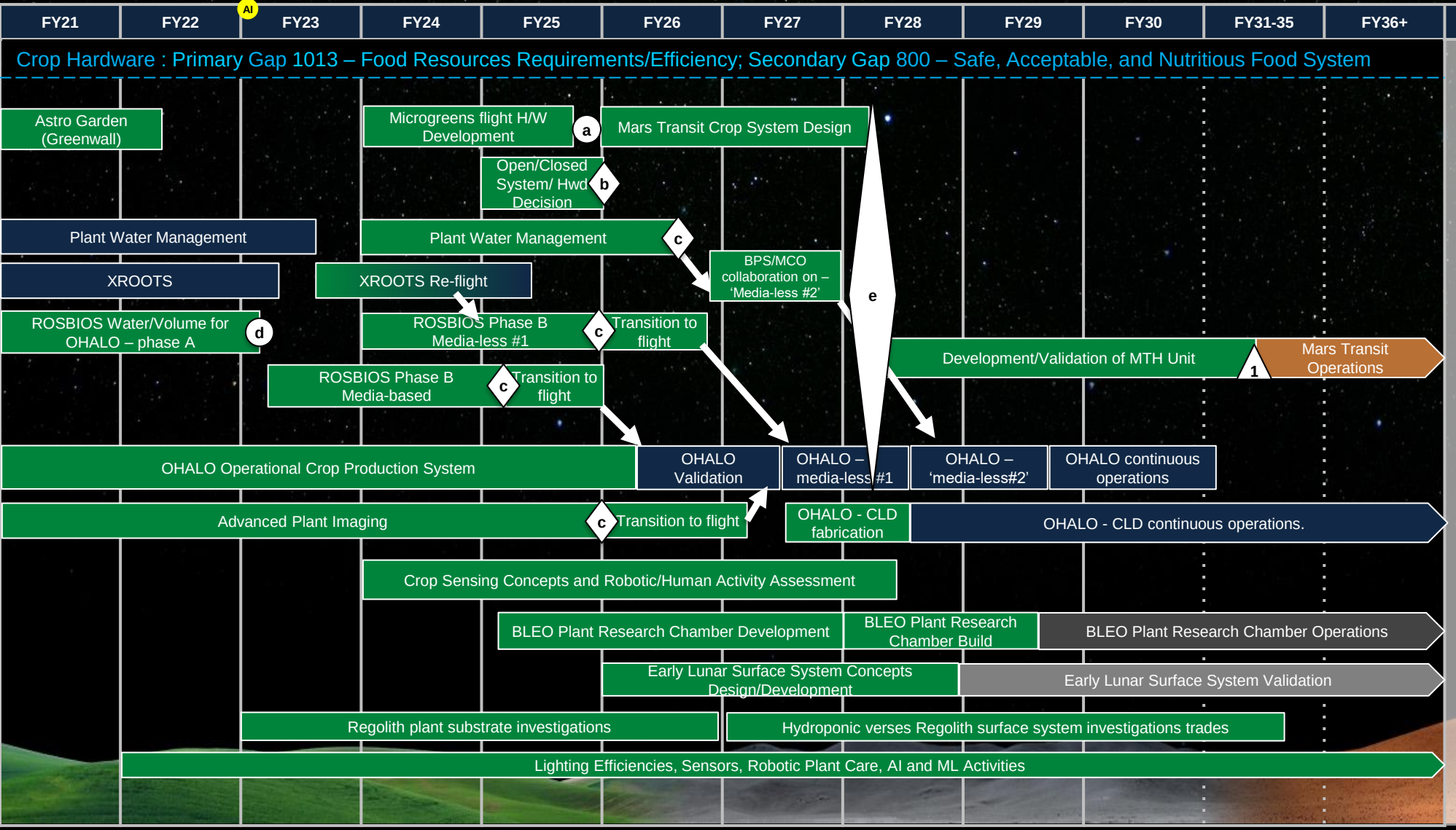
FOOD SYSTEMS (4 of 12) *Crops (2/4): Development and Evaluation of Crops and Hardware*

TIMELINE NOTIONAL



Additional Information

Gap 1013

Deliverables

1. **Exploration Food System with Mars Transit Crop System delivered**

Decision Points/Comments

a. **Potential collaboration with Canadian Space Agency (CSA) for microgreens growth module which could be demonstrated in Veggie and used in Ohalo**

b. **Decision point on whether crop production systems should be open or closed to the vehicle cabin environment.**

c. **Decision gates for flight development**

d. **ROSBIO awards: Media starts 4/23, 'Media-less' starts 10/23. BPS funded PWM option also is possible which would provide three potential options for reliable water/nutrient delivery**

e. **Down select of requirements for MTH Crop System Hardware**

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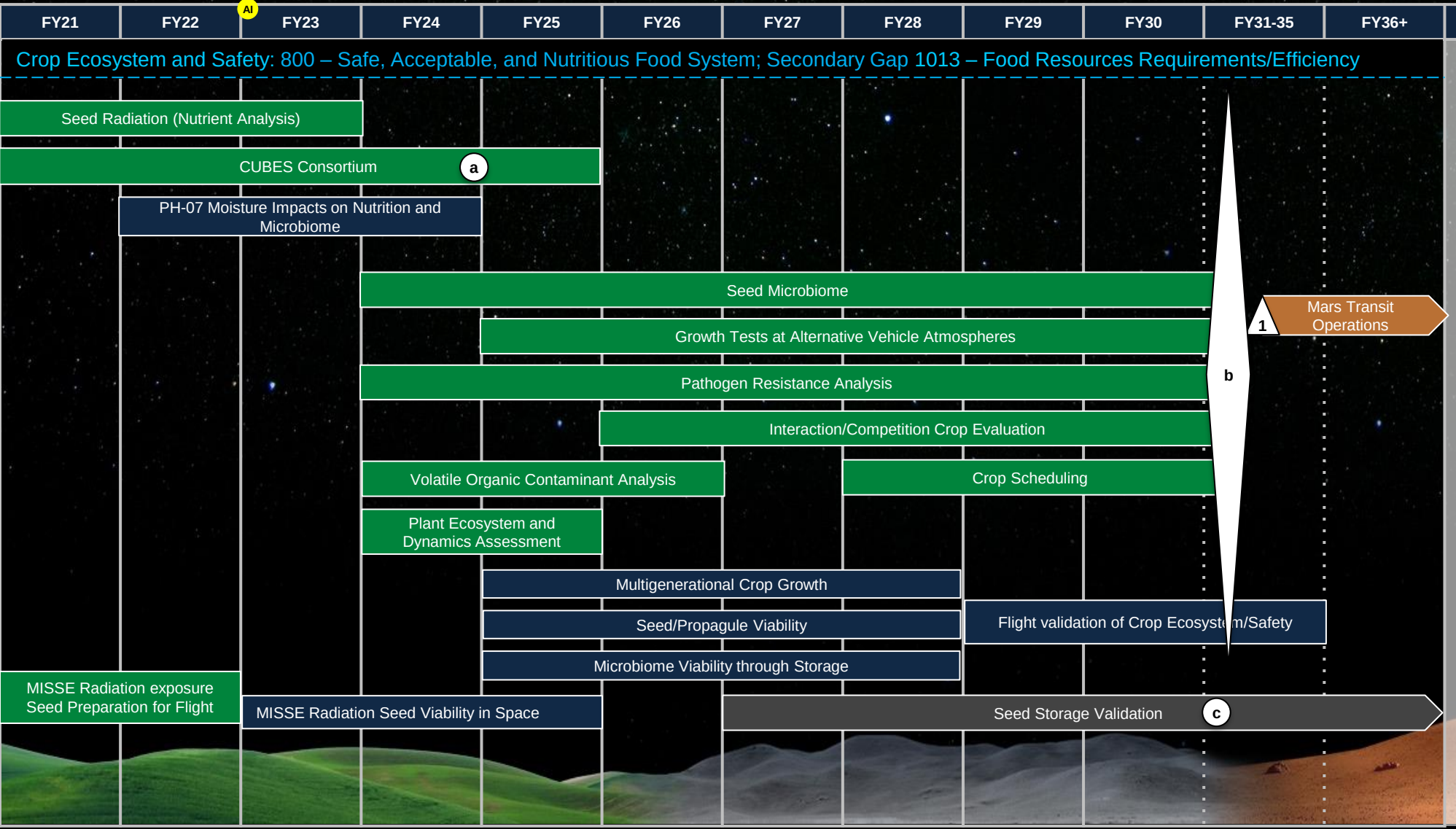
FOOD SYSTEMS (5 of 12) *Crops (3/4): Development and Evaluation of Crops and Hardware*

