IMPACTing Medical System Design with a Risk Analysis Tool

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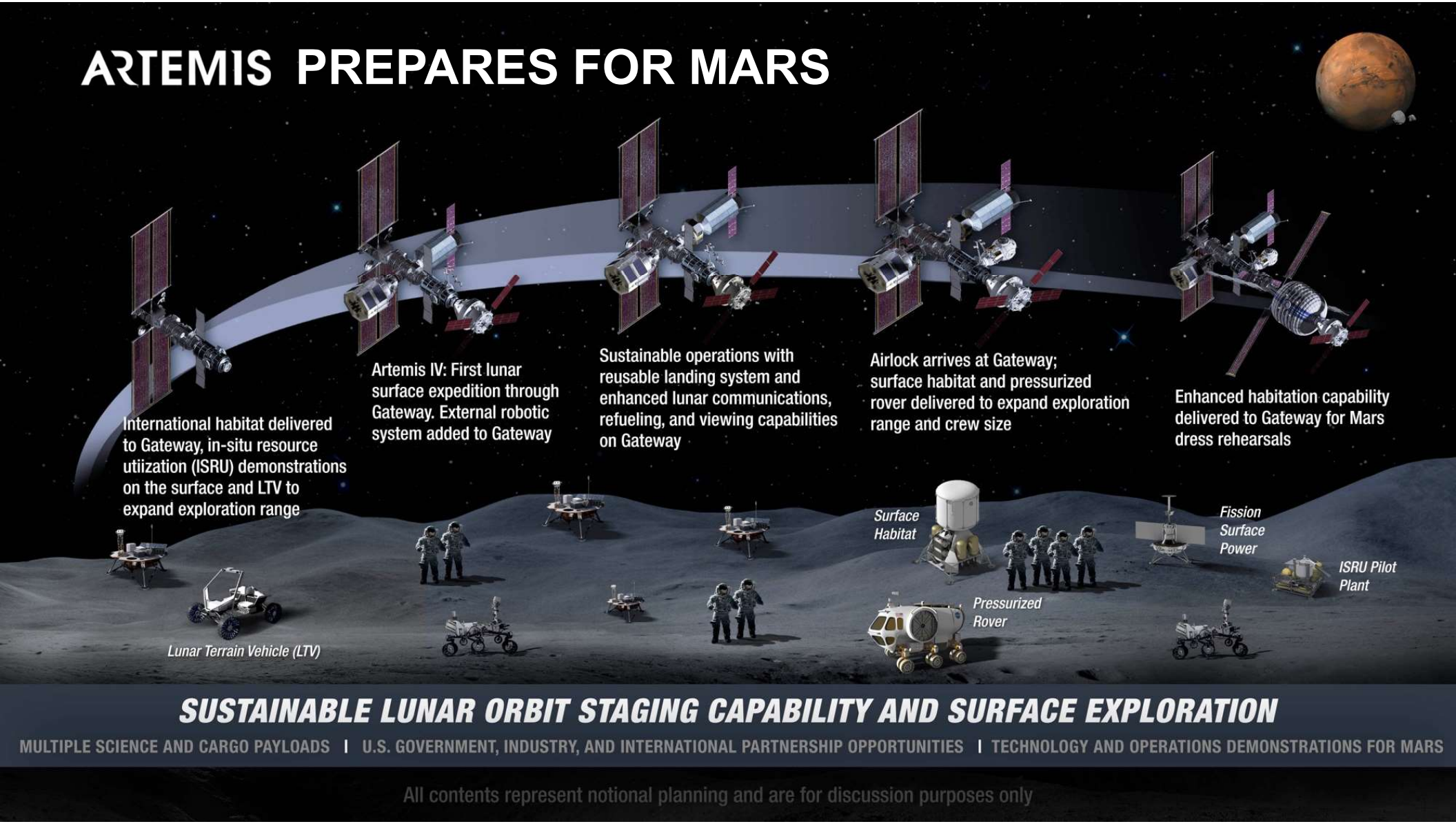
Exploration Medical Capability Element

Element Overview

The Exploration Medical Capability Element promotes human health and performance in space by advancing medical systems design and risk-informed decision-making for exploration beyond low Earth orbit.

The ExMC is one of FIVE research elements of the NASA Human Research Program.

