HRP Research Approach Plans

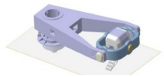
June 2026

Index of Legend Symbols

M2M Deliverable

Lunar Deliverable

For Data Field



Brookhaven National Laboratory

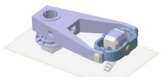
For Legend


Animal Models


Artemis


Atmospheric Chamber

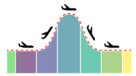

Bedrest


Centrifuge


CLDP

Brookhaven National Laboratory

For Data Field



For Legend

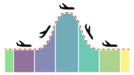

Commercial Freeflyers/PAM


Drop tower/sled


Isolation


ISS


Neutral Buoyancy Lab


Parabolic Flight

Organization Graphic Identifiers

Extravehicular Activity and Human Surface Mobility


Commercial Crew

Human Landing Systems

Flight Operations

Office of the Chief Health and Medical Officer

Mars Campaign Office

Health and Medical Technical Authority

Behavioral Health (BH) and Performance Risk Approach Plan

HRR Knowledge Gap

Risk Characterization / Formulation

BH-109: Characterize in-mission and **long-term effects** of long-duration spaceflight on behavioral health and performance.

1 **Impacts of exploration spaceflight on in-mission and long-term behavioral health and performance: BHP Ops by 2031 (interim), 2034**

CM Development / Evaluation

BH-201: Identify **indicators, measures,** and **thresholds,** to inform semi-autonomous behavioral health and performance monitoring

2 **Recommendations to inform crew selection for Mars: BHP Ops by 2027 (interim), 2034**

3 **Recommendations for semi-autonomous monitoring system, integrating relevant measures and evidence/threshold-based guidelines for countermeasures: BHP Ops by 2031 (interim), 2034**

BH-202: Identify evidence-based **design recommendations** for habitat/vehicle interfaces, to mitigate impacts to behavioral health and performance

4 **Recommendations to inform habitat/sub-system design: HMTA by 2027 (interim), 2034**

BH-203: Develop, test/refine, and validate **countermeasures** to support behavioral health and performance for future exploration missions

5 **Behavioral health training curriculum/modules: BHP Ops by 2031**

6 **Countermeasures for in-mission social support: BHP Ops by 2031**

7 **Family and crew social support toolbox to enable post-mission re integration: BHP Ops by 2031**

8 **Validated countermeasures to support behavioral health & performance: BHP Ops by 2034**

BH-204: Identify, test and refine **therapeutic interventions** for treating adverse behavioral outcomes associated with exploration missions

9 **Therapeutic interventions to treat adverse health outcomes: BHP Ops by 2031 (interim), 2034**

LEGEND: Isolation · ISS · Artemis · Animal Models · M2M Deliverable

TIMELINE:

2025 — **2a 4a** — 2027 — **1a 3a 5 6 7 9a** — 2031 — **1b 2b 3b 4b 8 9b** — 2034 — 2035

Risk Maps to ESDMD–0404

Bone Risk Approach Plan

HRR Knowledge Gap

Risk Characterization / Formulation

BONE-101: Characterize changes in **bone density and structure** (quality) in astronauts.

BONE-102: Characterize **bone turnover and other biochemical markers** of skeletal health.

BONE-201: Identify/develop/apply tools (e.g., computational modeling or alternative) to inform the **estimation bone strength and probability of overloading bones and fracture assessment**.

BONE-301: Identify, develop, and implement **monitoring tools** for bone health following long-duration spaceflight.

1 **Bone Standards and Recommendations: OCHMO by 2028**
MRI Informing Pharmaceutical Use TTO 2027

CM Development / Evaluation

BONE-401: Identify and test preventative and mitigating **countermeasures** for changes induced by spaceflight.