TIMELINE NOTIONAL



Additional Information

Gap 800

Deliverables

1. Informs Mars transit Crop System hardware design

Decision Points/Comments

a. Workshop held to determine microbiological and cleaning requirements for crops/hardware in spaceflight. Further work remains to be done as agreed to standards have yet to be developed

b. ECLSS infusion – must work with ECLSS on any sanitation methods that impact water/air

c. This indicates a need for a technology to do crop testing to address crop safety for crew consumption

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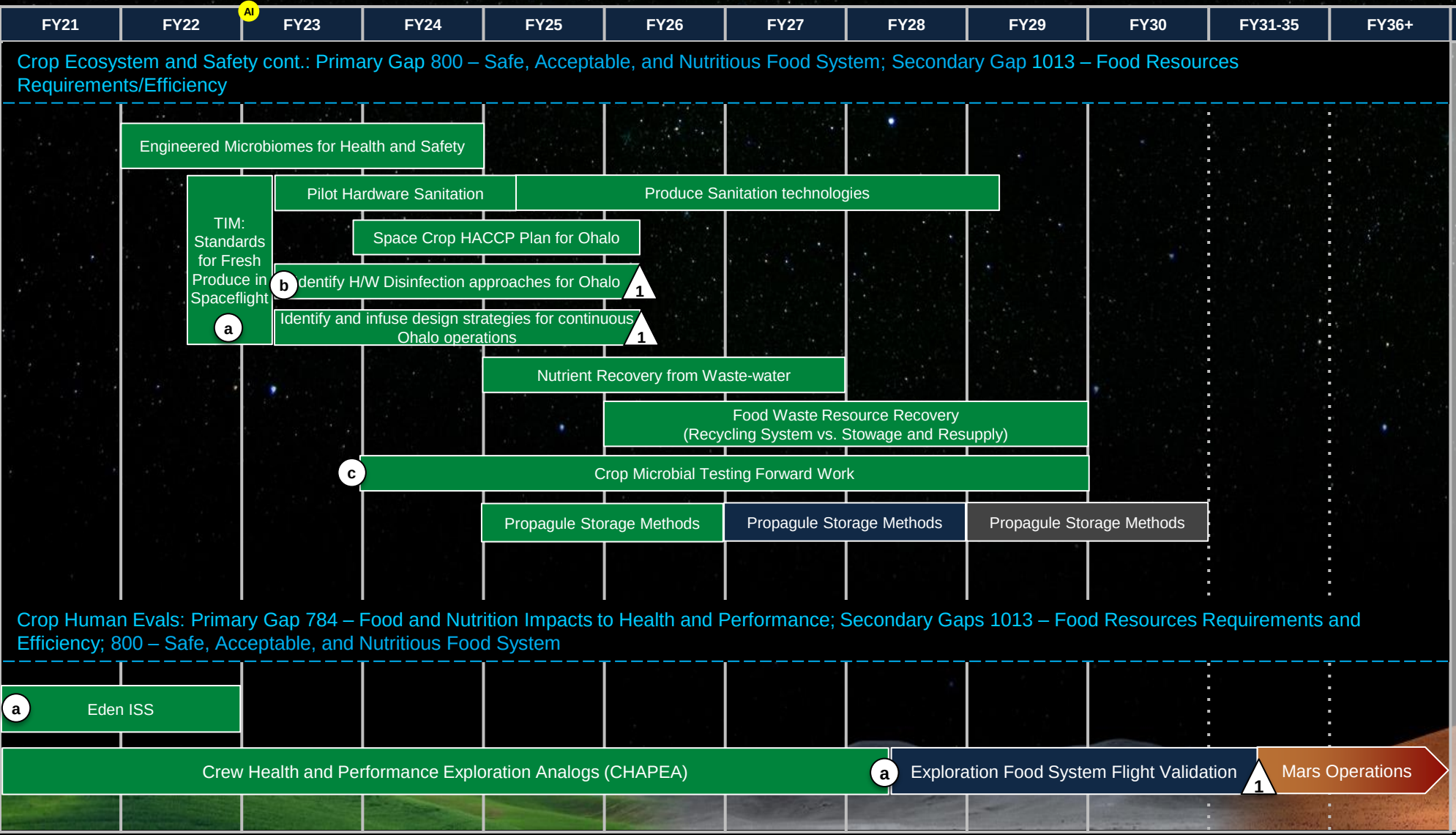
ECLSS-CHP SCLT ROADMAP – REVISION 2023.3

NASA EXTERNAL

FOOD SYSTEMS (6 of 12) *CROPS (4/4): Development & Evaluation of Crops and Hardware & Analogs/Flight – Impacts of Food and Nutrition on Human Health and Performance*

TIMELINE NOTIONAL



Additional Information

Gap 800

Deliverables

1. **Informs Mars transit Crop System hardware design**

Decision Points/Comments

a. **Workshop held to determine microbiological and cleaning requirements for crops/hardware in spaceflight. Further work remains to be done as agreed to standards have yet to be developed**

b. **ECLSS infusion – must work with ECLSS on any sanitation methods that impact water/air**

c. **This indicates a need for a technology to do crop testing to address crop safety for crew consumption**