Exploration Medical Capability


ARTEMIS PREPARES FOR MARS
International habitat delivered to Gateway, in-situ resource utiization (ISRU) demonstrations on the surface and LTV to expand exploration range
Artemis IV: First lunar surface expedition through Gateway. External robotic system added to Gateway
Sustainable operations with reusable landing system and enhanced lunar communications, refueling, and viewing capabilities on Gateway
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Lunar Terrain Vehicle (LTV)
Surface Habitat
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SUSTAINABLE LUNAR ORBIT STAGING CAPABILITY AND SURFACE EXPLORATION
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All contents represent notional planning and are for discussion purposes only

Medical System Design

- **Low Earth Orbit vs. Exploration Missions**
  - New challenges: Distance, Comm Latency, Resupply, Evacuation, Power/Volume/Mass, Crew Training

- **Ideal Medical System Design**
  - Quantitative, evidence-based estimates of medical risk
  - Systematically defines clinical capabilities
  - Determines best resources given constraints

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

Step 1 – Scope the System

- Determine medical conditions that are in scope or out of scope for system design (i.e. which conditions to plan around)
- **119 medical conditions** of greatest likelihood and consequence for exploration missions
- Nothing specific about that number – determined by schedule/resources

Reference HRP-48036, Rev A

Step 2 – Identify Inputs

- Spaceflight data
- Analog data
- Modeling predictions
- Terrestrial data

- **Incidence**
- **Best Case/Worst Case Definitions and probabilities**
- **Clinical Phase Durations (Diagnosis, Treatment, End State)**

PubMed.gov

Google Scholar

NTRS | NASA Technical Reports Server

Cochrane Library

DynaMed®

*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 2 - Identify Inputs

- **Capability:** skillset or action (e.g., deliver IV antibiotics)
- **Resource:** equipment, pharmaceutical, or skillset (e.g., 20g IV, interpret physical exam)
- **600+ capabilities and 800+ discrete resources in IMPACT**
- **Mission-specific Inputs**
  - Mission Duration, Destination, Crew Characteristics, EVA number and frequency

Step 2 – Define Outputs

Loss of Crew Life (events/mission)

- Likelihood of a crewmember's death during the mission

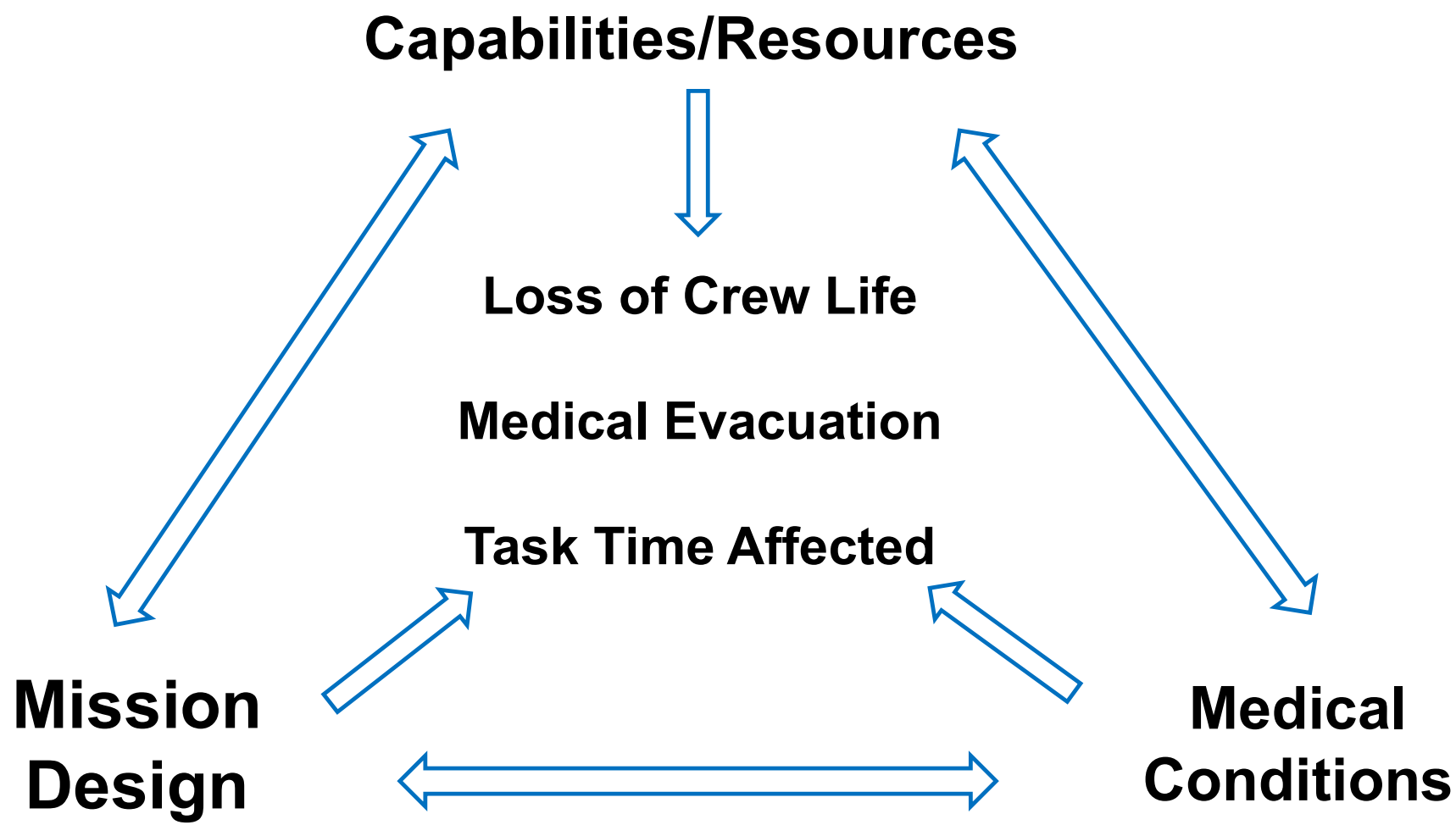
Medical Evacuation (events/mission)

