EARTH INDEPENDENT MEDICAL OPERATIONS

FOUNDATIONS TO ADVANCE LONG DURATION MISSION HEALTH

National Aeronautics and
Space Administration

Jay Lemery, MD, FACEP FAWM
Benjamin Easter, MD, MBA, FACEP, AFAsMA
Kris Lehnhardt, MD, FACEP, FAsMA

Exploration Medical Capability (ExMC)
NASA Human Research Program

AsMA
May 24th 2023

ARTEMIS

Exploration Medical Capability

Disclosure Information

AsMA 93rd Annual Scientific Meeting

Jay Lemery MD

I have the following financial relationships to disclose:

- Consultant for: The Climate & Health Foundation
- Grant/Research support from: NASA, DoD, NSF
- Employee of: The University of Colorado School of Medicine

I will not discuss off-label use and/or investigational use in my presentation

Risk of Inflight Medical Conditions

- **Risk Title**: *Risk of Adverse Health Outcomes & Decrements in Performance due to Medical Conditions that occur In Mission*

- **Risk Statement:** *Given that medical conditions will occur during human spaceflight missions, there is a possibility of adverse health outcomes & decrements in performance during these missions and for long term health.*

- **What is required for the Medical Risk to be acceptable:** *High confidence that astronauts can accomplish mission medical tasks in a progressively autonomous fashion (HSRB May 2021)*

Risk of Inflight Medical Conditions

DRM Categories	Mission Type and Duration	Operations		Long-Term Health	
		LxC	Risk Disposition *	LxC	Risk Disposition *
Low Earth Orbit	Short (<30 days)	3x2	Accepted	3x2	Accepted
	Long (30 days-1 year)	4x2	Accepted	4x2	Accepted
Lunar Orbital	Short (<30 days)	4x2	Accepted	3x2	Accepted
	Long (30 days-1 year)	5x3	Requires Mitigation	4x2	Requires Characterization
Lunar Orbital + Surface	Short (<30 days)	4x3	Requires Characterization	4x2	Requires Characterization
	Long (30 days-1 year)	5x4	Requires Mitigation	4x4	Requires Characterization
Mars	Preparatory (<1 year)	5x4	Requires Mitigation	4x4	Requires Characterization
	Mars Planetary (730-1224 days)	5x5	Requires Mitigation	5x4	Requires Characterization

DRM = design reference missio

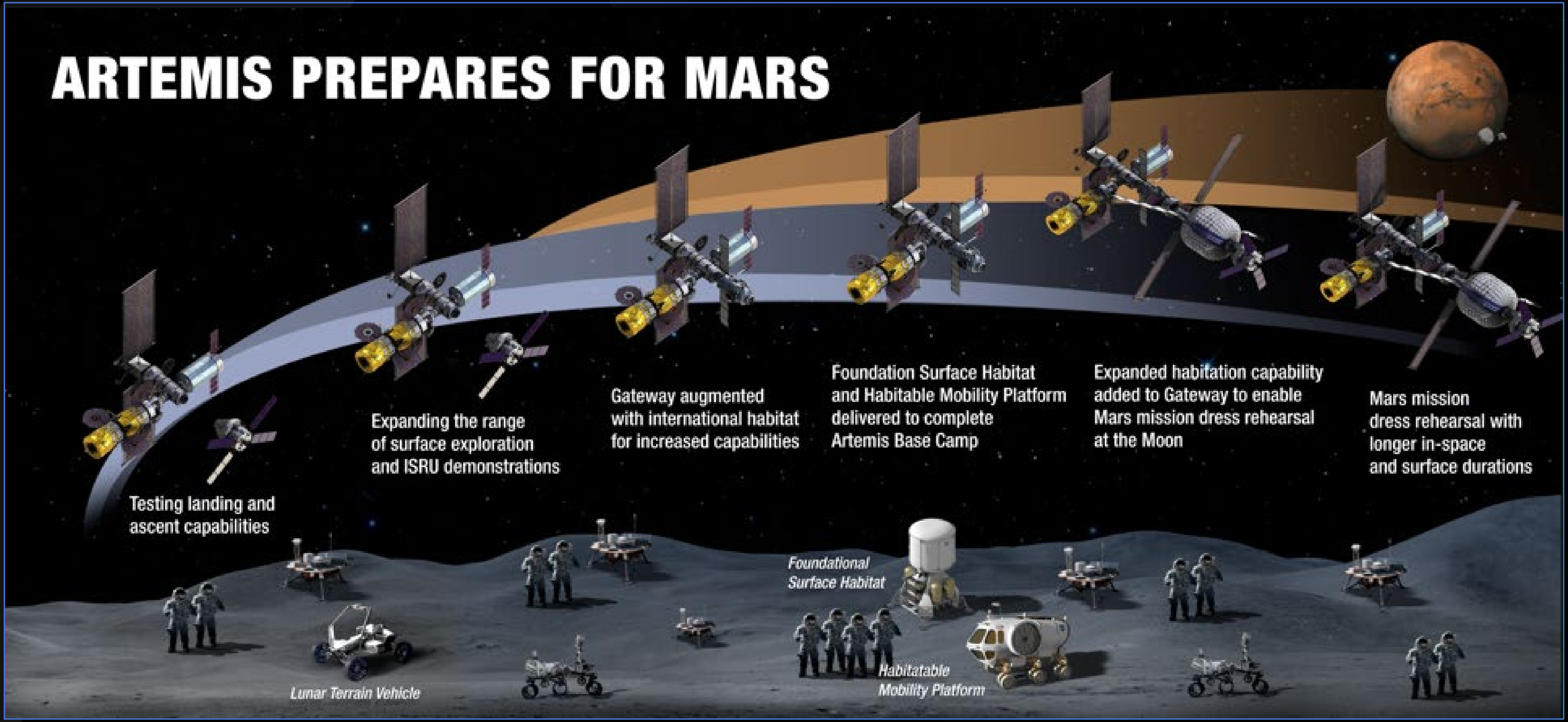
L x C = likelihood and conseque

MEDICAL RISK INCREASES WITH DISTANCE FROM EARTH

International Space Station → Gateway → Lunar Surface → Mars Transit

A New Paradigm: Moon to Mars

Artemis missions must lay the medical foundations for the first human mission to Mars

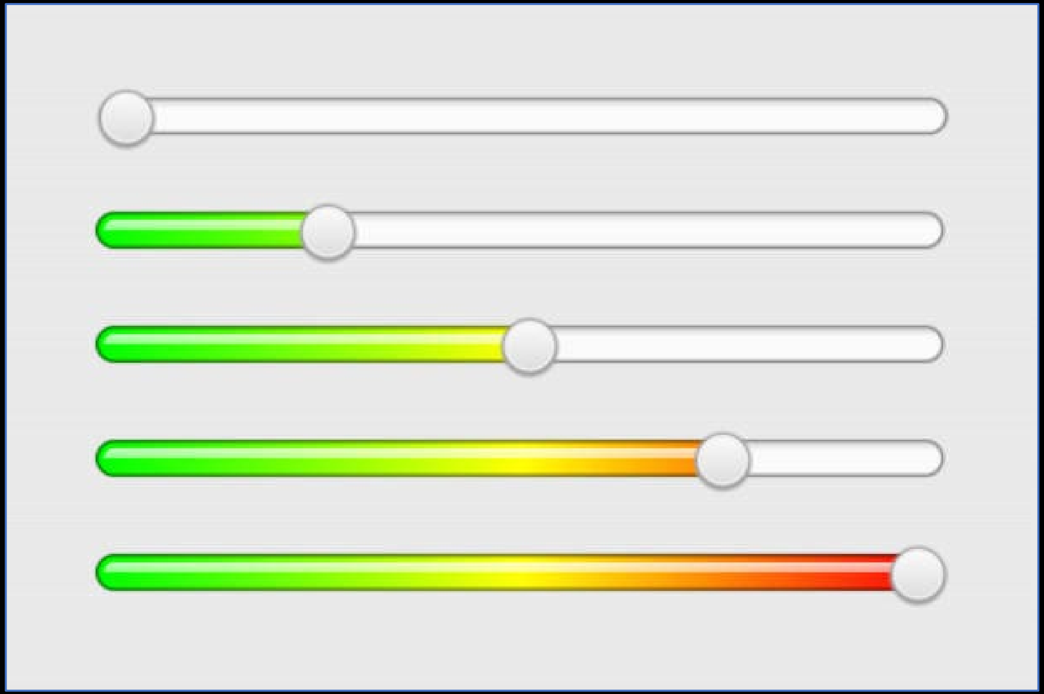


A Progressive Approach

On-board care will increasingly become the responsibility of the astronauts for primary management.

Terrestrial assets will continue to be paramount in pre-mission screening and planning, as well as health maintenance and prevention activities.

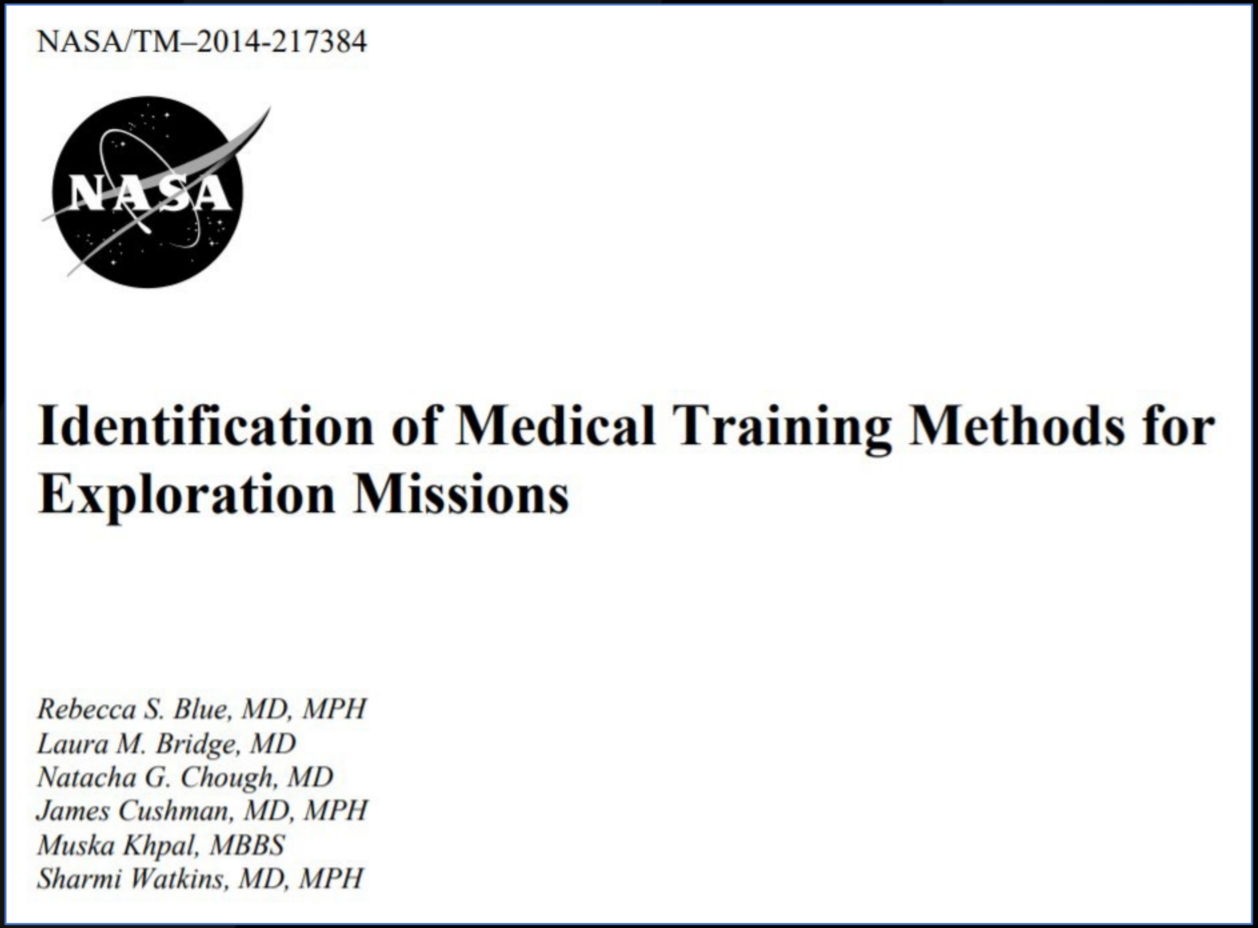
New capabilities and procedures that enable progressively more robust and resilient systems and crews will reduce risk and increase probability of deep space exploration mission success.