Gap 784

Deliverables

1. **Exploration Food System delivered. First crops to support early Mars missions selected/validated**

Decision Points/Comments

a. **Inform crew health and performance risk/resource trades for Mars surface mission**

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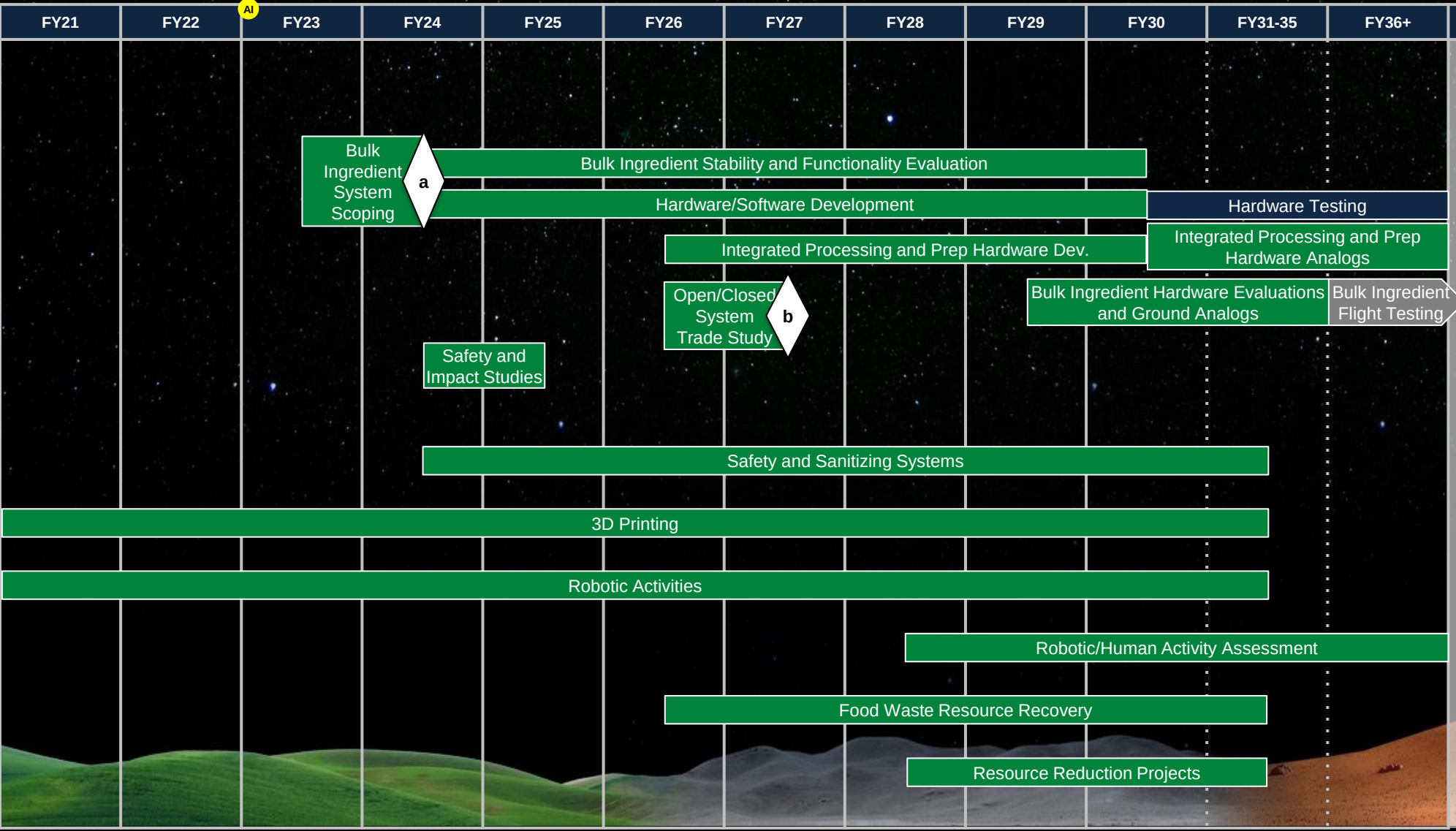
FOOD SYSTEMS (7 of 12) *Bulk Ingredients (1/1) Development & Evaluation of Bulk Ingredient Feasibility*

TIMELINE NOTIONAL



Additional Information

a. Decision on feasibility of bulk system.

b. Decision point on whether systems should be open or closed to the vehicle cabin environment.

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FOOD SYSTEMS (8 of 12) *Bacterial Production (1/2): Development and Evaluation of Bacterial Production Feasibility*

TIMELINE NOTIONAL

FY21	FY22	FY23 (AI)	FY24	FY25	FY26	FY27	FY28	FY29	FY30	FY31-35	FY36+	Additional Information

Bacteria: Primary Gap 800 – Safe, Acceptable, and Nutritious Food System; Secondary Gap 1013 – Food Resources Requirements/Efficiency

- GMO Regulatory
- Bacterial Production System Scoping (a) → Bacterial Production System Development
- Bacterially Processed Foods Ground Analog → Bacterially Processed Food Testing
- Determine Bioavailability/Effectiveness of Products → Bacterially Processed Foods Lunar Testing
- Bacterial Hardware/Software Scoping (a) → Bacterial Hardware/Software Development → Bacterial Production Flight Validation
- Bionutrients → BioNutrients
- BioNutrients Flight Experiments 1,2,3
- Develop Radiation Countermeasures for Hardware/Software/Microbial Growth/Storage
- HACCP Procedures for Earth Assembly and Flight Ops
- Safety Systems Development
- In Situ Methods for Microbial/Toxin Contam. Detection
- Engineering Organisms
- CO2 Based Manufacturing → Cont. ISRU to Feed Methods for Biomanufacturing
- CUBES

Gap 800

Decision Points/Comments

a. Decision on feasibility and further work. Includes Engineering Organisms for Nutrition, Palatability, Optimization

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FOOD SYSTEMS (9 of 12) *Bacterial Production (2/2): Development and Evaluation of Bacterial Production Feasibility*

TIMELINE NOTIONAL

Additional Information

Gap 800 (cont.)

Decision Points/Comments

b. Decision point on whether systems should be open or closed to the vehicle cabin environment.