1 **Bone Standards and Recommendations: OCHMO by 2028**
MRI Informing Pharmaceutical Use TTO 2027

LEGEND: Isolation ISS M2M Deliverable

TIMELINE: 1

2025 2030 2035

Risk Maps to ESDMD–0401

Carcinogenesis Risk Approach Plan

	Risk Characterization	Countermeasure (CM) Development, Evaluation, Validation, & Integration
HRR Knowledge Gap	**Cancer-103:** Determine the effects of **radiation quality** on cancer initiation, promotion, progression. **Cancer-104:** Determine the effects of radiation **dose and dose-rate** on cancer initiation, promotion, progression. Brookhaven National Laboratory **1** **NSCR update with Qnew development (2025)** **Cancer-202:** Evaluate the contribution of **genetic background/ diversity** on carcinogenesis risk. **Cancer-203:** Evaluate the **tissue-specific risks** of space radiation exposure on cancer outcomes. **Cancer-204:** Evaluate the **sex-specific risks** of space radiation exposure on cancer outcomes. Brookhaven National Laboratory **2** **NPR 8900 Baseline (PEL evaluation) (2025)** **3** **NPR 8900.1B Acceptance – Characterization Data (2030)**	**Cancer-403:** Identify and/or develop potential **biomarkers** to support health surveillance and countermeasure implementation. **Cancer-504: I**dentify and validate **safe and effective countermeasures** to reduce radiation carcinogenesis. **Cancer-604: Operationalize validated pharmaceutical countermeasures and surveillance technologies** for spaceflight. Brookhaven National Laboratory **4** **8** **Clinical Practice Guideline (CPG) Recommendations (2030, 2035)** **5** **Countermeasure Identification (2033)** **6** **8900 Acceptance - Mitigation Data (2035)** **7** **Integrated CM Toolkit (2035)**

LEGEND: M2M Deliverable | ISS | Brookhaven National Laboratory | Artemis

TIMELINE:

1 2 3 4 5 6 7 8

2025 2030 2035

Risk Maps to ESDMD–0308

Earth Independent Human-System Operations (EIHSO) Risk Approach Plan

HRR Knowledge Gap

Risk Characterization / Formulation

EIHSO – 102: Characterize human-system performance **impacts due to increasingly Earth-independent missions** (e.g. communication delays) and determine indicators of meaningful change to enable mission objectives

1 **Impacts of increasingly earth-independent mission operations on human-system performance: FOD, MCO by 2027 (interim); update 2034**

CM Development / Evaluation

EIHSO – 202: Develop and validate **monitoring countermeasures** of human-system performance (procedure execution, anomaly resolution) during increasingly Earth-independent operations (e.g. communication delays)

2 **Recommendations for semi-autonomous monitoring dashboard: BHP Ops, FOD by 2031 (interim), 2034**

EIHSO – 203: Develop & validate candidate **requirements for design** of vehicles, habitats, interfaces (e.g. displays for complex info presentation, fine motor decrements) to support increasingly Earth-independent operations

3 **Recommendations to inform habitat/sub-system design: HMTA by 2027 (interim), 2034**

4 **Guidelines, multi-modal methods to mitigate touch screen manipulation decrements: HLS by 2027 (interim), 2031**

EIHSO – 204: Develop and validate **countermeasures** to enable human-system performance (**procedure execution, decision support**) for increasingly earth independent crews

5 **Task simulation tools for anomaly resolution and decision support under communication delays: FOD by 2031**

6 **Procedure execution guidance & requirements under communication delays: MCO, FOD by 2027 (interim), 2031**

7 **Recommendations: personalized, adaptive training regimens/platforms: BHP Ops, FOD by 2031 (interim), 2034**

EIHSO – 205: Develop and validate **countermeasures** to enable **safe human-robot interaction**

8 **Safe human robot interaction guidelines and countermeasures: FOD by 2031 (interim); 2034**

LEGEND: Isolation · ISS · Artemis · Commercial Freeflyers/PAM · M2M Deliverable

TIMELINE:

2025: 1a 3a 4a 6a

2030: 2a 4b 5 6b 7a 8a

2034: 1b 2b 3b 7b 8b

2035

Risk Maps to ESDMD–1002 through 1005

EVA Risk Approach Plan

HRR Knowledge Gap

Risk Characterization / Formulation

EVA-101: Characterize **EVA preparedness** shortly post-landing on a planetary surface.