Earth-Independent Medical Operations (EIMO)

Previous ExMC Work in Support of EIMO

Medical Trai


NASA/TM–2014-217384

Identification of Medical Training Methods for Exploration Missions

Rebecca S. Blue, MD, MPH
Laura M. Bridge, MD
Natacha G. Chough, MD
James Cushman, MD, MPH
Muska Khpal, MBBS
Sharmi Watkins, MD, MPH

Autonomous Medical Officer Support | Medication Stability Assessments

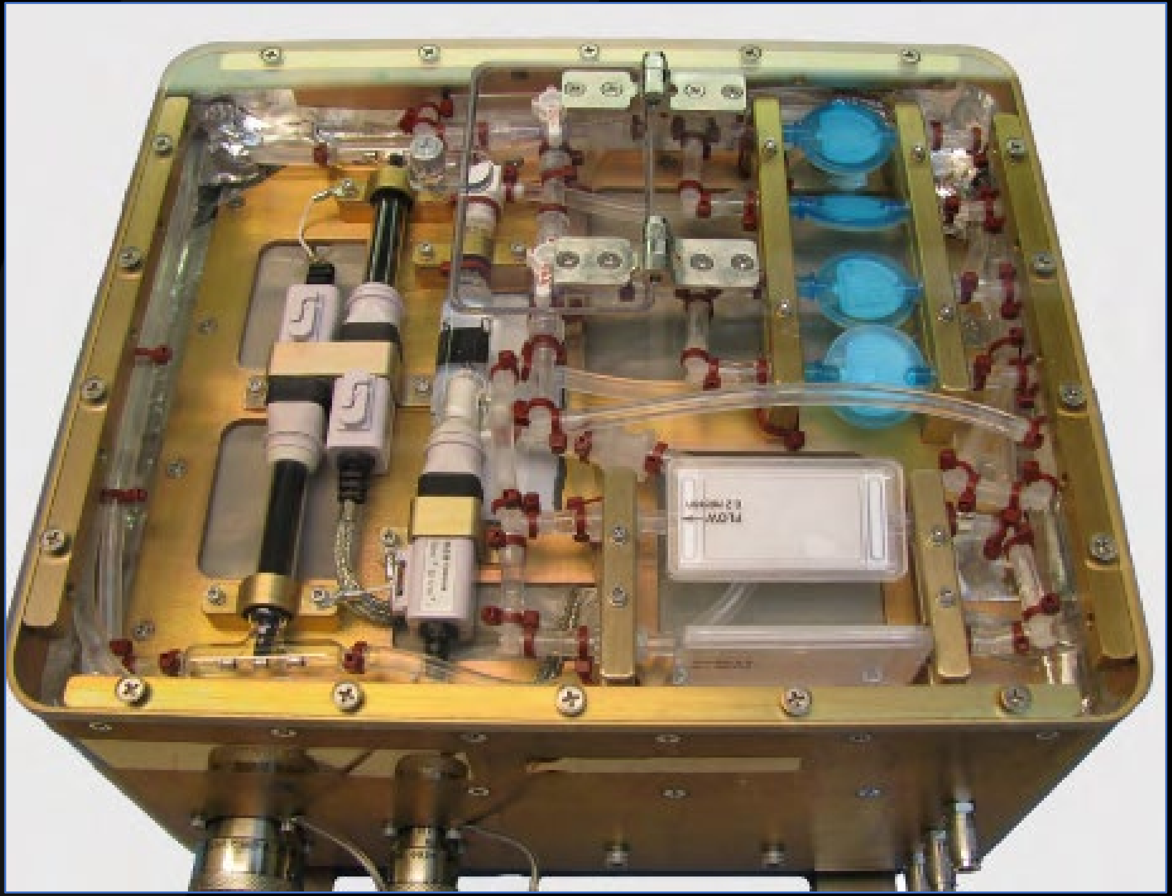
Previous ExMC Work in Support of EIMO

Procedural Guid

Technological Demonstrations

Previous ExMC Work in Support of EIMO

In-situ IV Fluid Gen

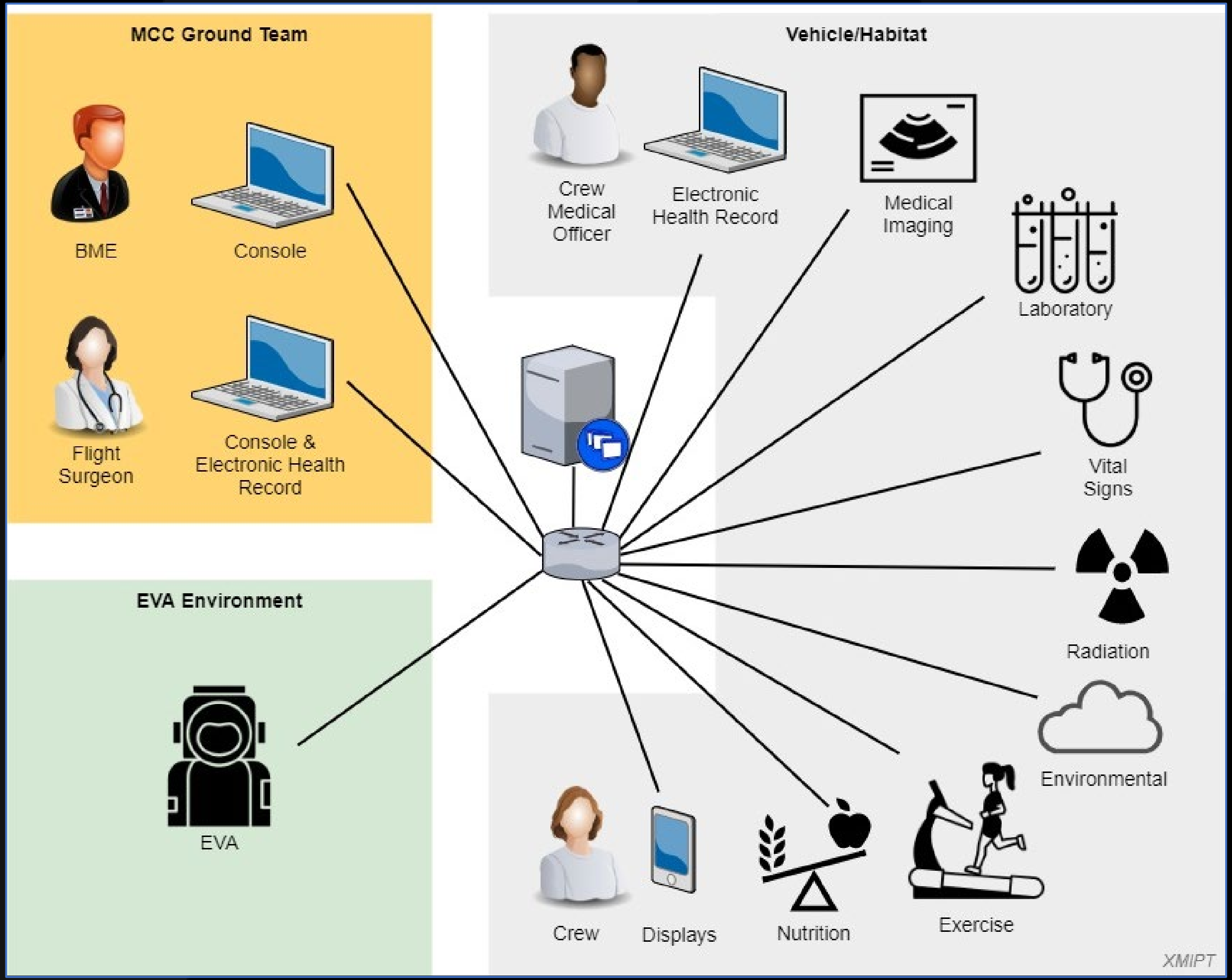


IVGEN

Medical Consumables Tracking (MCT)

Current EIMO ExMC Work

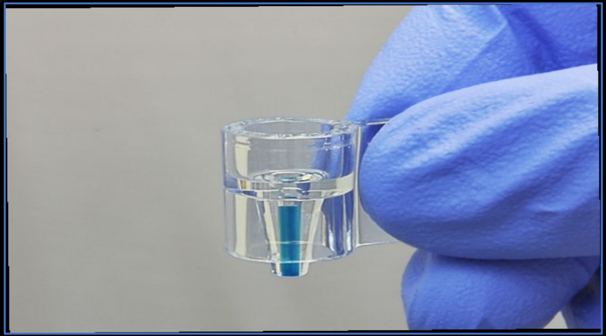
Integrated Data Arc



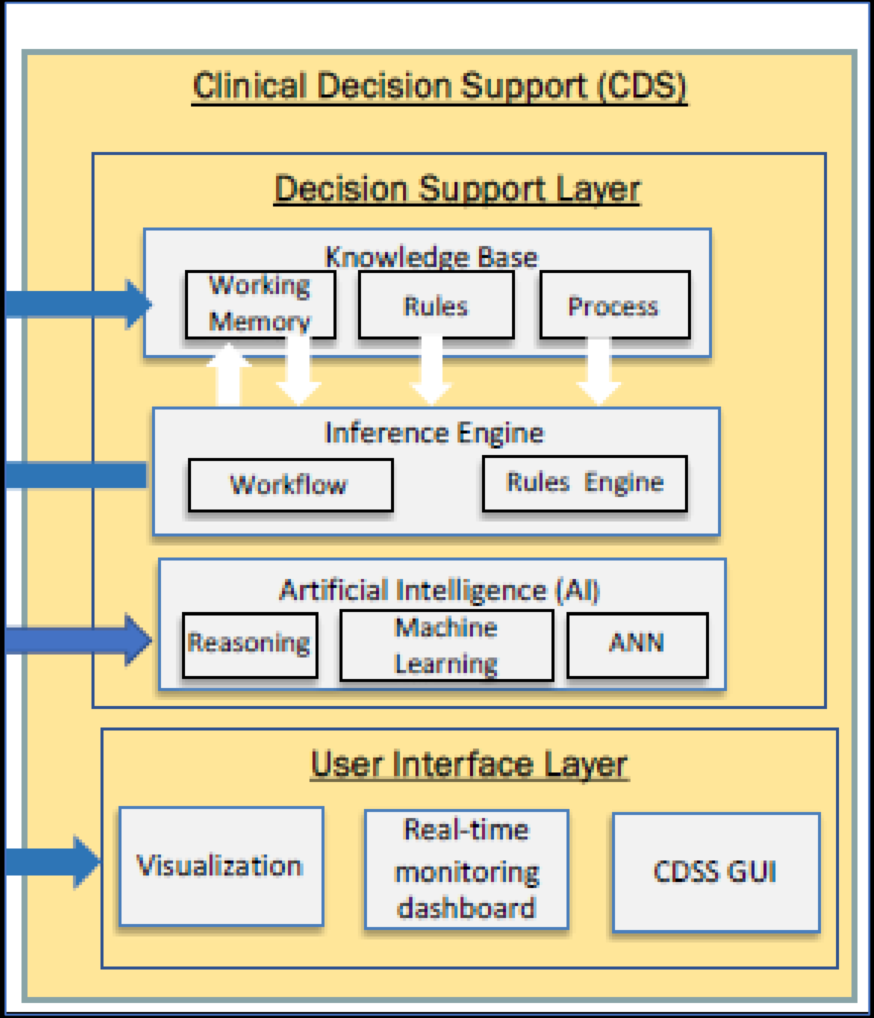
Crew Health & Performance - Integrated Data Architecture [CHP-IDA]

Current EIMO ExMC Work

Expanded In-situ Di



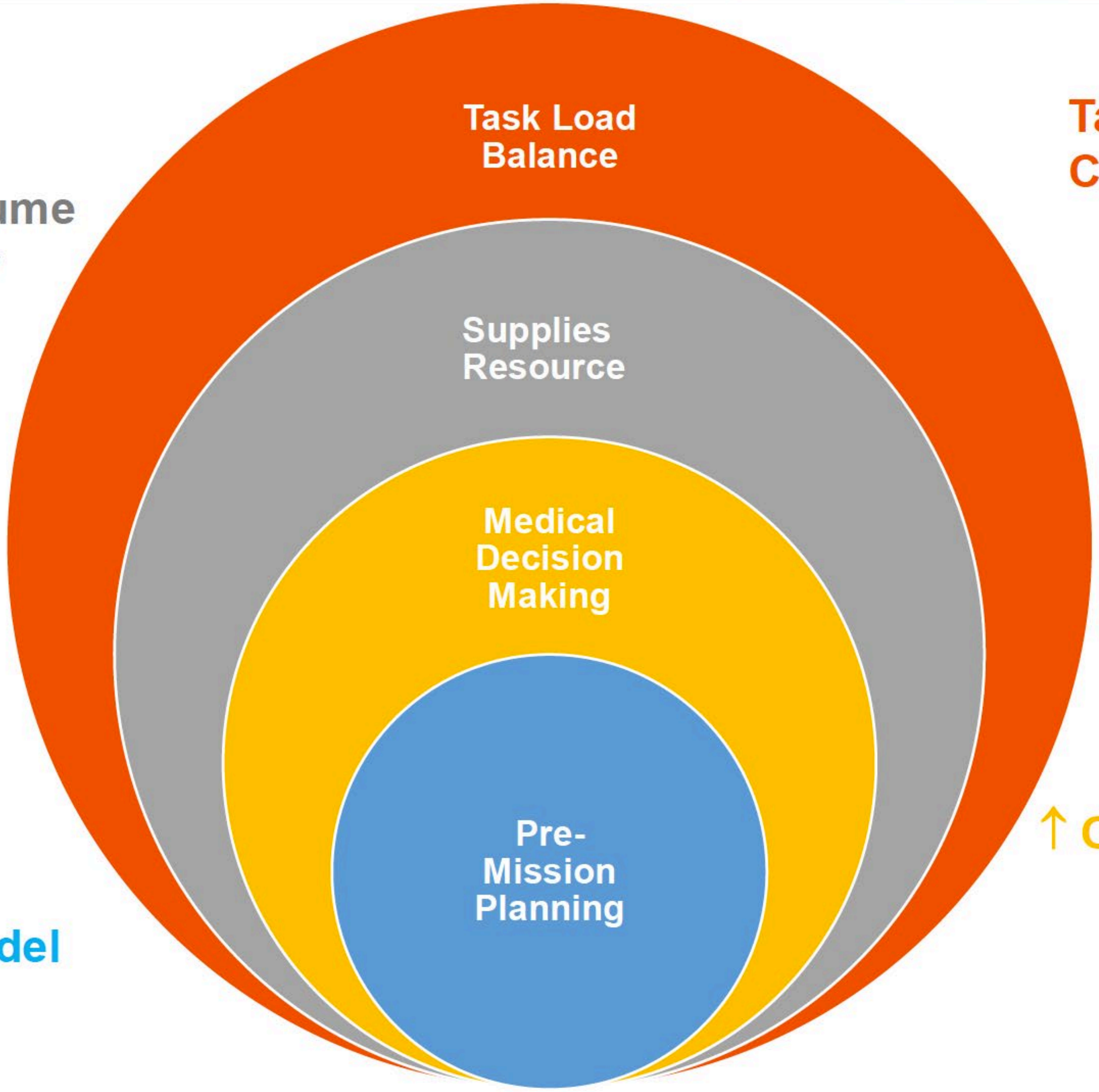
POC Laboratory/
Clinical Decision Support



EIMO Leadership TIM, *January 2023*

EIMO Components

↓ Mass/Volume
∅ Re-supply



Task Switching
Cognitive Load

↑ On-Board KSAs

Medical Model

Pre-mission planning

- Compared with current LEO operations, ***pre-mission planning is likely to be even more critical*** with EIMO.
- Key facet= maturation and operational integration of the ***IMPACT probabilistic risk assessment and trade space tool***, to better quantify medical risks across a broad swath of medical conditions.
- Likewise maturation and implementation of ***onboard routine medical training/practice modules*** (JITT) for diagnostic and therapeutic interventions.
- Such systems can provide estimations of the optimal crew ***knowledge, skills and abilities***, details of what trainings may be most beneficial, set research priorities for risk reduction, and help reallocate remaining in-flight resources for risk reduction.