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FOOD SYSTEMS (10 of 12) *Algae and Fungi Production (1/2): Development and Evaluation of Algae and Fungi Production Feasibility*

TIMELINE NOTIONAL

FY21	FY22	FY23	FY24	FY25	FY26	FY27	FY28	FY29	FY30	FY31-35	FY36+	Additional Information

AI

Activities in this section will investigate both Micro and Macro Algae and Micro and Macro Fungi Production:

Primary Gap 800 – Safe, Acceptable, and Nutritious Food System; Secondary Gap 1013 – Food Resources Requirements and Efficiency

- a – Evaluation of Existing Foods
- b – Evaluation of Existing Non-Food Based Nutrition Systems
- Production System Scoping
- c – Production System Development
- Ground Analog Integration
- Foods and Products/Production
- Product Testing
- Safety and Impact Studies
- Product Lunar Testing
- Pre/Post-Production Processing Approaches
- Trade Study on Resources
- Trade Study on Production
- Develop Radiation Countermeasures for Hardware/Software
- uG Hardware Design and Development
- Open/Closed System Trade Study
- d
- Beyond LEO Storage and Production (high radiation)
- uG Hardware Design and Development
- Maximizing Titer and Variety
- Automation/Robotic Activities
- CUBES 1,2
- Engineering of Organisms (for palatability, nutrition, optimization, bioavailability/effectiveness)

Gap 800

Decision Points/Comments

a. **Existing Foods: Algae: spirulina, seaweed, carrageenan. Fungi: yogurt, mushrooms, and novel items**

b. **Existing Non-Food Based Nutrition: Fungi: BioNutrients**

c. **Decision on feasibility and further work.**

d. **Decision point on whether systems should be open or closed to the vehicle cabin environment.**

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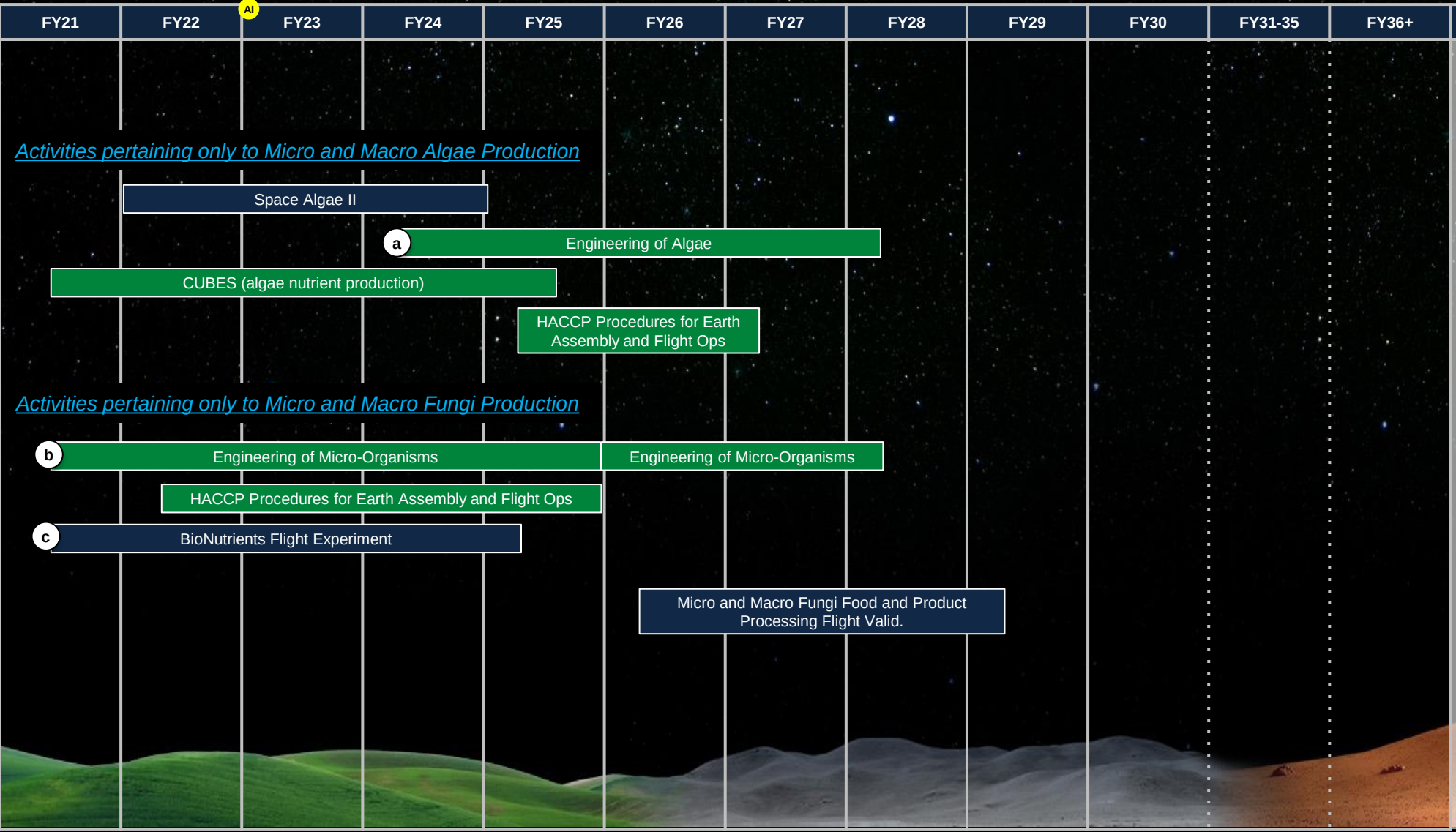
FOOD SYSTEMS (11 of 12) *Algae and Fungi Production (2/2): Development and Evaluation of Algae and Fungi Production Feasibility*

TIMELINE NOTIONAL



Additional Information

Gap 800

Decision Points/Comments

a. Engineering of micro-organisms to produce target compounds without the production of undesirable compounds

b. Engineering of micro-organisms to produce target compounds without the production of undesirable compounds, no macro fungi work is funded at this time

c. Includes storage viability testing and production, micro fungi, development of hardware for flight, minimizing inoculum/media needs, production schemes for multiple compounds, demo of strains/media/packaging longevity. System is designed for direct consumption, no processing required.