- Likelihood of evacuation to higher level of care

Task Time Affected (crewmember-days)

- Crew time affected by medical condition

Step 3 – Generate Predictions with PRA



Step 4 – Optimize via Tradespace Analysis

- Goal: Minimize medical risk relative to constraints (e.g. mass, volume)

- Knapsack problem: What combination of blocks yields the most money but does not exceed the weight limit?

Source: https://miro.medium.com/v2/resize:fit:1400/1*3bZOzhhzAtmcYYc427m5Aw.png

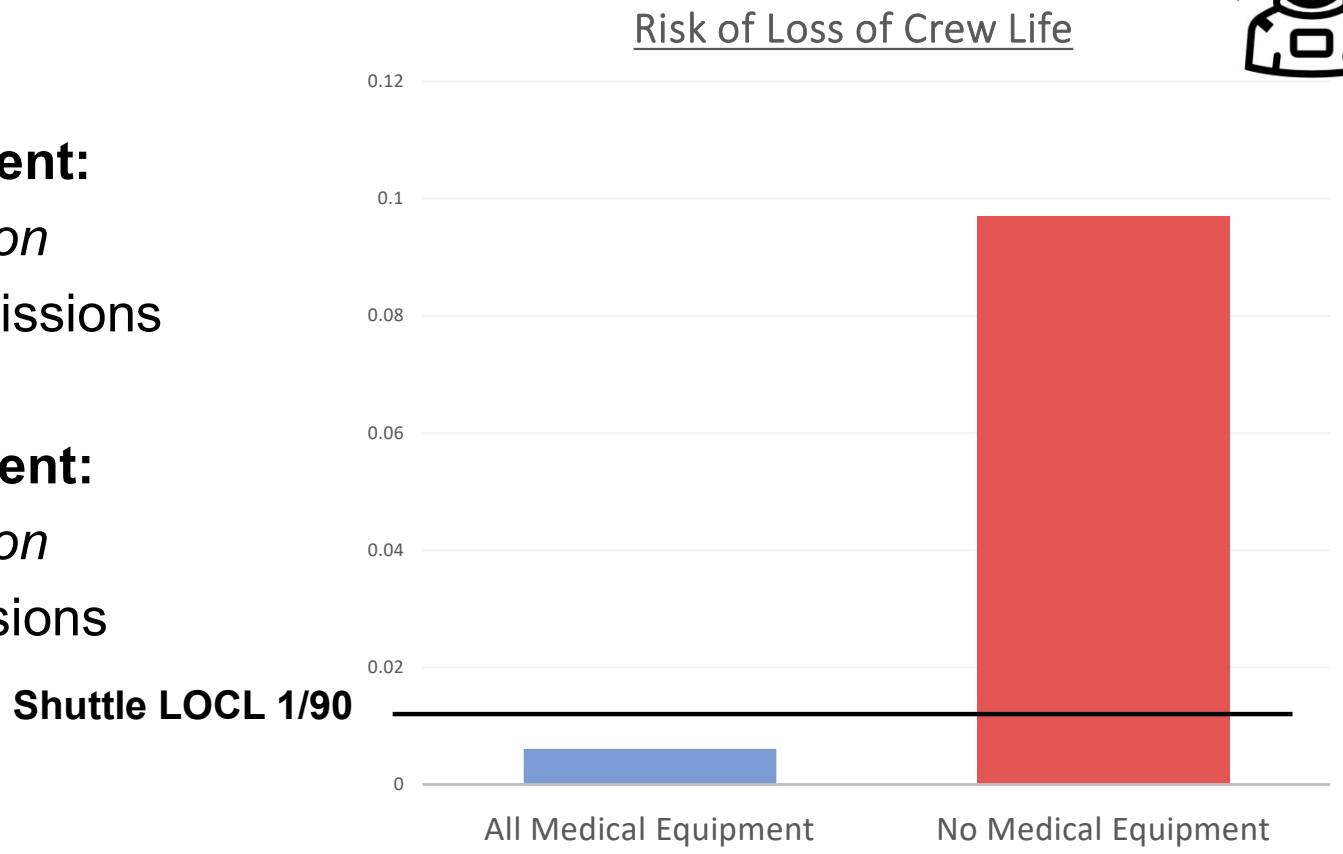