1 **Days post-landing prior to initial EVA: OCHMO by 2027**

EVA-102: Characterize **surface EVA performance** during exploration missions in partial gravity environments.

2a **Lunar Hi-Tempo Capabilities: EHP/FOD/OCHMO by 2028**

2b **Martian Hi-Tempo Capabilities: EHP/FOD/OCHMO by 2029**

EVA-201: Characterize impacts of **variable atmospheric conditions suits** on human health and performance, including exploration atmospheres, variable pressure suits, and alternate pre-breathe strategies.

3 **Elevated Suit Pressure Trade Space (EHP/HRP): EHP/FOD by 2028**

4 **DCS Risk Prediction Tool: EHP/OCHMO by 2030**

Initial model updates and implementation by 2027

CM Development / Evaluation

EVA-303: Identify and test **countermeasures related to exposure to variable atmospheric conditions**.

5 **Integrated DCS CM (e.g. CO_2, exercise, PFO, suit pressure): EHP/HLS by 2030**

CO_2–enhanced prebreathe evaluated by 2027

Exercise-enhanced prebreathe evaluated by 2027

PFO initial analysis by 2027

LEGEND: ISS · CLDP · Commercial Freeflyers/PAM · Neutral Buoyancy Lab · Atmospheric Chamber · Artemis · M2M Deliverable · Lunar Deliverable

TIMELINE:

DCS

1 — 2 — 3 — 4 — 5

2025 — 2029 — 2031 — 2035

Risk Maps to ESDMD–0406 and 0803

Food and Nutrition Risk Approach Plan

HRR Knowledge Gap

Risk Characterization / Formulation

FN-103: **Influence of temperature** on the nutritional content, safety, and acceptability of the spaceflight food system.

1. **Cold Storage Temperature Requirements - Mars: M2M by 2027**
2. **HLS Palatability and Nutrition of Food Stored at High Temps: M2M by 2028**

CM Development / Evaluation

FN-206: Using **food as a countermeasure** to mitigate decrements in nutritional status or DRM impacts on health and performance outcomes.

3. **Restricted Food System CM (CHAPEA early trends): M2M by 2027**
4. **Mass Reduced Food System Evaluations: M2M by 2031**
5. **EVA Dietary Requirements: M2M by 2028**

LEGEND: Isolation | Neutral Buoyancy Lab | Atmospheric Chamber | M2M Deliverable

TIMELINE:

2025 — 1, 3 — 2, 5 — 2029 — 4 — 2031 — 2035

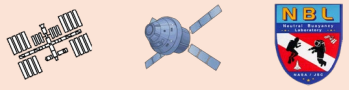
Risk Maps to ESDMD–0305

Immune Risk Approach Plan

HRR Knowledge Gap

Risk Characterization / Formulation

IM-106: Characterize the **effect of the stressors associated with spaceflight** (stress, microgravity, radiation, altered nutrition, circadian misalignment, hypoxia, etc.) on human immunity, determine clinical relevance and biomarkers to enable monitoring of astronauts.



1 **Likelihood and Consequences of Immune Dysfunction/Infectious Disease - ISS: OCHMO by 2026**

2 **Health status Biomarkers Validated – Exploration Missions: M2M by 2033**

CM Development / Evaluation

IM-404: Test, optimize, and validate nutrition, pharmacological, exercise, and stress reduction techniques as **preventive/mitigative countermeasures** for immune dysfunction.

3 **Ground Validation of Immune CMs: M2M by 2027**

4 **Flight Validation of Immune CMs: M2M by 2031**

LEGEND: Isolation | ISS | Neutral Buoyancy Lab | Artemis | M2M Deliverable

TIMELINE:

2025 — 1 — 3 — 2 — 2030 — 2035

Risk Maps to ESDMD–0305

Injury Due to Dynamic Loads (DL) Risk Approach Plan

HRR Knowledge Gap

Risk Characterization / Formulation	CM Development / Evaluation
DL-101: Characterize the true injury risk during dynamic phases of crewed vehicle operation.	DL-201: Determine **injury assessment reference values (IARVs)** for expected injuries.
1 **True injury from crewed vehicle operations – OCHMO 2026 (interim), 2034**	**3** **Tools to predict injury for early Lunar landing/traverse – HLS, EHP 2028**
DL-102: Characterize the effects of **spaceflight hazards and individual characteristics** on injury risk.	DL-202: Develop standardized approach for **individualized monitoring and modeling** during dynamic phases of crewed vehicle operations
2 **Effects of spaceflight hazards and individual characteristics – OCHMO 2026 (interim), OCHMO 2034**	**4** **Personalized tools to predict injury for Lunar landing/traverse – HLS, EHP 2032** **5** **Validated personalized tools to predict injury for Mars landing/traverse – HMTA 2034**

LEGEND: ISS | Commercial Freeflyers/PAM | Artemis | Drop tower/sled | Lunar Deliverable | M2M Deliverable

TIMELINE: 2025 — 2030 — 2035

- 2025: 1a 2a
- 3
- 4
- 1b, 2b, 5

Risk Maps to ESDMD–0406

SANS Risk Approach Plan

HRR Knowledge Gap

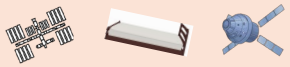
Risk Characterization / Formulation

SANS-101: Characterize the **temporal profile and magnitude** of ocular and brain manifestations during spaceflight and recovery to inform in-mission and long-term health consequences.

SANS-102: Characterize the **relationship between fluid shifts-induced ocular changes and fluid shifts** in the CNS, including whether elevated intracranial pressure or brain edema play a role.

SANS-202: Characterize the **inherent factors** (for example, genetic, metabolic, anatomical, sleep) that contribute to the individual variability in the ocular and brain manifestations.

SANS-203: Characterize the effects of **environmental factors** (for example, gravity, atmospheric conditions, radiation) during spaceflight on ocular and brain manifestations.



1 **Personalized SANS Prediction Capability: OCHMO by 2031**
Preliminary version to OCHMO by 2026

2 **LTH Monitoring Surveillance Guidelines: OCHMO by 2036**
Surveillance measures implemented 2029

CM Development / Evaluation

SANS-403: Develop and test **candidate countermeasure(s)** for SANS.

3 **Personalized SANS CMs Prescription (i.e. VTC, B-Complex, GLP-1): M2M by 2031**
B-Complex TTO 2028

SANS-404: Develop and test **candidate monitoring technologies** for SANS.

4 **Ocular monitoring devices: Gateway by 2029, M2M by 2035,**
HRP handover to MCO

LEGEND: ISS · Commercial Freeflyers/PAM · Parabolic Flight · Artemis · Bedrest · M2M Deliverable · Lunar Deliverable

TIMELINE:

2025 — 5 — 1 — 2026 — 3 — 2028 — 1 — 2031 — 4 — 2 — 2035

Risk Maps to ESDMD–0403

Sensorimotor Risk Approach Plan

HRR Knowledge Gap

Risk Characterization / Formulation

SM-105: Characterize the effects of spaceflight on **manual control and spatial disorientation** during and after G transitions that impact vehicular control.

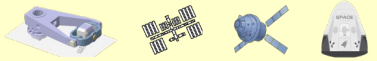
1 **Manual Control Onboard Training recommendations: Analog 2027 & Flight 2033 to FOD/HLS**

SM-106: Characterize the effects of spaceflight on **postural control and locomotion (gross motor control), and motion sickness** after G transitions that impact egress and early intravehicular / extravehicular activities.

2 **Days post-landing prior to initial EVA: OCHMO by 2033**

CM Development / Evaluation

SM-205: Develop and test **manual control countermeasures**, such as preflight disorientation training, onboard training and adaptive displays that impact vehicular control.



3 **GVS for Preflight disorientation training: HLS by 2027**

4 **Manual Control Adaptive Display and Training Recommendations: HLS by 2027**

1 **Manual Control Onboard Training recommendations: Analog 2027 & Flight 2033 to FOD/HLS**

SM-206: Develop and test **countermeasures for egress, early intravehicular / extravehicular activities, and motion sickness** such as inflight training, post-landing assessments and guidelines, including human factors aids.