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Crew Health and Performance (CHP) Systems

Earth Independent Human Operations (EIHO) Capability Area

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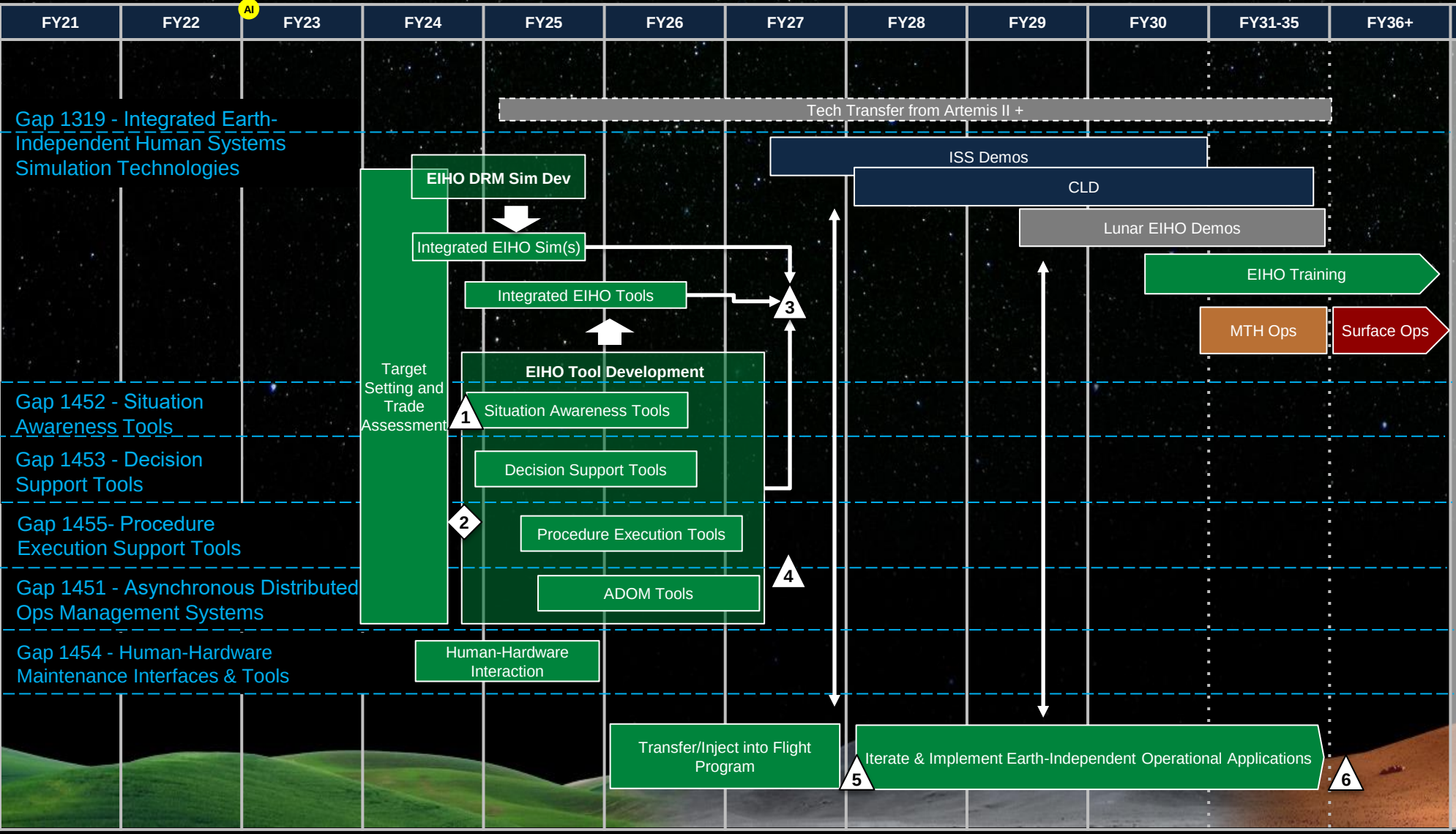
EARTH INDEPENDENT HUMAN OPERATIONS (1 of 8) *Summary*

TIMELINE NOTIONAL



Additional Information

All Gaps - Summary

Deliverables

1. **Simulation Requirements**
2. **Decide whether or not to build new simulation capability and decide what characteristics the sim needs to have.**
3. **EIHO Tool Development Recommendations**
4. **Set of EIHO tools deliverables**
5. **Application into flight program. This needs to be done by element PDR.**
6. **Validated application. This activity can be performed through the analog missions, must be done before flight certification for Mars mission.**

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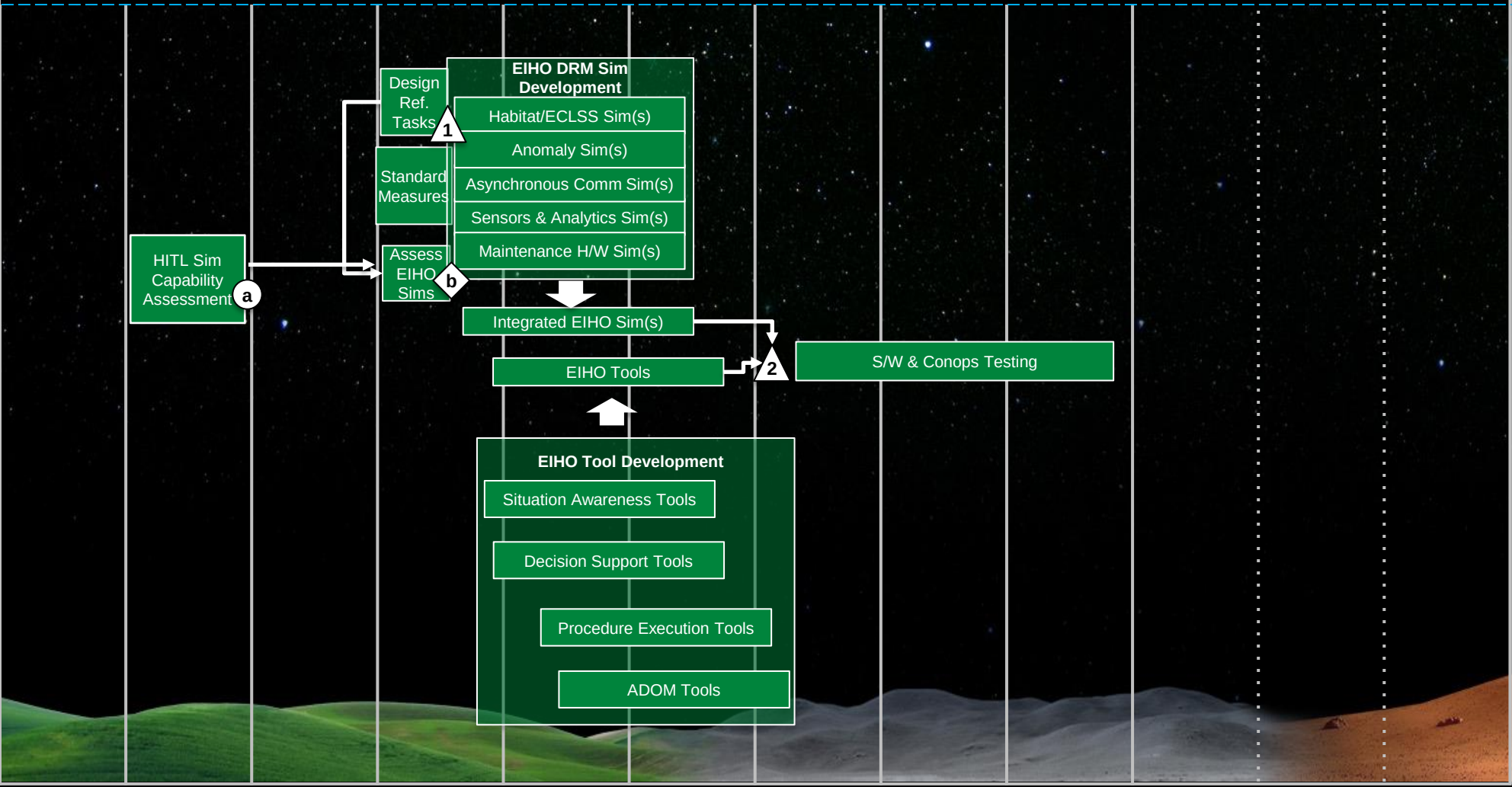
EARTH INDEPENDENT HUMAN OPERATIONS (2 of 8)