Acute & Emergent Decision Making

Distance, communication latency, and reduced data channel capacity…

- An imperative to enhance an onboard medical provider's skills via JITT, **decision support tools**, **knowledge data bases**, and through *mixed reality augmentation*.
- Clinical decision support systems (CDSS) can ***drastically increase treatment proficiency*** in space without direct support from the ground.

Prolonged Medical Decision Making

- *Non emergent conditions are often manageable via telemedicine and may not require immediate subject matter expert (SME) input.*
- However, a lack of continuous availability of SME input, significant response latency, and lower data transmission rates will affect the ability to transmit high resolution images, video, and other telemedical data.
- Thus, ***even for non-emergent medical problems, there will be a requirement for high onboard KSA***—via a skilled medical practitioner and/or a highly functional CDSS.

Supplies & Resource Management

- Resourcing historically been chosen via expert opinion.
- Mismatches mitigated by either the *short duration of the mission* or *proximal resupply*.
- Exploration class missions = ***account for mass and volume restrictions, medication stability, and their potential for re-use***.
- Regenerable/ on-demand resourcing could significantly enhance the resilience of exploration medical systems
  - 3D printers
  - plant based pharmaceutical "farms"

Task Load Management

- LEO operations offload many medical decisions, monitoring, and other tasks to ground based support teams
- Long duration constraints may stress CMO's with higher task demand, increased task switching, and higher cognitive load.
- A clinical decision support system could assist with tasks such as ***inventory management, locating resources, storing and retrieving medical records, highlighting trends in recorded data, scheduling reminders, record keeping, and even diagnostic and treatment suggestions***.
- More advanced systems may even be able to passively monitor crew for early signs of behavioral or medical anomalies, provide diagnostic assistance, autonomously suggest treatments, and guide crew members through procedures.

Further EIMO considerations

What other factors might drive a need for a new paradigm? What have we left out?

- While EIMO systems will need to be designed for robustness, there is a concomitant need for systems that are nimble, malleable, and with the capacity to evolve over time.
- Crew health and performance will need to be supported across multiple habitats, vehicles and suits, in some cases designed over many years and with differing requirements. The ***importance of information flow throughout the systems via an integrated data architecture cannot be overstated***.

Training paradigms

Another factor that needs to be considered are the training paradigms best suited for advancing EIMO.

- To what degree do we train toward technical specialization and expertise versus just hiring a ‘MacGyver,’ i.e. improvisational proficiency and just-in-time learning?
- This consideration will be key in not only astronaut selection, but in training, policies, and procedures for ground support

How to strike the right balance between medical risk reduction and exploration mission resource constraints?

- Probabilistic risk assessment has demonstrated that medical risk in long duration, explorations missions will be significantly greater than anything in NASA's historical experience
- These types of tools will help to ***facilitate conversations*** with appropriate stakeholders ***about the trade-offs*** between medical risk and medical system resource allocations.
- It is widely assumed that initial medical risks will be formidable but will decline over subsequent missions with increased experience and medical system refinement.

How to strike the right balance between medical risk reduction and exploration mission resource constraints?

In balancing the trade-off between medical risk and resources, there are two potential approaches, top-down and bottom-up, that can help in defining risk envelopes.

- Top down: consider everything we could potentially want in capabilities and resources, and then begin a process of tailoring to specific missions and vehicles.
- Bottom-up: what are the truly essential 'must-have' systems and resources via OCHMO and NASA 3001 standards.
- Each approach will generate different estimates of medical risk, and the approaches can then be integrated to bring medical risk and resource utilization into acceptable ranges.
- EIMO will push the evolution of the conversation from that of '*what's in our medical kit to treat the astronaut?'* to that of '*how redundant, sophisticated and resilient is our medical system, such that it can include autonomous medical support and be integrated with crew health and performance integrated data architectures?'*

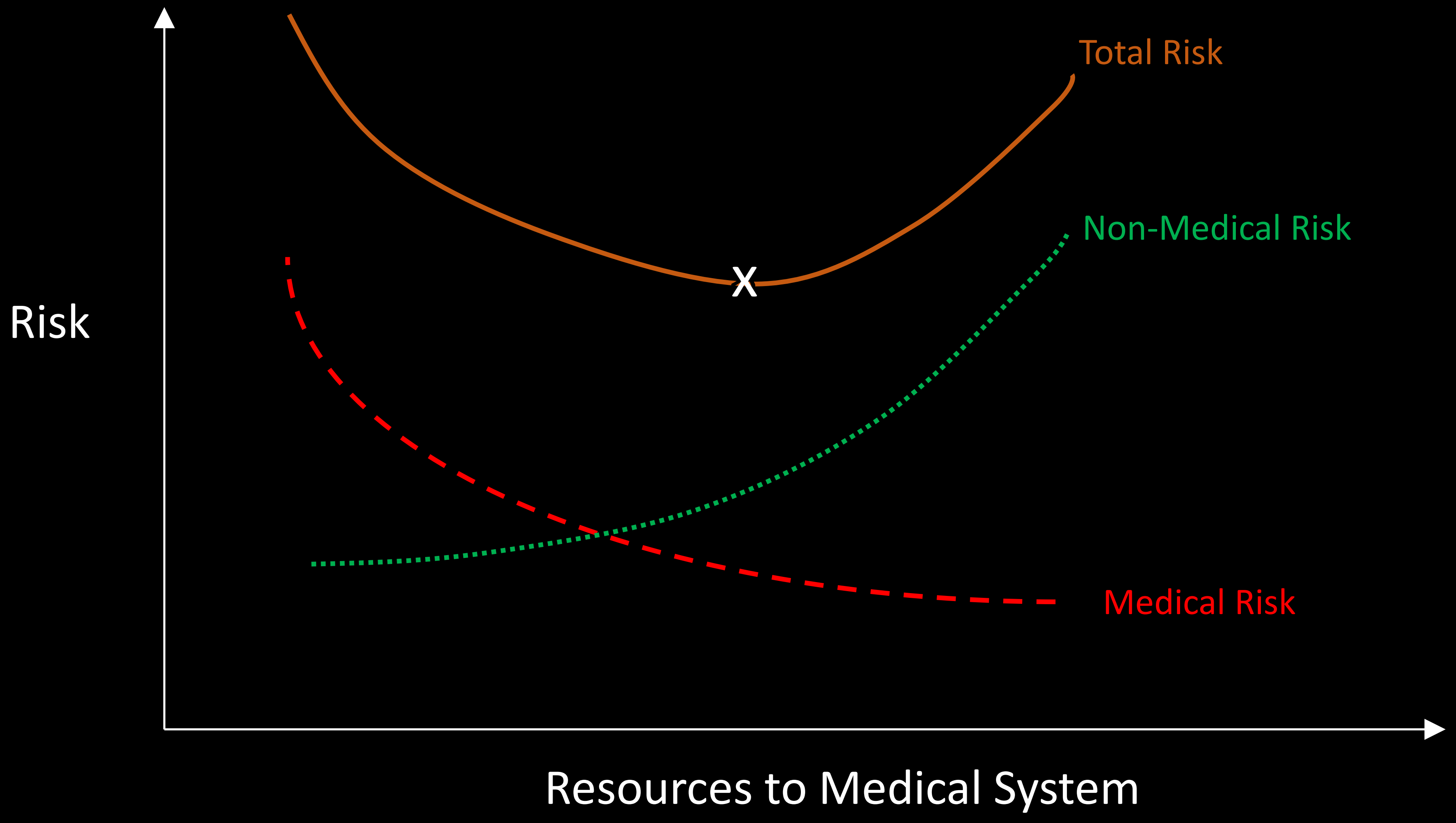
What does success look like?

- A pure concept of EIMO could be the fictional sick bay on Star Trek's *USS Enterprise*.
- Is there a hard endpoint for EIMO or if it is instead a constant pursuit for medical system improvement.
- Milestones will indeed be useful, and discrete re-evaluations of medical capabilities will be needed as the Artemis missions progress, in order to advance and refine EIMO concepts.
- Should EIMO be an aspirational goal or a coordinated effort to accomplish functions that are absolutely necessary? ***It was generally agreed that EIMO should be conceived less as an endpoint, but more as a spectrum.***

Takeaways

- EIMO is not a binary state with terrestrial support or the antonym of LEO medical operations, ***but rather a gradual shift in the balance of medical responsibility, management, and authority*** from terrestrial to space-based assets.
- A precondition for EIMO is that it ***advances the prime metric of a lower overall mission risk***, and therefore must be integrated with all Agency efforts to achieve the more comprehensive Earth independent operations necessary to successfully complete a human mission to Mars.

Minimizing *Medical* Risk is NOT the Goal



Notional

Updated definition of Earth Independent Medical Operations:

The gradual transition of medical care and decision making from terrestrial to space-based assets, enabling support of astronaut health and performance and reducing overall mission risk.


National Aeronautics and
Space Administration
What's Next?
www.nasa.gov
"Expanding the Boundaries of Space Medicine and Technology"

EIMO in 2023 and beyond

- Sub-topic TIMs in 2023 & 2024
- Maximize utility of ground testbeds and analog environments (including ISS), as well as Artemis opportunities
- Establishing Requirements & Concept of Operations
- Continued conversations with NASA and external stakeholders and SMEs

National Aeronautics and
Space Administration

Thank you

jay.lemery@nasa.gov

Exploration Medical Capability

ADVANCING EXPLORATION MEDICAL CAPABILITY

Coordinated Integration of Research, Demonstrations and Systems Engineering

National Aeronautics and Space Administration

Jay Lemery, MD, FACEP FAWM
Benjamin Easter, MD, MBA, FACEP, AFAsMA
Kris Lehnhardt, MD, FACEP, FAsMA