5 **Balance Trainer CM Validated: Bedrest 2028, Flight 2031 to M2M**

6 **Pre-EVA SM assessments: Analog 2027 Flight 2031 to SD & EHP**

7 **Head/body motion recovery guidelines: Analog 2027 & Flight 2031 to CCP & OCHMO**

LEGEND: ISS · Centrifuge · Commercial Freeflyers/PAM · Parabolic Flight · Artemis · Bedrest · M2M Deliverable · Lunar Deliverable

TIMELINE: 2025 — 3 4 — 5 — 2030 — 6 Egress — 7 — 1 MC — 2 — 2035

Risk Maps to ESDMD–0402

Team Cohesion and Performance (Team) Risk Approach Plan

HRR Knowledge Gap

Risk Characterization / Formulation

Team-101: Characterize the key threats, indicators, and **evolution of the multi-team system** under shifting autonomy, for exploration missions

1 **Impacts of exploration mission characteristics on multi-team system performance: FOD, BHP Ops 2027 (interim); update 2034**

CM Development / Evaluation

Team-201: Define indicators, measures, and thresholds, to inform semi-autonomous **monitoring** of team functioning and performance

2 **Interim recommendations to inform crew composition for Mars: BHP Ops by 2027 (interim), 2034**

3 **Recommendations for semi-autonomous monitoring system, integrating relevant measures and evidence/threshold-based guidelines for countermeasures: BHP Ops by 2031 (interim), 2034**

Team-202: Inform **design recommendations** for habitat/vehicle interfaces, to mitigate impacts to team functioning and performance

4 **Recommendations to inform habitat/sub-system design: HMTA by 2027 (interim), 2034**

Team-203: Develop, test/refine, and validate **countermeasures to support team functioning** and performance during exploration missions

5 **Countermeasures for maintaining team functioning & performance: BHP Ops by 2031**

6 **Countermeasures for within-crew social support: BHP Ops by 2031**

Team-204: Identify, test, and refine monitoring approaches and **countermeasures to address the multi-team system**, for exploration missions

7 **Measures & Countermeasures for multi-team system: BHP Ops/FOD by 2031**

8 **Validated measures and CMs for multi-team system for Mars: BHP Ops by 2034**

LEGEND: Isolation | ISS | Artemis | Commercial Freeflyers/PAM | M2M Deliverable

TIMELINE:

2025 — **1a 2a 4a**

2030 — **3a 5 6 7**

2035 — **1b 2b 3b 4b 8**

Risk Maps to ESDMD–0404

Venous Thrombosis Risk Approach Plan

HRR Knowledge Gap

Risk Characterization / Formulation

CV-104: Determine **biomarkers** relevant for development of venous thrombosis in spaceflight.

CV-105: Determine the influence of **anatomical variations** for development of venous thrombosis in spaceflight.

CV-106: Determine the influence of **genetic predispositions** for development of venous thrombosis in spaceflight.

CV-107: Determine the influence of **immune factors** for development of venous thrombosis in spaceflight.

CV-108: Determine the contribution of **flow abnormalities** to venous thrombosis risk in 0G and partial-G.

1 **Likelihood and Consequences (LxC) of Venous Thrombosis in 0-G: OCHMO by 2031**

2 **Likelihood and Consequences (LxC) of Venous Thrombosis in partial-G: OCHMO by 2033**

CM Development / Evaluation

CV-202: Identify, develop, and test **monitoring strategies** for venous thrombosis in spaceflight.

CV-203: Identify, develop, and test candidate countermeasures for venous thrombosis in spaceflight.

3 **Thigh Cuffs CM for Venous Thrombosis: OCHMO/M2M by 2032**

4 **Novel CM for Venous Thrombosis (e.g. pharmaceutical/ nutraceutical): OCHMO/M2M by 2035**

LEGEND: CLDP | ISS | Commercial Freeflyers/PAM | Parabolic Flight | Artemis | M2M Deliverable

TIMELINE:

2025 — 2030 — 2035

1 — 2 — 3

Risk Maps to ESDMD–0401