TIMELINE NOTIONAL

FY21	FY22	FY23	FY24	FY25	FY26	FY27	FY28	FY29	FY30	FY31-35	FY36+	Additional Information

AI

Gap 1319 - Integrated Earth Independent Human Systems Simulation Technologies



Gap 1319

Deliverables

1. Simulation Requirements
2. EIHO Tool Development Recommendations

Decision Points/Comments

a. EIHO Human-in-the-Loop (HITL) Recommendations – need to be complete as early as possible because other EIHO tool development will depend on sim/analog capability.

b. Decide whether or not to build new simulation capability and decide what characteristics the sim needs to have.

Ground
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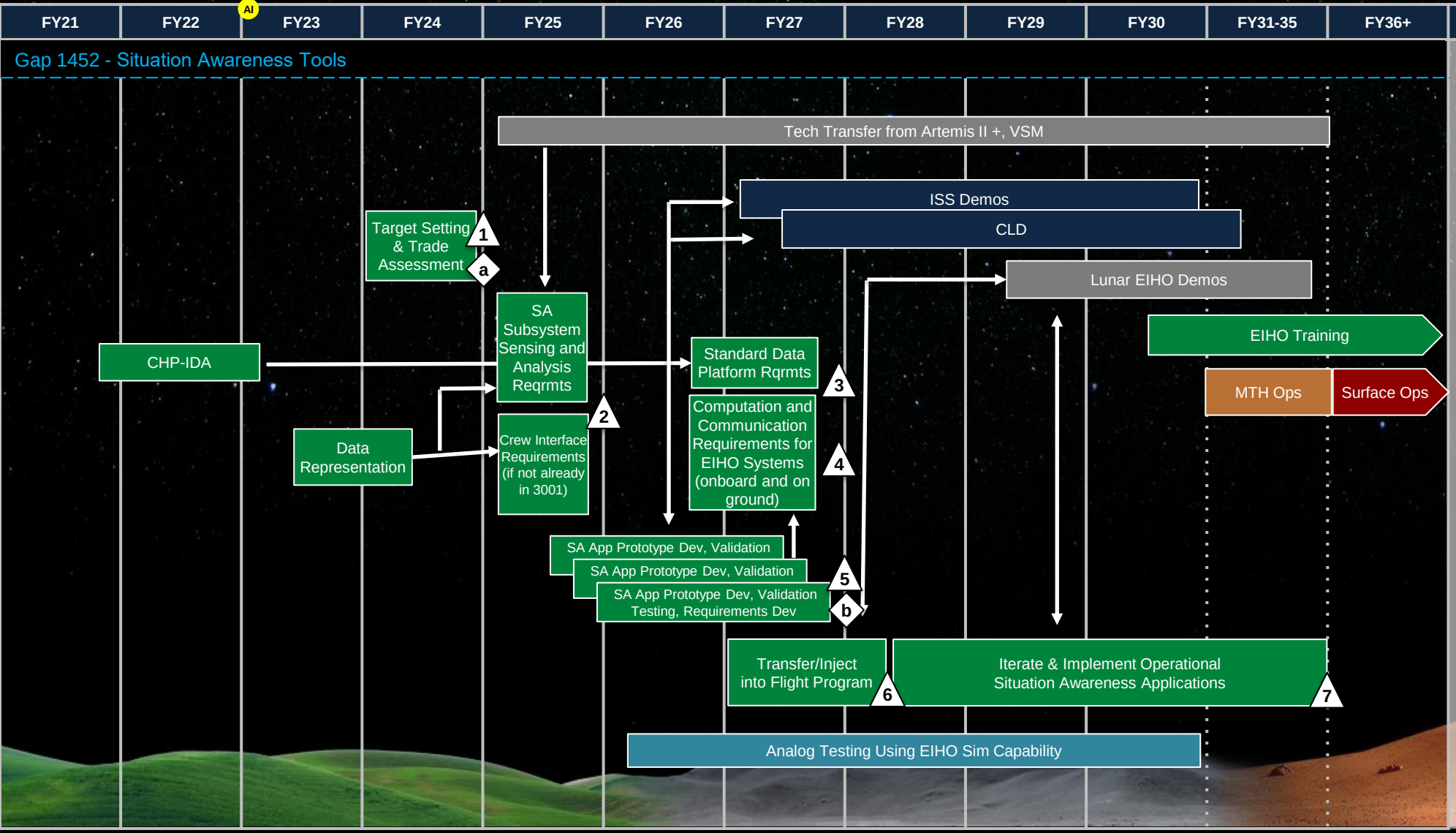
TIMELINE NOTIONAL

FY21	FY22	FY23	FY24	FY25	FY26	FY27	FY28	FY29	FY30	FY31-35	FY36+

AI



Additional Information

Gap 1452

Deliverables

1. Risk-informed targets for instrumentation and sensing for all subsystems identified as insufficient.
2. Functional and performance requirements for subsystems and technologies.
3. Standard Data Platform requirements
4. Computation & communication requirements
5. A set of situational awareness applications, rated with respect prototype decision support requirements
6. Situational awareness application. This needs to be done by element PDR.
7. Validated situational awareness application. This activity can be performed through the analog missions, must be done before flight certification for Mars mission.

Decision Points/Comments

a. Decide whether to accept targets and fund additional development or whether to accept the risk from lack of independence.

b. Based on results, identify best-in-class situational awareness approach and carry forward. Includes any new sensor development or maturation.

Please see the Spacesuit Physiology, Crew Health Countermeasures, and Exploration Medical roadmaps for other CHP situation awareness tools.