Exploration Medical Capability (ExMC)
NASA Human Research Program

AsMA
May 24th 2023

ARTEMIS

ExMC
Exploration Medical Capability

ELEMENT EVOLUTION

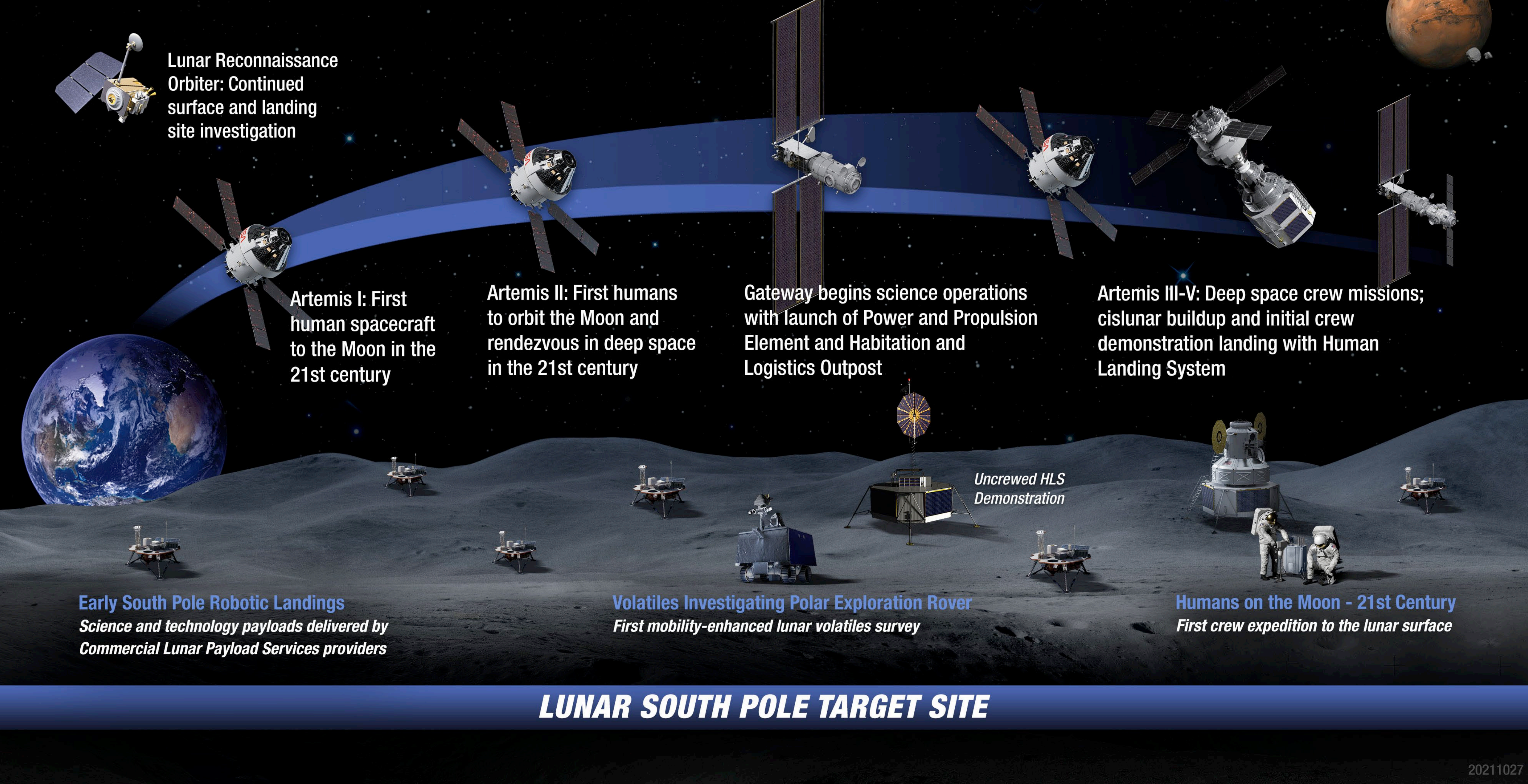
Mars Focus

Mars Fo

HSRB RISK REDUCTION APPROACH	2015-2018 *IDEATION* "Exploring Multiple Ideas"	2019-2022 *ORGANIZING & IMPLEMENTATION* "Delivering Products"	2023-? *IMPLEMENTATION & IDEATION* "Developing New Partnerships"
CAL RISK	• Birthplace for Applying PRA to Medical Risks & Delivery of IMM	• New Generation of PRA for Medical Risk (IMPACT)	• Using IMPACT for Medical System Design After TtO • Expanding EIMO Concepts
SYSTEMS ENGINEERING	• Birth of Applying SE to Medical System Design	• Added SE Rigor to Ideas • Medical Foundation Models • Birthed Concept of Crew Health & Performance (CHP) System	• Applying SE Rigor to Ideas • Determining ExMC's Role in CHP System
TECHNOLOGY	• Tech Development • Tech Watch	• COTS Tech Demos • Autonomy (AMOS, MDA, CDS)	• COTS Tech Demos • Autonomy Demos
PHARM RISK	• Pharm Risk Combined (Stability & PK/PD Risks)	• Defined Stability & PK Strategies • NSRL Study	• Implement Stability & PK Strategies • Define PD Strategy
RENAL RI		• AMOS • UW Stone Propulsion Study	

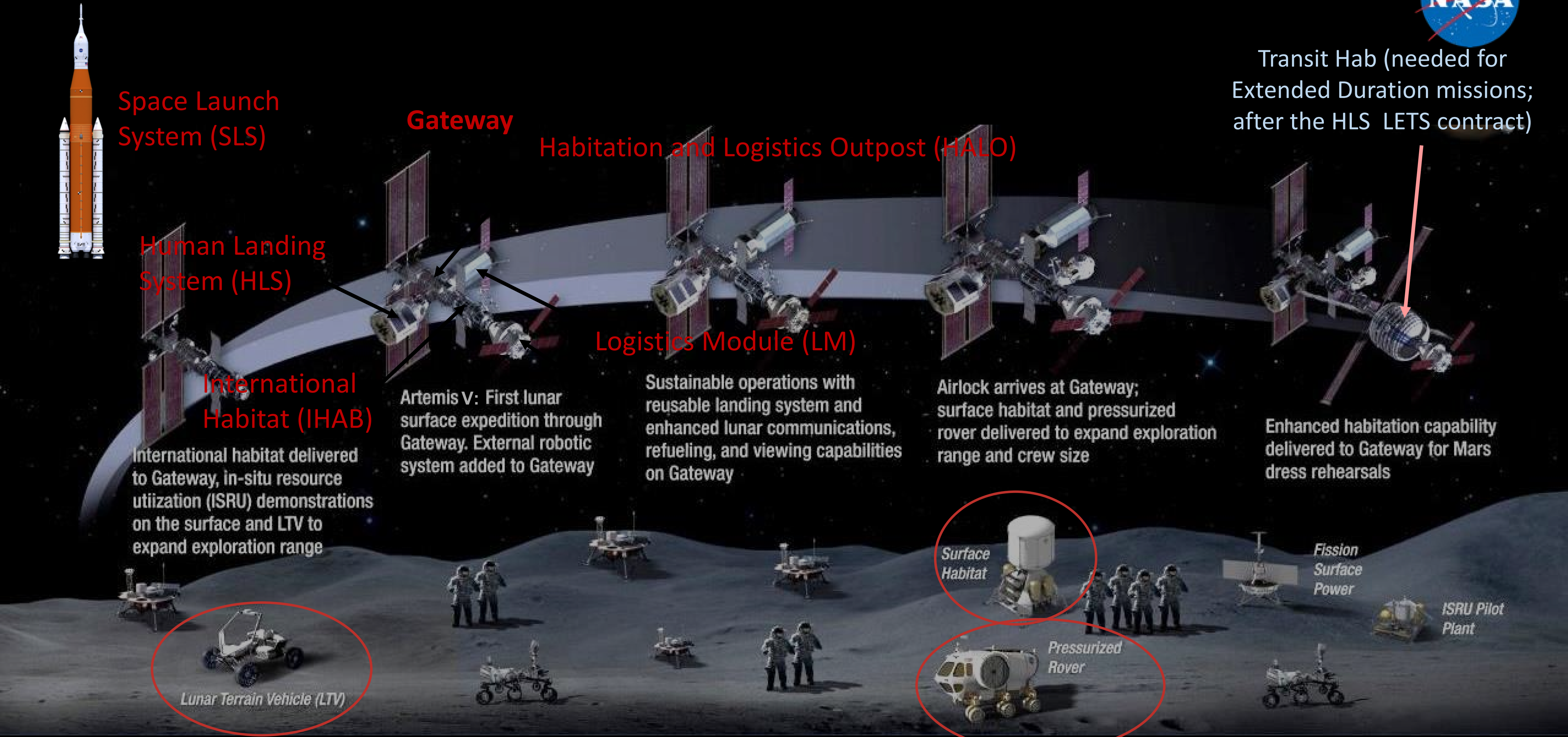
cus

INITIAL ARTEMIS: LANDING HUMANS ON THE MOON



SUSTAINING ARTEMIS -COMPONENTS/VEHICLES

ESD
AES
TBD



HSRB Medical Risk

DRM Categories	Mission Duration	OPS	Risk Disposition	LTH	Risk Disposition
Low Earth Orbit	< 30 D	3x2	Accepted	3x2	Accepted
Low Earth Orbit	30 D - 1 Y	4x2	Accepted	4x2	Accepted
Lunar Orbital	< 30 D	4x2	Accepted	3x2	Accepted
Lunar Orbital	30 D - 1 Y	5x3	Requires Mitigation	4x2	Requires Characterization
Lunar Orbital + Surface	< 30 D	4x3	Requires Characterization	4x2	Requires Characterization
Lunar Orbital + Surface	30 D - 1 Y	5x4	Requires Mitigation	4x4	Requires Characterization
Mars	< 1 Y	5x4	Requires Mitigation	4x4	Requires Characterization
Mars	730-1224D	5x4	Requires Mitigation	5x4	Requires Characterization

Current Risk Model: 5x5

Risk Disposition Rationale:

Ops for LEO, short-duration Lunar Orbital missions accepted based on current countermeasures and availability for rapid evacuation to Earth for more comprehensive medical care. Missions >30d in Lunar orbit, lunar surface missions, and Mars missions require mitigation to provide more effective prescreening and in-mission medical management capability with limited mass and volume. LTH considerations for >30d lunar orbital, all lunar surface, and Mars missions likely require mitigation to minimize impact on crew. Mitigation strategies require further research.

HSRB Pharm Risk

DRM Categories	Mission Duration	OPS	Risk Disposition	LTH	Risk Disposition
Low Earth Orbit	< 30 D	1x1	Accepted	1x1	Accepted
Low Earth Orbit	30 D - 1 Y	1x1	Accepted	1x1	Accepted
Lunar Orbital	< 30 D	1x1	Accepted	1x1	Accepted
Lunar Orbital	30 D - 1 Y	1x1	Accepted	1x1	Accepted
Lunar Orbital + Surface	< 30 D	1x1	Accepted	1x1	Accepted
Lunar Orbital + Surface	30 D - 1 Y	1x1	Accepted	1x1	Accepted
Mars	< 1 Y	2x2	Accepted	1x1	Accepted
Mars	730-1224D	3x4	Requires Mitigation	3x4	Requires Mitigation

Current Risk Model: 3x4

Risk Disposition Rationale:

"**Accepted**" for Ops & LTH regarding all DRMs except Planetary as current formulary medications will support a one year shelf life, the production of degradation products may only lead to minor outcomes, and these inflight minor episodes will have no impact on the quality of life. The Planetary DRM "**Requires Mitigation**" for both OPS and LTH as most drug formularies do not support a shelf life of 3+ years and the extended effects of deep space on degradation products is not known.

Disclosures

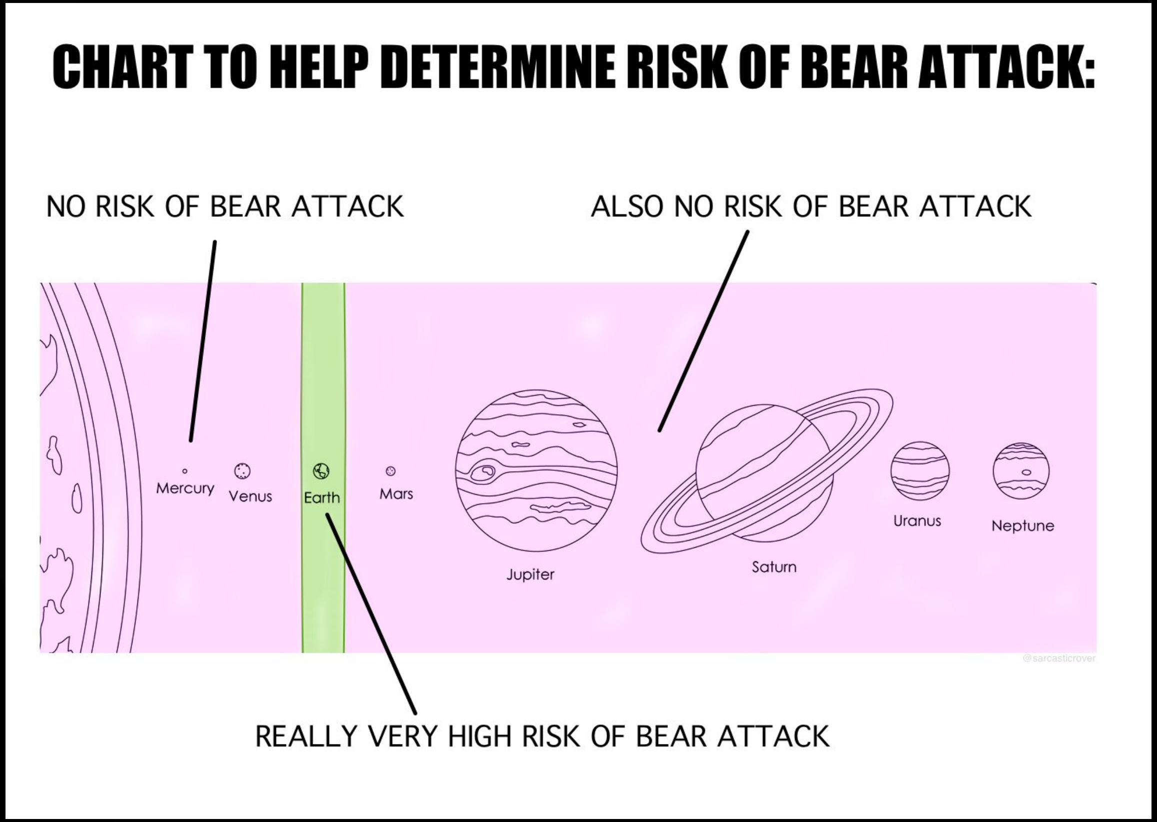
- I have no actual or potential conflict of interest in relation to this presentation.
- I have funding through the following sources:
  - Associate Element Scientist, Exploration Medical Capability, NASA Human Research Program
  - Professor, Emergency Medicine, University of Colorado School of Medicine

Exploration Medical System Planning Needs

Significant new constraints in distance, comms, latency, resupply & evac
ALSO *mass, volume, power, & crew training*

Goal = inform medical system design via:

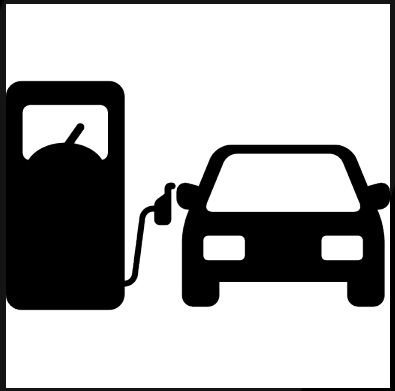
- ***Quantitative*** evidence-based estimates of medical risk
- ***Systematic*** definition of needed clinical capabilities
- Determination of best resources given constraints
- ***Traceable:*** Communication of medical system needs to engineers



What is IMPACT?