Notional Data for Current DRM

- **Design Reference Mission (DRM):**
  - Destination: Lunar orbit & surface with habitat
  - Four, healthy crew (2 male, 2 female)
  - Mission duration – 9 months, 6 days
  - 36 lunar surface EVAs

Notional Data Example

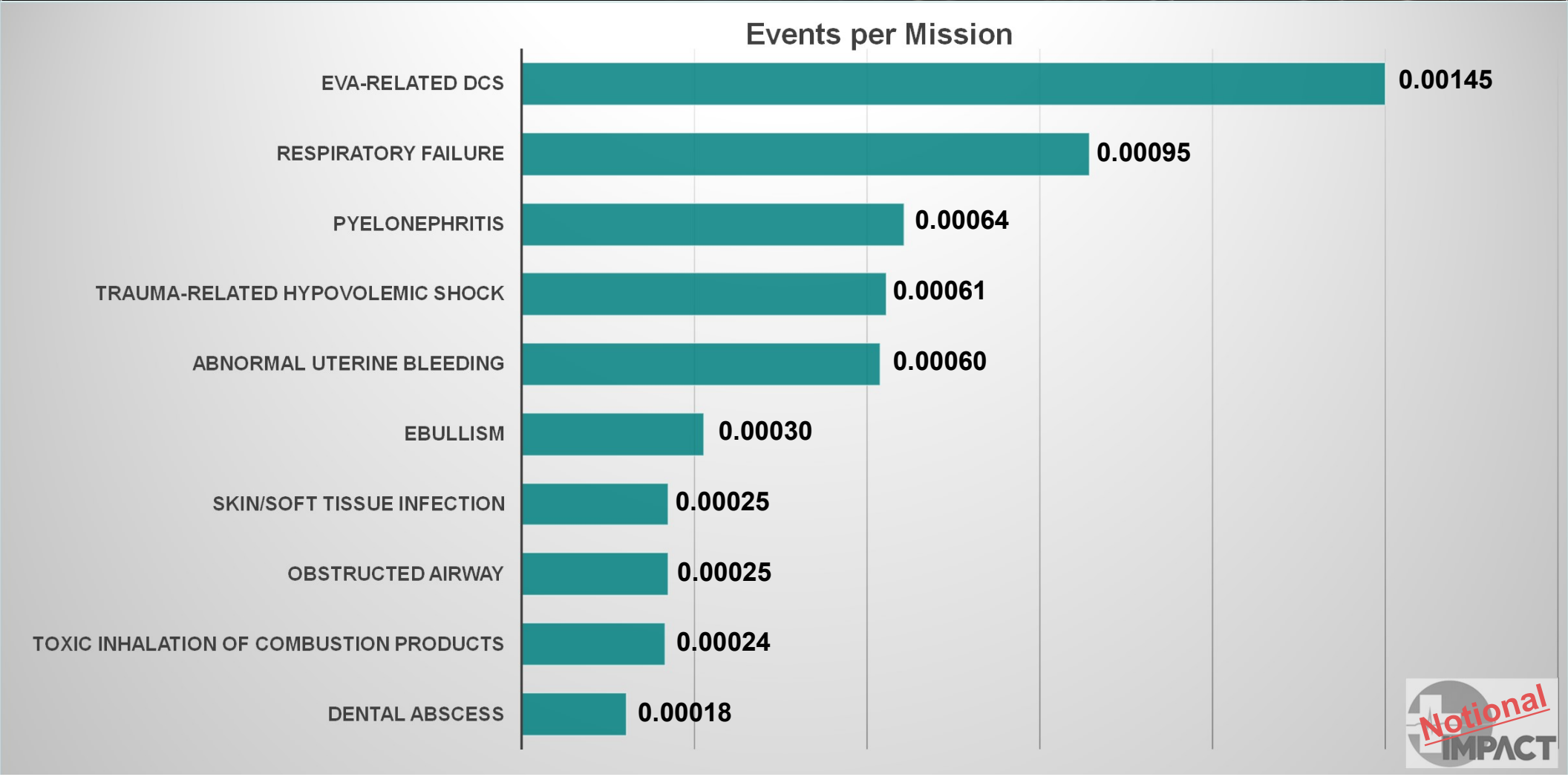
Loss of Crew Life

- **All Medical Equipment:**
  - *0.006 events/mission*
  - 6 deaths in 1000 missions
- **No Medical Equipment:**
  - *0.097 events/mission*
  - 1 death in ~10 missions