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TIMELINE NOTIONAL

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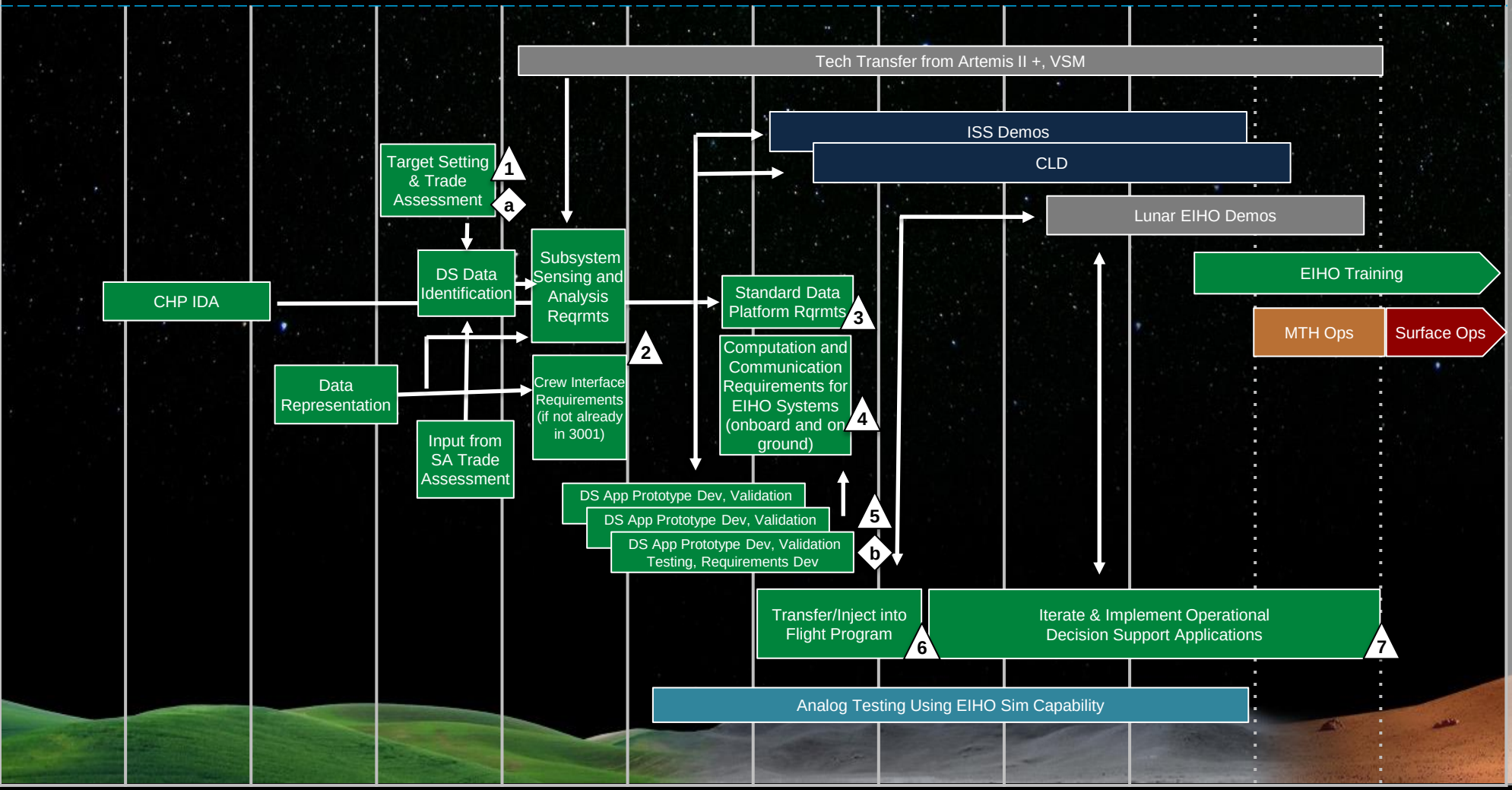
AI

Gap 1453 - Decision Support Tools



Gap 1453

Deliverables

1. **Risk-informed targets for instrumentation and sensing for all subsystems identified as insufficient.**
2. **Functional and performance requirements for subsystems and technologies.**
3. **Standard data platform requirements**
4. **Computation & communication requirements. Onboard computation needs definition for network options and rad tolerance for LOC/LOM critical decision support.**
5. **A set of applications, rated with respect prototype decision support requirements.**
6. **Decision support application. This needs to be done by element PDR.**
7. **Validated decision support application. This activity can be performed through the analog missions, must be done before flight certification for Mars mission.**

Decision Points/Comments

a. **Decide whether to accept targets and fund additional development or whether to accept the risk from lack of independence.**

b. **Based on results, identify best-in-class decision support approach and carry forward. Includes any new sensor development or maturation.**

Please see the Spacesuit Physiology, Crew Health Countermeasures, and Exploration Medical roadmaps for other CHP decision support tools.

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TIMELINE NOTIONAL

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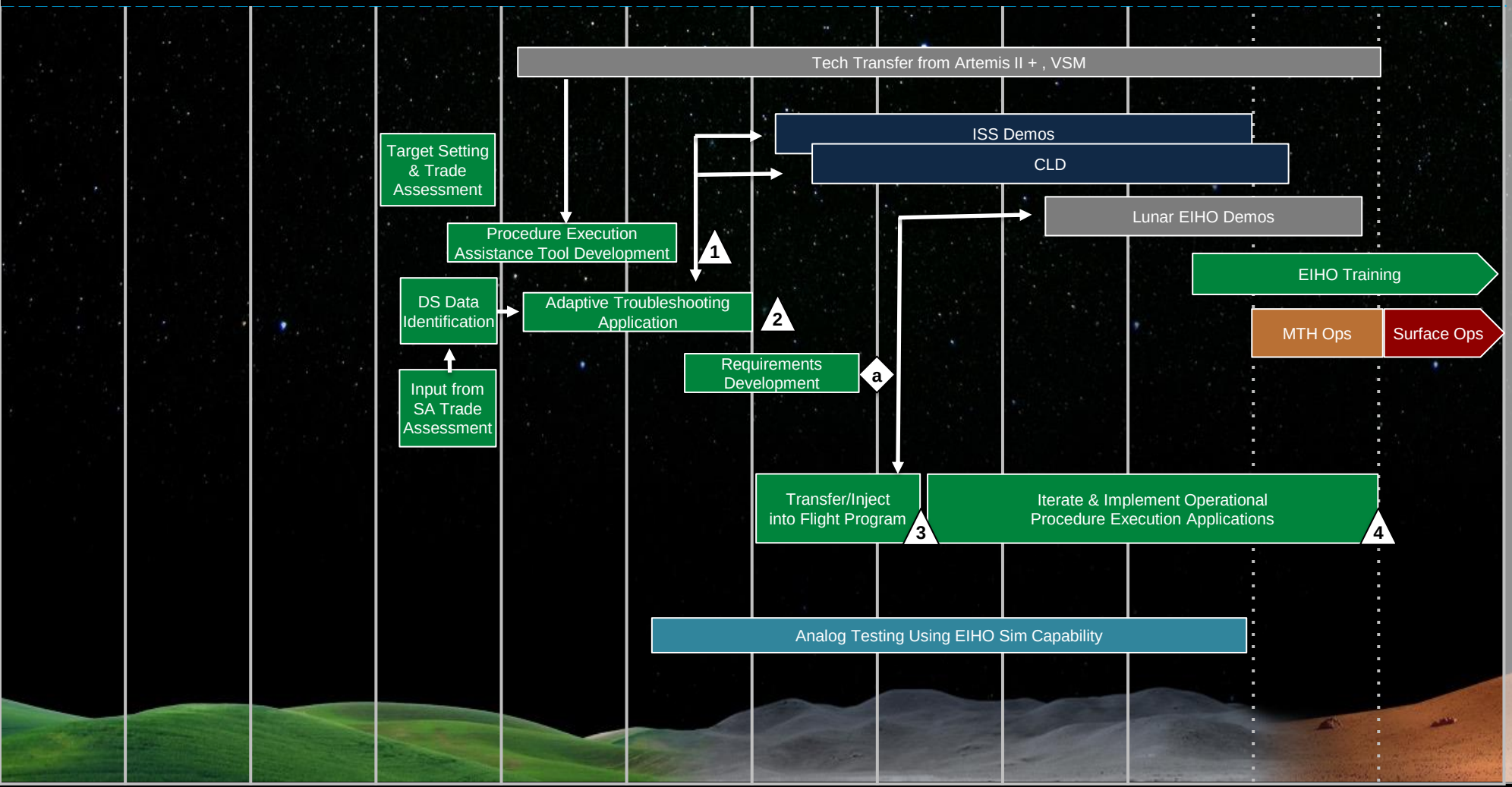
AI