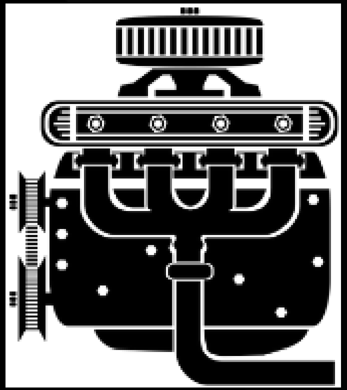
Informing **M**ission **P**lanning via **A**nalysis of **C**omplex **T**radespaces

Evidence



\+

Computational Engine (PRA) = ***MEDPRAT***



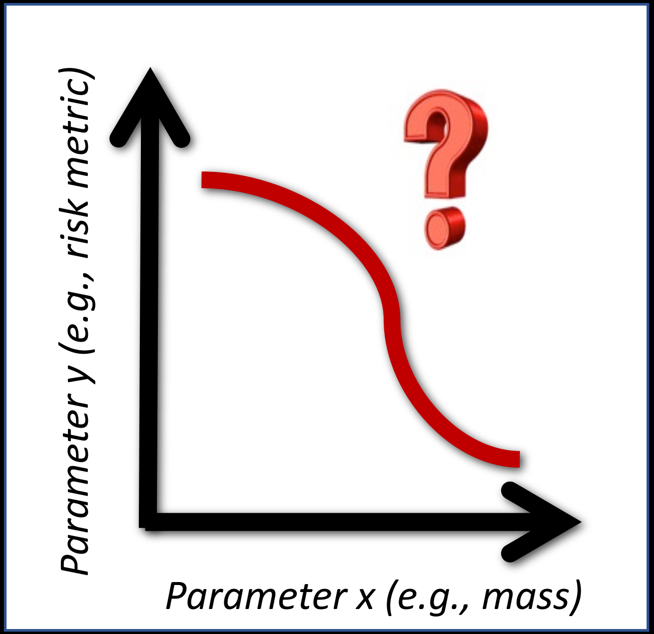
=

IMPACT

- Exploration-focused
- Evolution of Integrated Medical Model (IMM)
- Operational by end of 2023

Medical System Risk Analysis in 4 steps

- Step 1- Scope the system (medical condition list)
- Step 2- Gather data and build model
- Step 3- Probabilistic Risk Analysis
- Step 4- Optimize the trade space



Step 1- IMPACT Medical Condition Selection

- Determine medical conditions that are in scope or out of scope for system design (i.e. which conditions to plan around)
- Reviewed 9 existing condition lists, including:
  - *IMM*
  - *Artemis*
  - *Lunar EVA Incapacitation*
  - *historical spaceflight conditions*
- 443 conditions on Master List
- Consensus-based process to get to 120 conditions for IMPACT v1.0
  - Nothing magical about 120 – determined by schedule/resources
  - Plan to add additional conditions in future versions

Step 1- IMPACT v1.0 Condition List

Abdominal Wall Hernia	Barotrauma (Ear/Sinus Block)	Burn - Chemical Skin	Dental Fracture/Exposed Pulp	EVA Related Fingernail Delamination	Fracture - Arm
Abnormal Uterine Bleeding	Benzodiazepine or Opioid Overdose	Burn - Mild, Thermal	Dental Luxation/ Avulsion (Tooth Loss)	EVA Related Hand Injury	Fracture - Cervical Spine
Acute Coronary Syndrome	BHP - Adjustment Disorder	Burn - Moderate To Severe, Thermal	Dislocation - Finger	EVA Related Heat Illness	Fracture - Distal Leg
Acute Radiation Syndrome	BHP - Anxiety	Cerebrovascular Accident	Dislocation - Shoulder	EVA Related Paresthesia	Fracture - Femur
Allergic Reaction (Mild To Moderate)	BHP - Depression	Cerumen Impaction	Diverticulitis, Acute	EVA Related Shoulder Injury	Fracture - Hand
Altitude Sickness	BHP - Grief Reaction	Choking/Obstructed Airway	Dust Exposure - Lunar	EVA Related Suit Contact Injury	Fracture - Wrist
Anaphylaxis	BHP - Psychosis Secondary To Depression	Cholelithiasis/Biliary Colic, Acute	Ebullism	Eye - Retinal Injury	Fracture- Thoracic/ Lumbar Spine
Appendicitis	BHP - Sleep Disturbance	Dental Abscess	Epistaxis	Eye Foreign Body	Gastritis/Reflux/ Esophagitis
Arthritis, Acute	BHP - Spaceflight Related Relationship Problems	Dental Crown Loss	EVA Related Decompression Sickness	Eye Irritation/Corneal Abrasion/Ulceration	Gastroenteritis/ Acute Diarrhea
Atrial Fibrillation/ Atrial Flutter	Burn - Chemical Eye	Dental Filling Loss	EVA Related Dehydration	Eyelid And Anterior Eye Infection	Glaucoma, Acute Angle-Closure

Step 1- IMPACT v1.0 Condition List

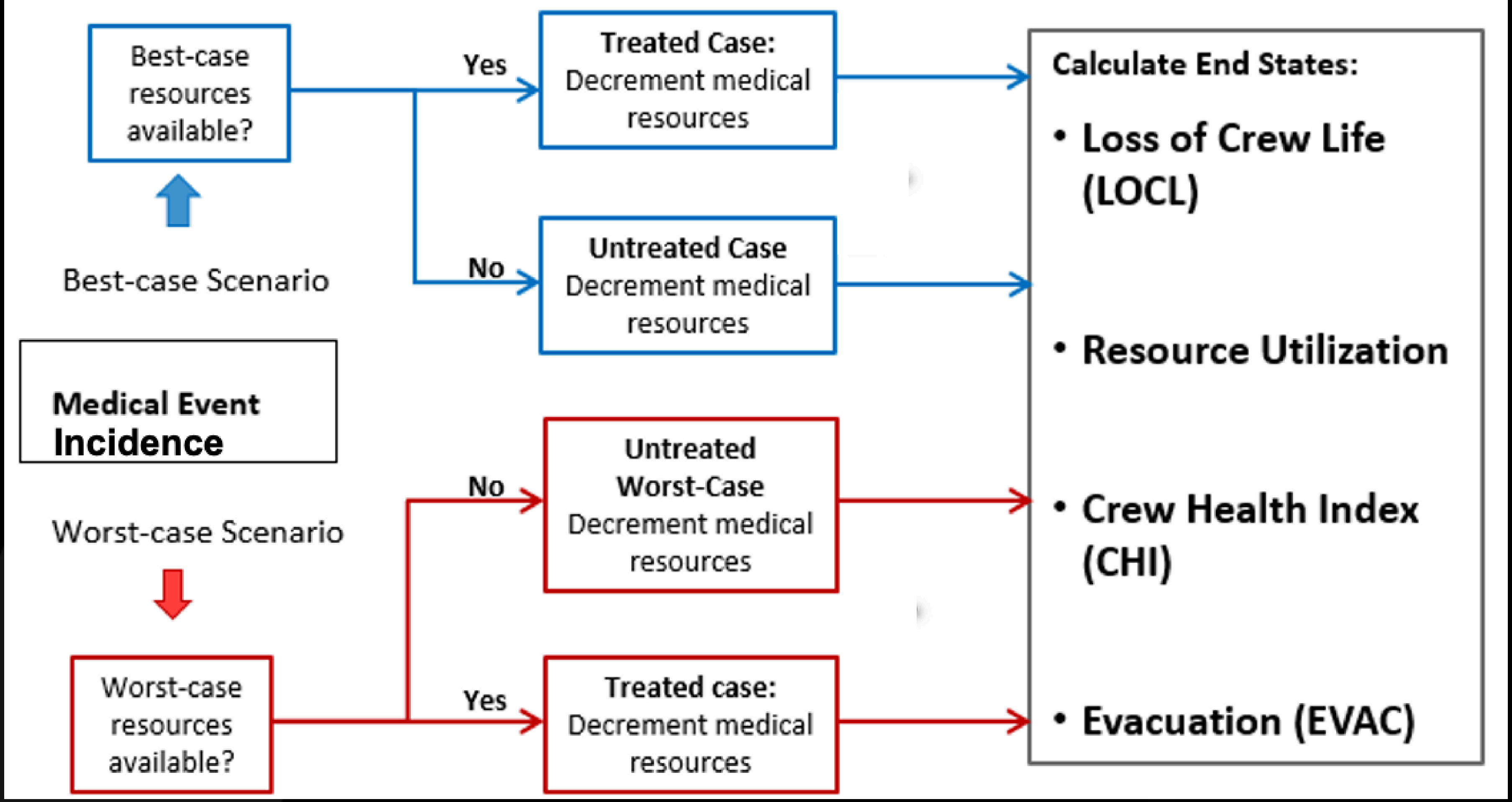
Gravity Well - Entry Motion Sickness	Nephrolithiasis	Respiratory Failure	Small Bowel Obstruction	Spaceflight Associated Neuro-Ocular Syndrome (SANS)	Toxic Inhalation Exposure
Gravity Well – Neurovestibular Disturbance	Neuropathy - Central, Impingement Related	Respiratory Tract Infection - Lower	Space Adaptation - Back Pain	Sprain/Strain - Back	Toxic Inhalation Exposure - Combustion Products
Gravity Well - Orthostatic Intolerance	Otitis Externa	Respiratory Tract Infection - Upper	Space Adaptation - Constipation	Sprain/Strain - Lower Extremity	Trauma - Abdominal Injury (Blunt)
Headache	Otitis Media	Seizures	Space Adaptation - Epistaxis	Sprain/Strain - Neck	Trauma - Chest Injury (Blunt)
Headache - Co2 Induced	Pancreatitis, Acute	Sepsis	Space Adaptation - Headache	Sprain/Strain - Upper Extremity	Trauma - Minor Head
Hearing Loss	Pregnancy, First Trimester	Shock - Cardiogenic	Space Adaptation - Insomnia	Streptococcal Pharyngitis	Trauma - Severe Head
Hearing Loss - Noise-Related	Pregnancy, Risk For	Skin Abrasion	Space Adaptation - Nasal Congestion	Sudden Cardiac Arrest	Traumatic Hypovolemic Shock
Hemorrhoids	Prostatitis, Acute	Skin Infection - Bacterial	Space Adaptation - Space Motion Sickness	Tendinopathy/Enthesopathy/Bursitis/Over-Use Injuries - Lower Extremity	Urinary Tract Infection
Herpes Zoster Reactivation (Shingles)	Rash, Spaceflight Associated	Skin Infection - Viral/Fungal	Space Adaptation - Urinary Retention	Tendinopathy/Enthesopathy/Bursitis/Over-Use Injuries - Upper Extremity	Vaginal Yeast Infection
Mouth Ulcer	Reactive Airway	Skin Laceration	Space Adaptation - Urinary Incontinence	Toxic Dermal Exposure	Venous Thromboembolism

Step 2 – Gather data and build the model

1. Spaceflight data
2. Analog data
3. Modeling predictions (e.g. ISS fire model)
4. Terrestrial conditions- keywords/MeSH terms of databases using ***Rapid Systematic Review-*** search for data is sufficiently broad and deep to capture the most relevant literature, ***but not exhaustive****

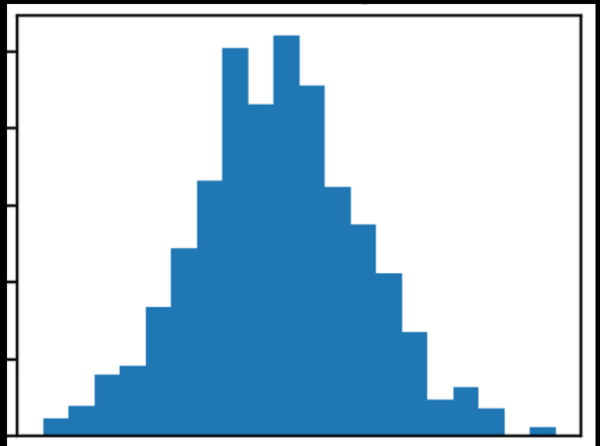
*Tricco AC, Antony J, Zarin W, et al. A scoping review of rapid review methods. *BMC Med* **13**, 224 (2015). https://doi.org/10.1186/s12916-015-0465-6

Step 3 - Probabilistic Risk Assessment

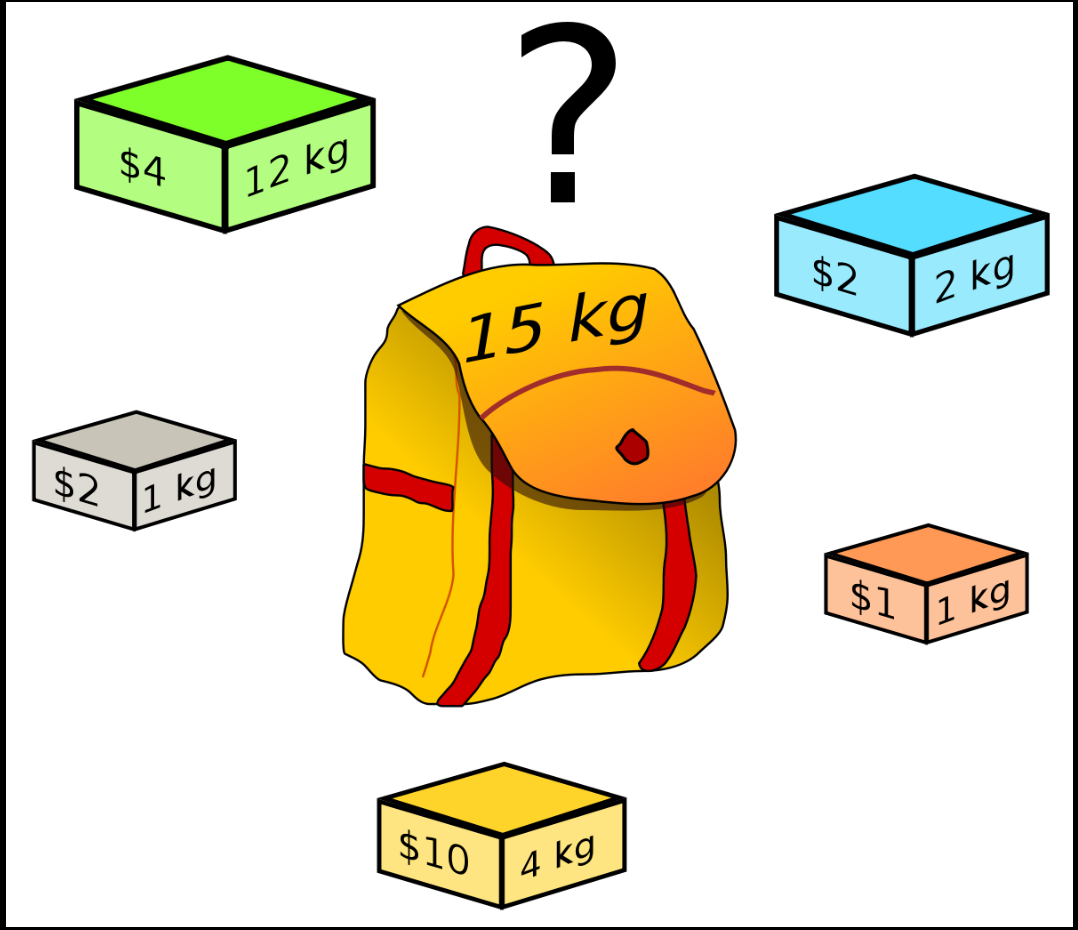


x100,000 Monte Carlo simulations

LOCL



Step 4 – Optimize (The Backpack Problem)



- Optimization problem
- Maximize value subject to constraints
- Question: what combination of blocks yields the most money but does not exceed the weight limit?

Why do we need a computer to do this?

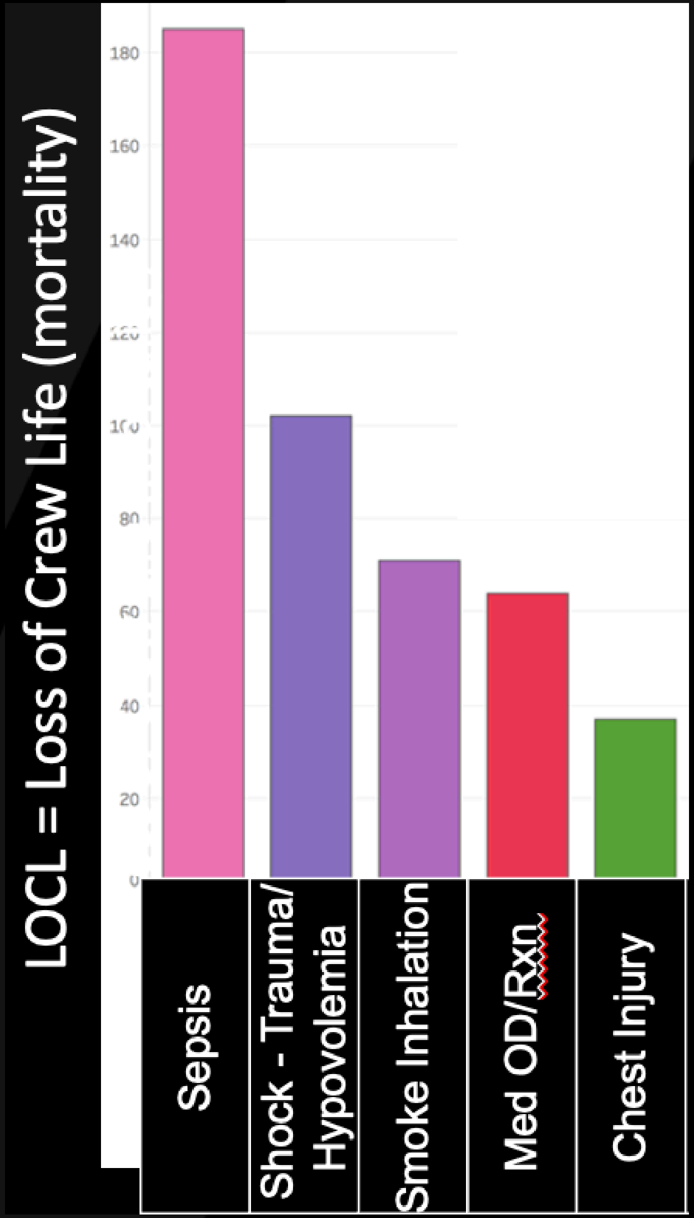
So many variables!

- Dependent Variables
  - Loss of Crew
  - Loss of Mission
  - Quality of Life
  - Long Term Health
- Independent Variables
  - Literally anything we use in medicine
- Constraints
  - Mass, volume, power, data, skills, training

So many questions!

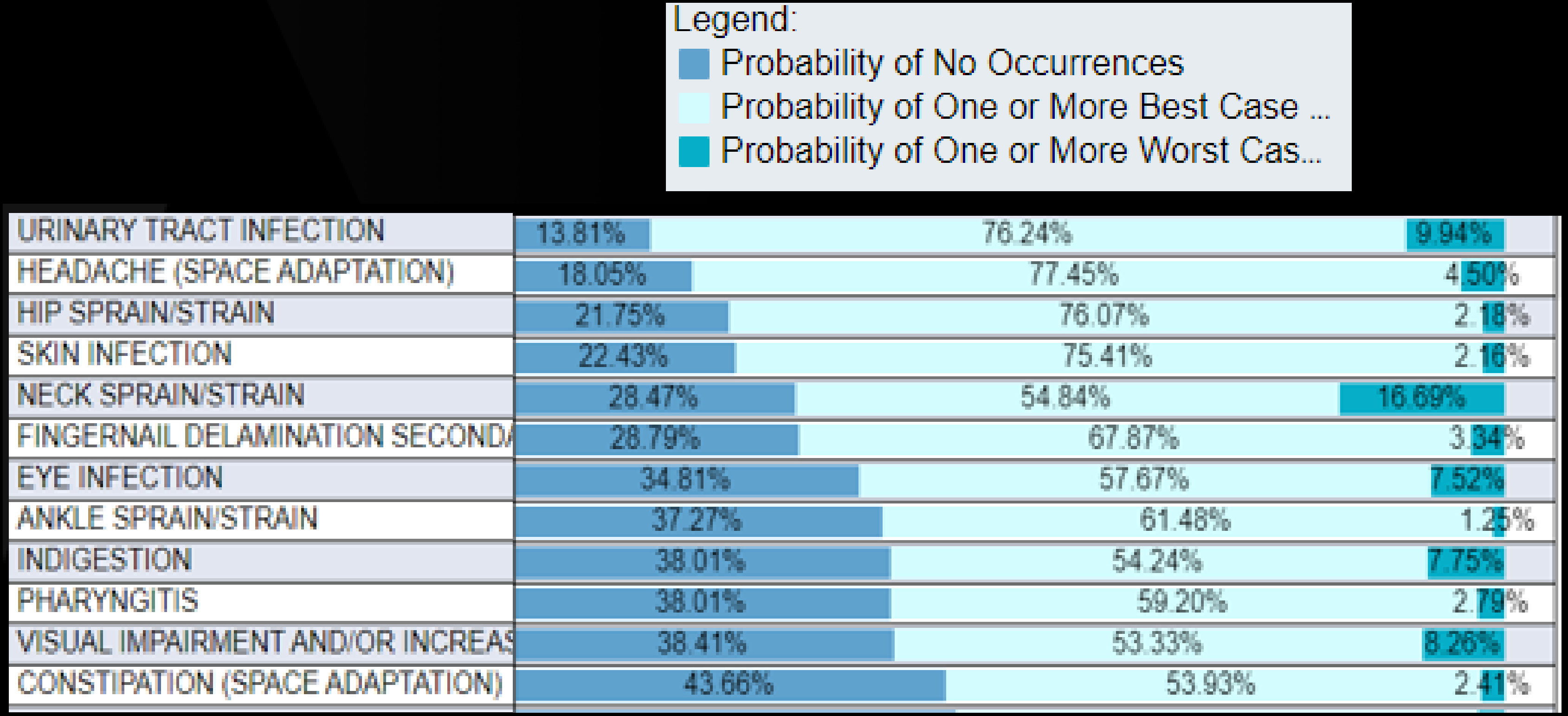
- *What if the mission is extended by 6 months?*
- *What if mass allocation lowers by 25%?*
- *Which imaging technology is most useful? Ultrasound or X-ray?*
- *What is the risk of reducing crew's water rations from 3L to 2L daily?*
- *If I can reduce the mass/volume of a CT by 50%, would it make the cut to fly in space?*

Sample results: Condition Occurrence (Notional)



As a Flight Surgeon/Medical Operations

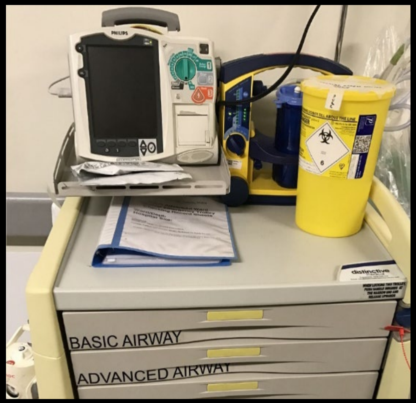
- **I want to: Determine the occurrence probabilities of medical conditions for a specific mission and crew**
- **So that I can: appropriately scope the medical system and determine which conditions to design around**



Sample results: Create risk vs. mass allocation curves

As a: Medical systems engineer

- I want to: Plot Loss of Crew Life (LOCL) vs. mass or volume
- So that I can: Understand how medical risk changes with changes to medical system mass allocation



System Characteristic	Without Airway Equipment	With Airway Equipment	Delta
Mass (kg)	106.6	115.2	+8.6 kg
Prob of Loss of Crew	0.61%	0.57%	-0.04%
Prob of Evacuation	10.1%	9.99%	-0.11%
Crew Health Index	92.8%	92.9%	+0.1%
Requirements Met	-4	0	+4
Conditions Addressed	-32	0	+32

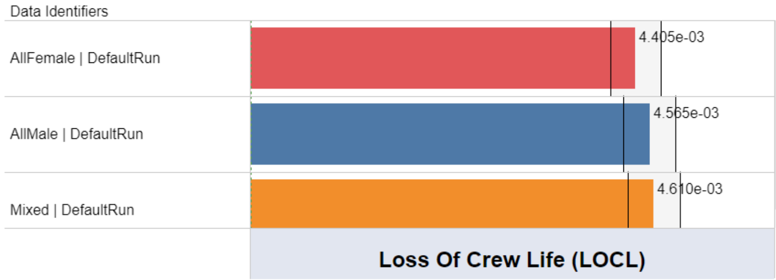
These data are notional only

Sample results - Mission/crew trades (notional)

As a Mission manager

- **I want to: Use IMPACT to predict how changing the mission parameters (e.g. duration, crew attributes) affects overall medical risk**
- **So that I can: Make decisions regarding mission parameters while considering medical risk *<u>among other factors</u>***