Gap 1455 - Procedure Execution Support Tools



Gap 1455

Deliverables

1. **Nominal procedure execution support tool.**
2. **Troubleshooting and procedure generation capability validation on Artemis surface missions.**
3. **Procedure execution support tools for nominal operations and adaptive troubleshooting.**
4. **Validated procedure execution support tools. This activity can be performed through the analog missions, must be done before flight certification for Mars mission.**

Decision Points/Comments

a. **Decide on either flight test of procedure execution support tools or accepting the risk of low TRL for procedure execution support.**

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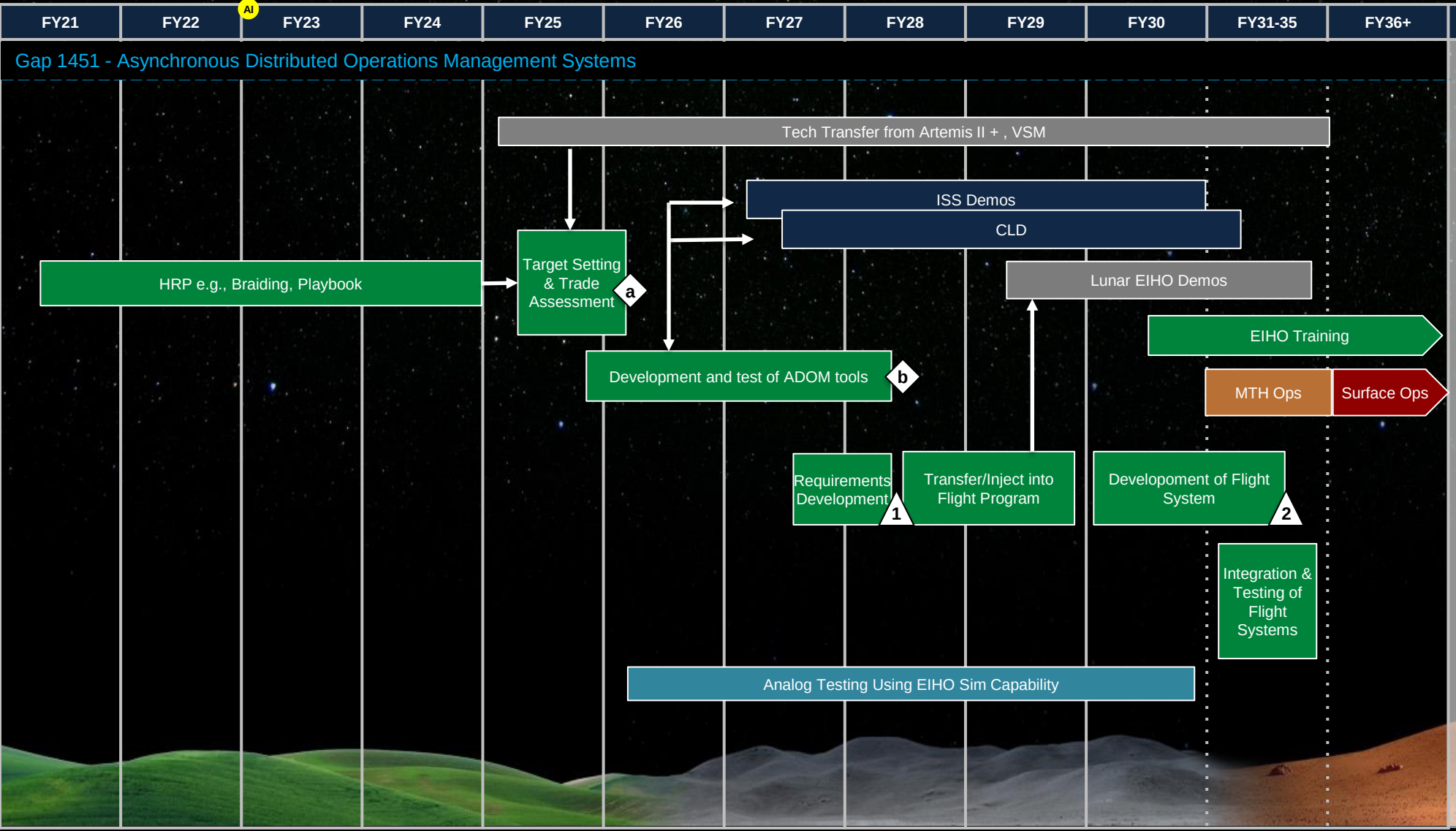
TIMELINE NOTIONAL



Additional Information

Gap 1451

Deliverables

1. **Requirements for Asynchronous Distributed Operations Management (ADOM) solution.**
2. **ADOM solution injection or infusion plan.**

Decision Points/Comments

a. **Seek management approval for either the recommended approach(es) or for funding to develop a new solution.**

b. **Seek management approval for the downselect.**

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AI

Gap 1454 - Human-Hardware Maintenance Interfaces and Tools

- Design for Maintainability Study
- Subsystem (ECLSS focus) Maintenance Assessment
- Assessment of level of impact across subsystems of maintainability/reliability requirement
- CLD
- Lunar EIHO Demos
- EIHO Training
- MTH Ops
- Surface Ops
- Implementation of Common Standards (Tools, metrics, etc.) 1
- Analog Testing Using EIHO Sim Capability

Gap 1454

Deliverables

1. **Implementation of common standards set across Mars Transit Habitat element.**

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