Crew Composition – Male/Female



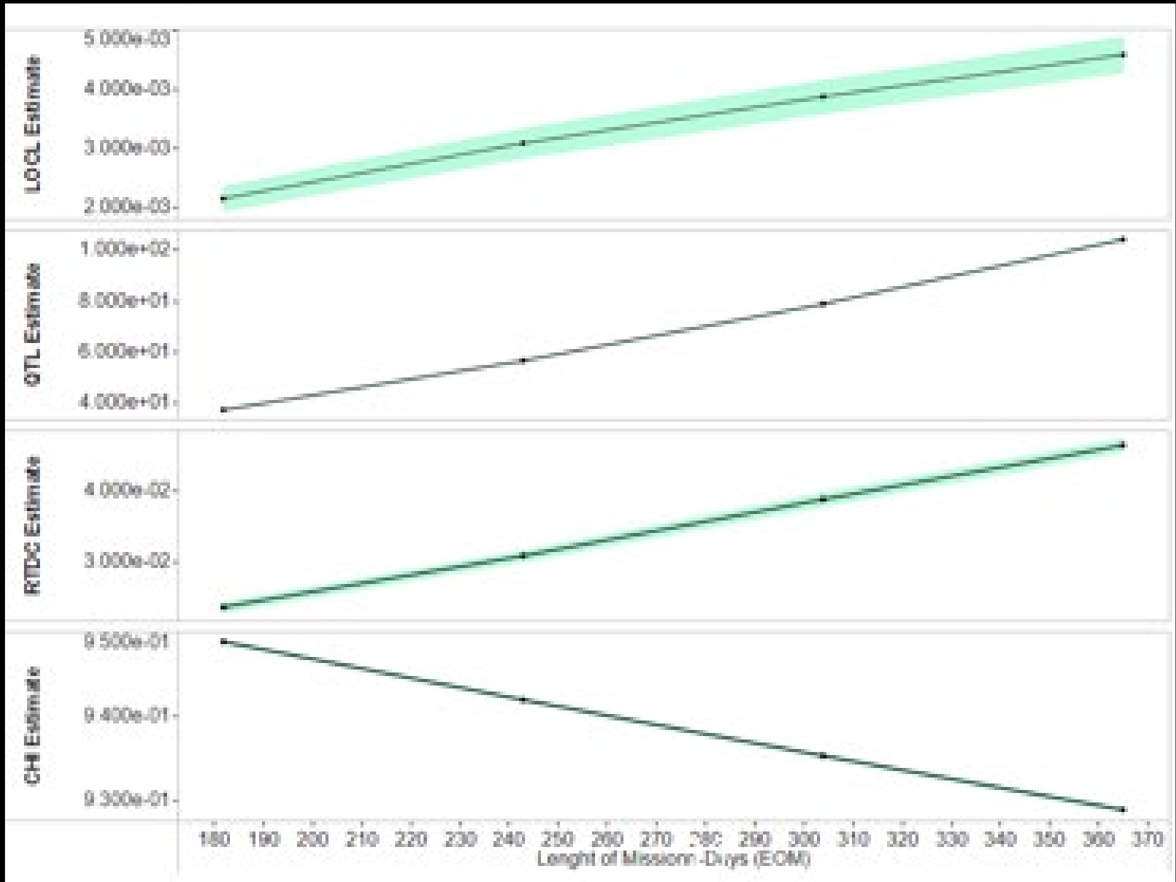
Risk vs. Mission Duration

Loss of Crew Life

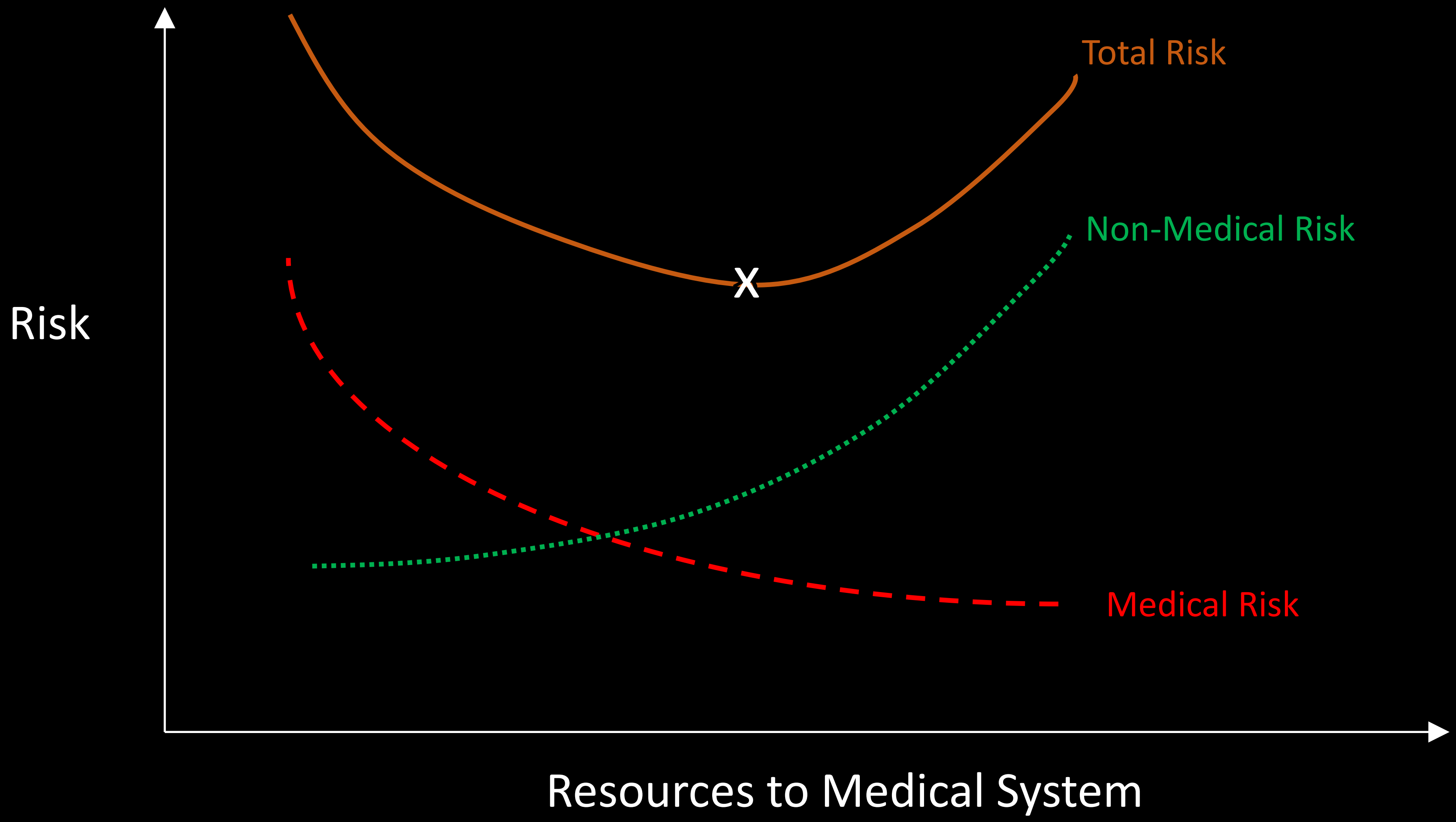
Task Time Lost

Evacuation Risk

Crew Health Index



Minimizing *Medical* Risk is NOT the Goal



Notional

Conclusions

- We need a ***quantitative*** method to estimate medical risk for exploration missions
- IMPACT has sophisticated ***trade space capabilities*** that can help inform how trading medical capabilities affects risk
- NASA plans to start using IMPACT for medical risk modelling at end of 2023
  - Use by international partners and commercial providers is in discussion

Bottom Line Up Front

- With the delivery of this LDLOLS Foundation, ExMC believes that we have:
  - Established a **systematic and repeatable medical system design process** that combines **clinical and systems engineering inputs** to enable the integration of medical capabilities into exploration vehicle design and mission planning
  - Developed a medical system ConOps, clinical condition/capability/resource sets, and **traceable, evidence-based requirements**
  - Generated medical system recommendations that are applicable to **sustaining/extended phase Artemis** missions and **Mars Transit Hab**

Agenda

- Part 1 – Motivation, The LDLOLS DRM, Approach
- Part 2 – Technical Content of the Medical System Foundation
- Part 3 – Potential Use Cases, Reviews, Forward Work

Motivation Behind this Effort

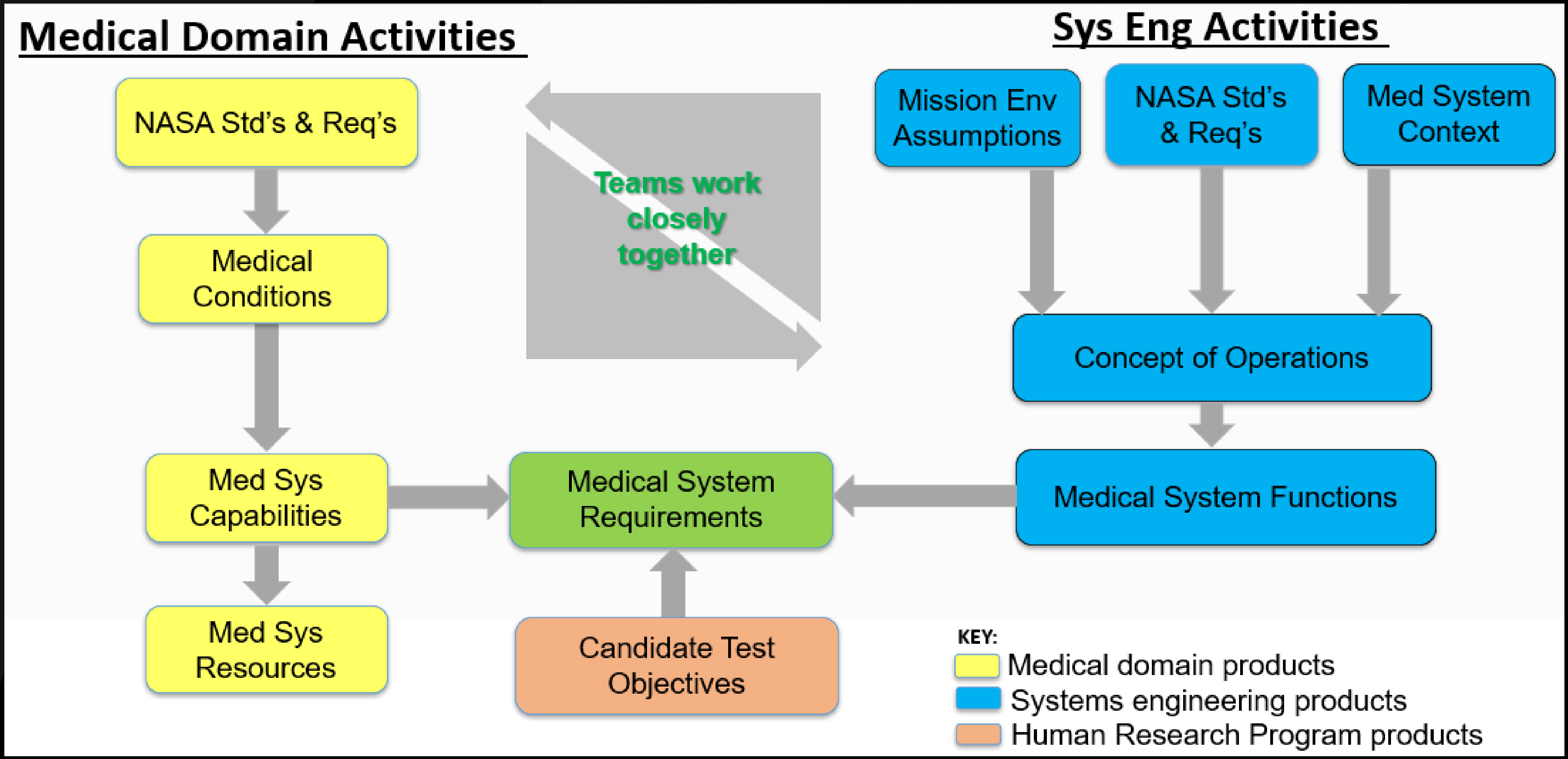
- How will the provision of medical care change for deep-space, long-duration exploration missions?

- How can ExMC help to facilitate communication among exploration program managers, engineers, and clinicians?

- Identified need to:
  - Assist in the development of evidence-based medical system **requirements** and their rationales
  - Enable **traces** among requirements, medical capabilities, medical conditions, and medical resources.
  - Advance and refine the medical **system architecture** for future mission planning.
  - Present information in an easily accessible format that is **understandable** across disciplines.

What is the LDLOLS Medical System Foundation?

- A process of integrating clinical and systems engineering inputs to generate recommendations for medical system design



ExMC's Approach

- We followed the same robust process that ExMC created for the Short Duration Lunar Orbital Foundation presented in 2020.
- All LDLOLS model content was developed by a multidisciplinary team (e.g., clinicians, scientists, and engineers from ExMC, SD, SF, ARC, GRC, LaRC)
- Employ systems engineering principles (similar to other vehicle systems) and use a model-based systems engineering (MBSE) approach to capture information
  - MBSE recognized by the Office of the Chief Engineer as **best practice** for system design and is consistent with the use of digital architectures by Exploration Programs
  - MBSE makes it easy to determine how changes to high level assumptions or requirements lead to changes in the medical system architecture
  - Enable users to visualize the medical system functions, conditions, capabilities, and resources and understand how they all trace to medical system recommended requirements.
    - Assess the impact of removing resources via traces to functions/capabilities/conditions.
    - Identify medical requirements that may need to be levied on other vehicle systems.
- In FY23, this LDLOLS Foundation model will be updated to align with the current 3001 versions (which removed Levels of Care):
  - 3001 Vol 1 Rev B Change 1
  - 3001 Vol 2 Rev C

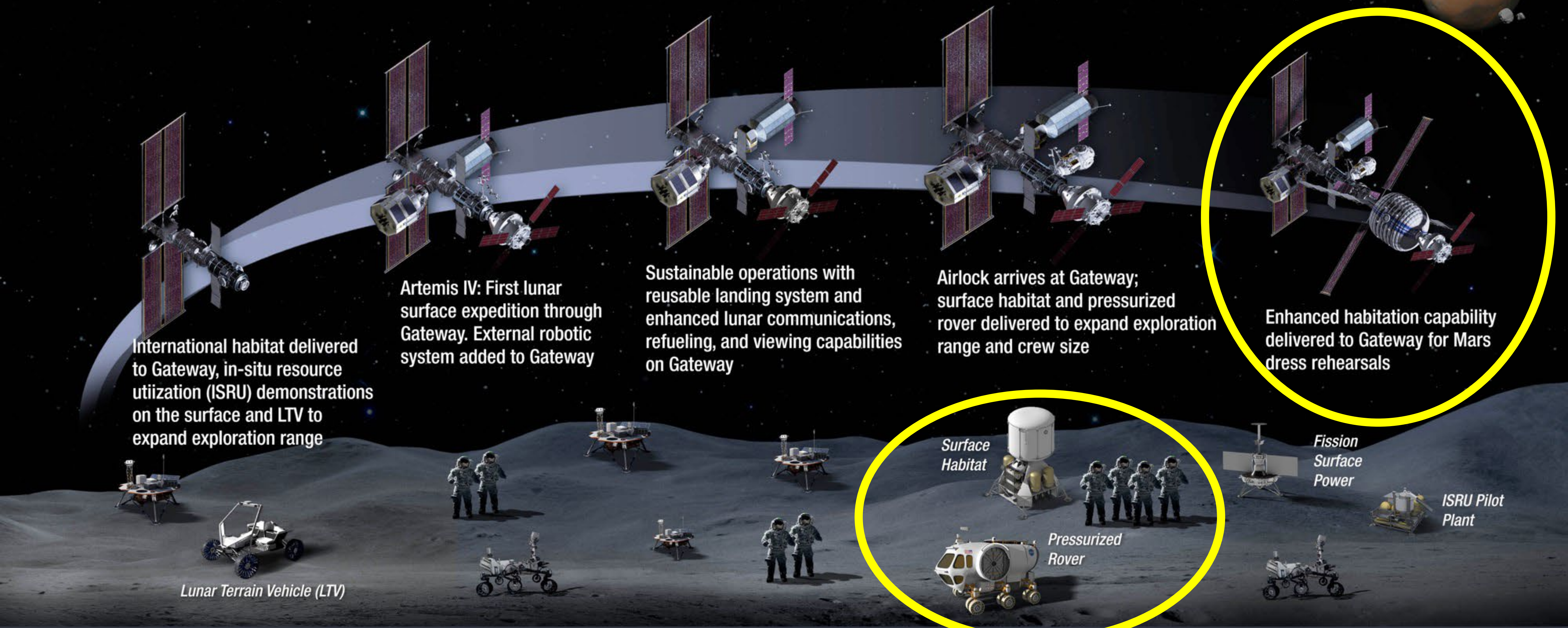
LDLOLS Foundation Outputs

- Principle Components of the Foundation
  1. A **Concept of Operations** baselined to deep space, long-duration exploration missions
  2. A corresponding **medical condition list, clinical capabilities set, and medical resource set**
  3. Recommended **medical system requirements**

- Intended to be a starting point (a “Foundation”) for early medical system design to build from and that can be tailored for specific missions

- In FY23, this LDLOLS Foundation model will be updated to align with the current 3001 versions (which removed Levels of Care):
  - 3001 Vol 1 Rev B Change 1
  - 3001 Vol 2 Rev C

ARTEMIS PREPARES FOR MARS



SUSTAINABLE LUNAR ORBIT STAGING CAPABILITY AND SURFACE EXPLORATION

MULTIPLE SCIENCE AND CARGO PAYLOADS | U.S. GOVERNMENT, INDUSTRY, AND INTERNATIONAL PARTNERSHIP OPPORTUNITIES | TECHNOLOGY AND OPERATIONS DEMONSTRATIONS FOR MARS

All contents represent notional planning and are for discussion purposes only

Why now? Transit Habitat Pre-Phase A work is happening now!

quests for medical syste … ments will be here soo


Assumptions Used for the LDLOLS Foundation

Parameter	Assumption
Crew composition	Four-person crew (at least 2 crew medical officers)
Mission duration	Total: ~ 9 months Lunar Orbit: 6 months Lunar Surface: 3 months
Location	Lunar orbit and Lunar South Pole
Target Level of Care	Level of Care IV, NASA-STD-3001 Volume 1, Revision A* *will be updated to current 3001 revision in FY23
EVAs	Lunar orbit (contingency only) Lunar surface (frequent, nominal EVAs on foot, with pressurized rover, with unpressurized rover)

Foundation assumptions align well with proposed HEOMD-004 requirement

HEO-R-29 Mars-Forward Validation. The NASA Human Spaceflight architecture shall enable the validation of Mars-like operations and utilization capabilities, including the extended mission durations and crew subjects given in Table HEO-R-29.

DRAFT

Table HEO-R-29 Mars-Forward Validation Durations

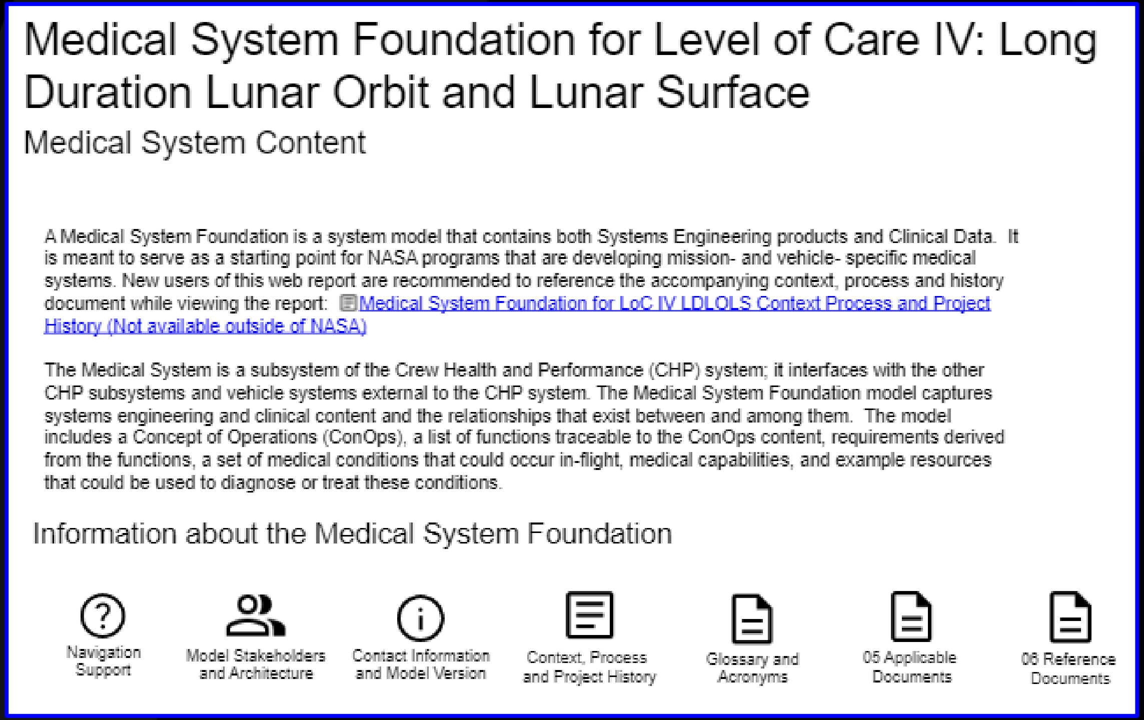
Extended Missions	Time in Microgravity Pre-Lunar Surface [days]	Time on Lunar Surface [days]	Additional Time Prior to Return to Earth Post-Lunar Surface [days]	Total Crew Sample Size [n]
Research and Development Testbed	45*-105*	32 Threshold/ 60 Goal	N/A	4-10
Extended Missions - Standard	120*-180*	32 Threshold/ 60 Goal	N/A	10-12
Extended Missions – Shakedown	360#* (TBR-HEOR-023)	32 Threshold/ 60 Goal	270* (TBR-HEOR-024)	4^

The Development and Review Process

- LDLOLS Foundation content was developed and reviewed iteratively by the ExMC Systems Engineering (SE) team and Clinical and Science Team (CST):
  - SE team is comprised of **systems engineers** from a variety of engineering and science backgrounds (e.g., systems, bio/biomedical, aerospace, mechanical, and human factors engineering).
  - CST is comprised of **ExMC and SD clinicians** such as pharmacists, nurses, and physicians (e.g., aerospace, emergency, internal, physical med & rehab, physician-astronaut) and provides clinical expertise and a spaceflight medicine knowledge base.

- The ExMC SE and CST teams followed all available NASA processes and best practices for Foundation development:
  - NPR 7123.1C – NASA Systems Engineering Processes and Requirements
  - JPR 7210.3C – Program/Project Management and Systems Engineering
  - SP 6105 rev2 – NASA Systems Engineering Handbook
  - Expanded Guidance for NASA Systems Engineering – Volume 1 and 2

Medical System Contents – High Level Organization



Medical System Foundation for Level of Care IV: Long Duration Lunar Orbit and Lunar Surface

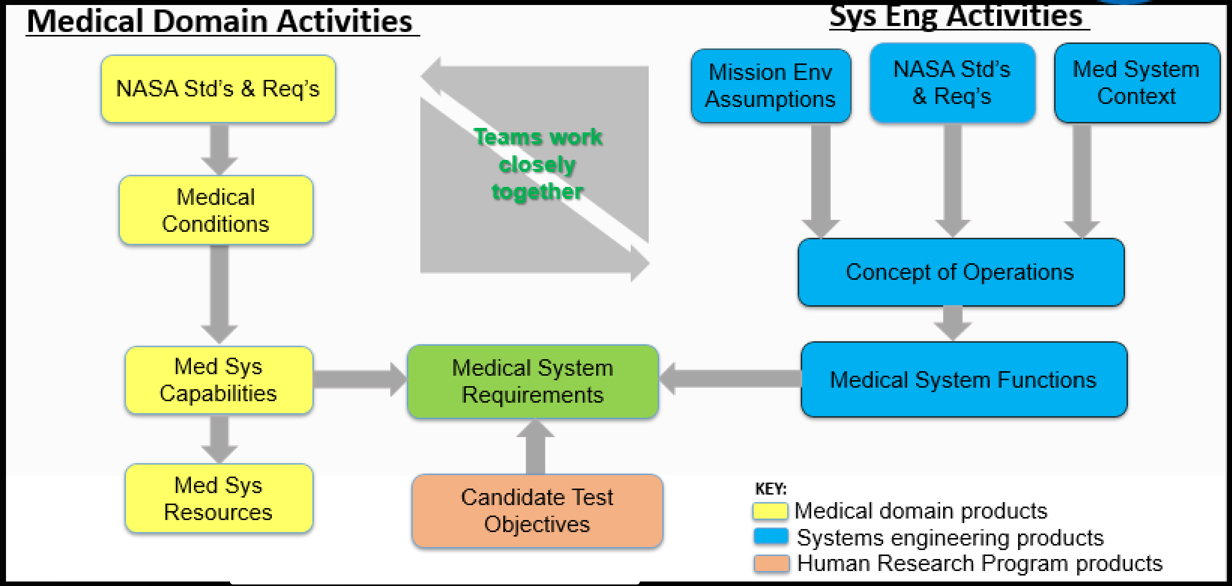
Medical System Content

A Medical System Foundation is a system model that contains both Systems Engineering products and Clinical Data. It is meant to serve as a starting point for NASA programs that are developing mission- and vehicle- specific medical systems. New users of this web report are recommended to reference the accompanying context, process and history document while viewing the report: Medical System Foundation for LoC IV LDLOLS Context Process and Project History (Not available outside of NASA)

The Medical System is a subsystem of the Crew Health and Performance (CHP) system; it interfaces with the other CHP subsystems and vehicle systems external to the CHP system. The Medical System Foundation model captures systems engineering and clinical content and the relationships that exist between and among them. The model includes a Concept of Operations (ConOps), a list of functions traceable to the ConOps content, requirements derived from the functions, a set of medical conditions that could occur in-flight, medical capabilities, and example resources that could be used to diagnose or treat these conditions.

Information about the Medical System Foundation

Navigation Support | Model Stakeholders and Architecture | Contact Information and Model Version | Context, Process and Project History | Glossary and Acronyms | 05 Applicable Documents | 06 Reference Documents



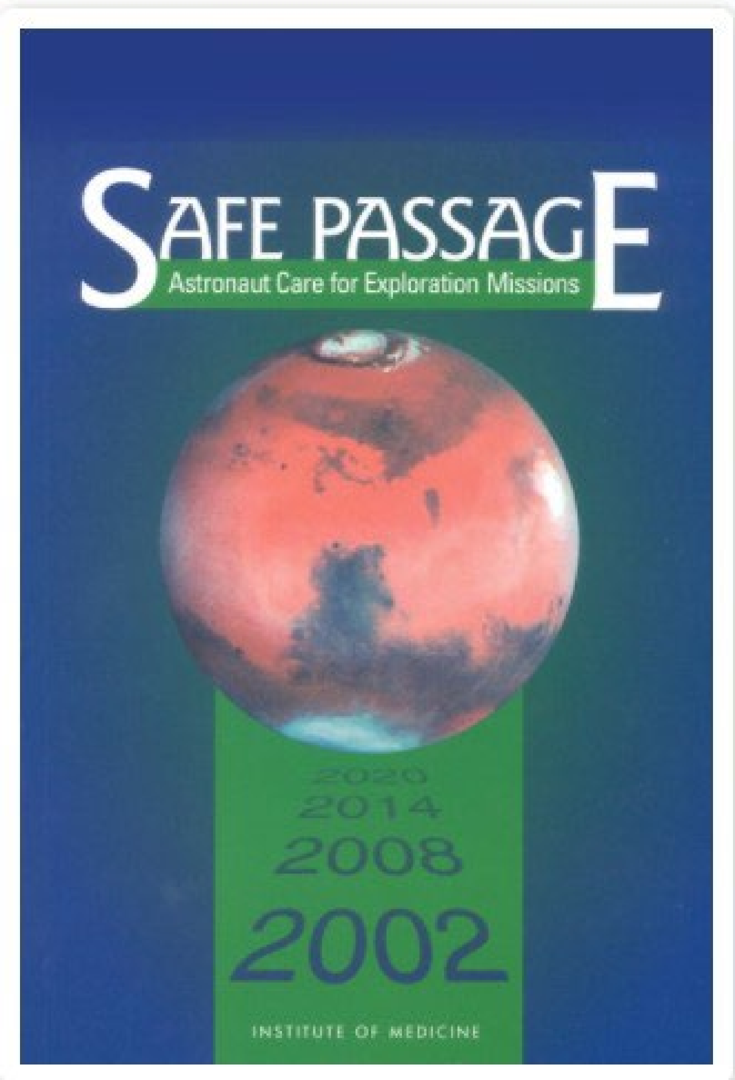
National Aeronautics and Space Administration

Questions?

jay.lemery@nasa.gov

Exploration Medical Capability

Why does the Medical Risk matter for exploration missions?



Human Exploration of Mars: Preliminary Lists of Crew Tasks

Autonomous Medical Care for Exploration Class Space Missions

Hamilton, Douglas MD, PhD; Smart, Kieran MD, MPH; Melton, Shannon BS; Polk, James D. DO; Johnson-Throop, Kathy PhD

Author Information

The Journal of Trauma and Acute Care Surgery

The Journal of Trauma: Injury, Infection, and Critical Care: April 2008 - Volume 64 - Issue 4 - p S354-S363

doi: 10.1097/TA.0b013e31816c005d