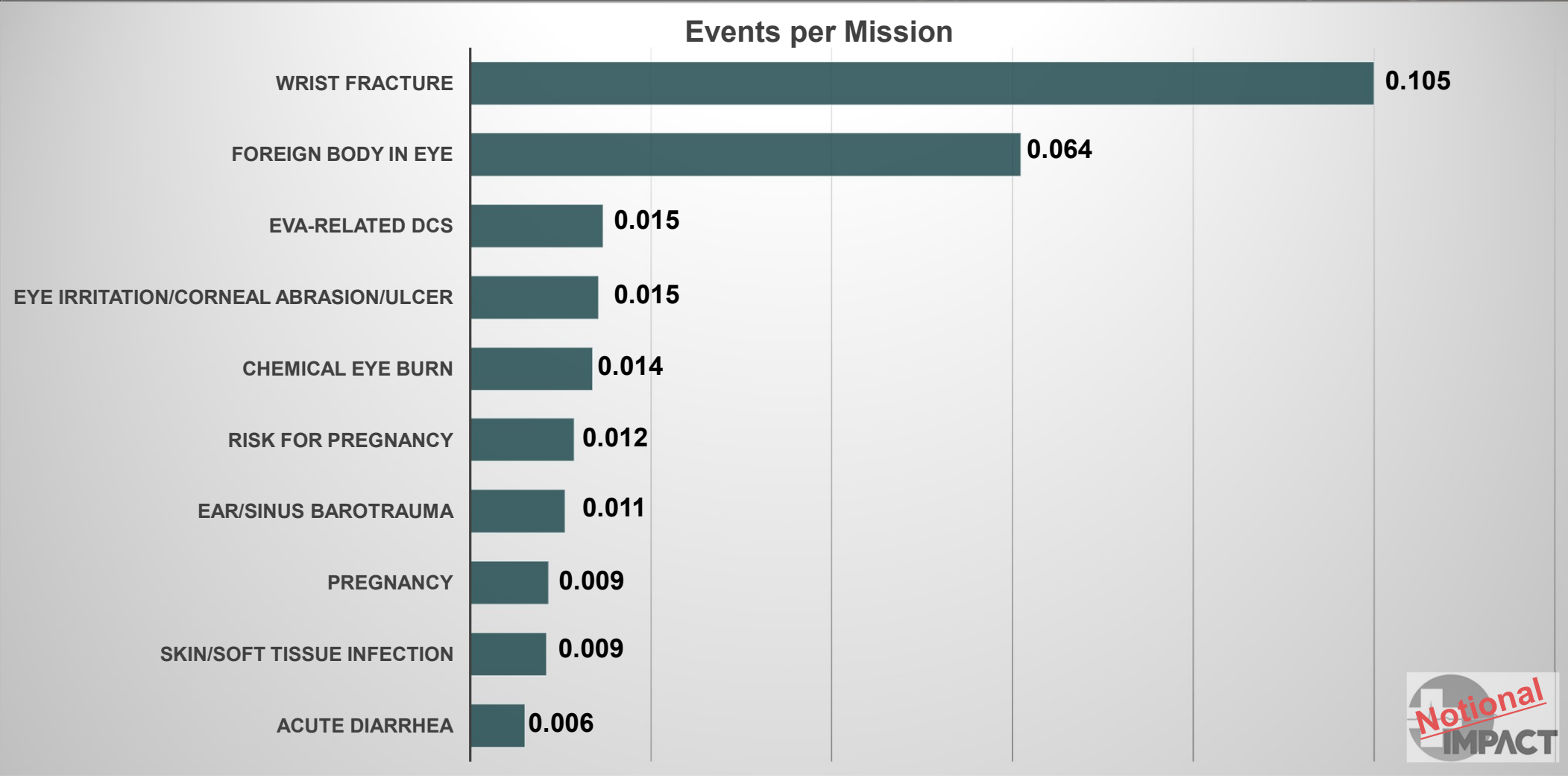


Notional

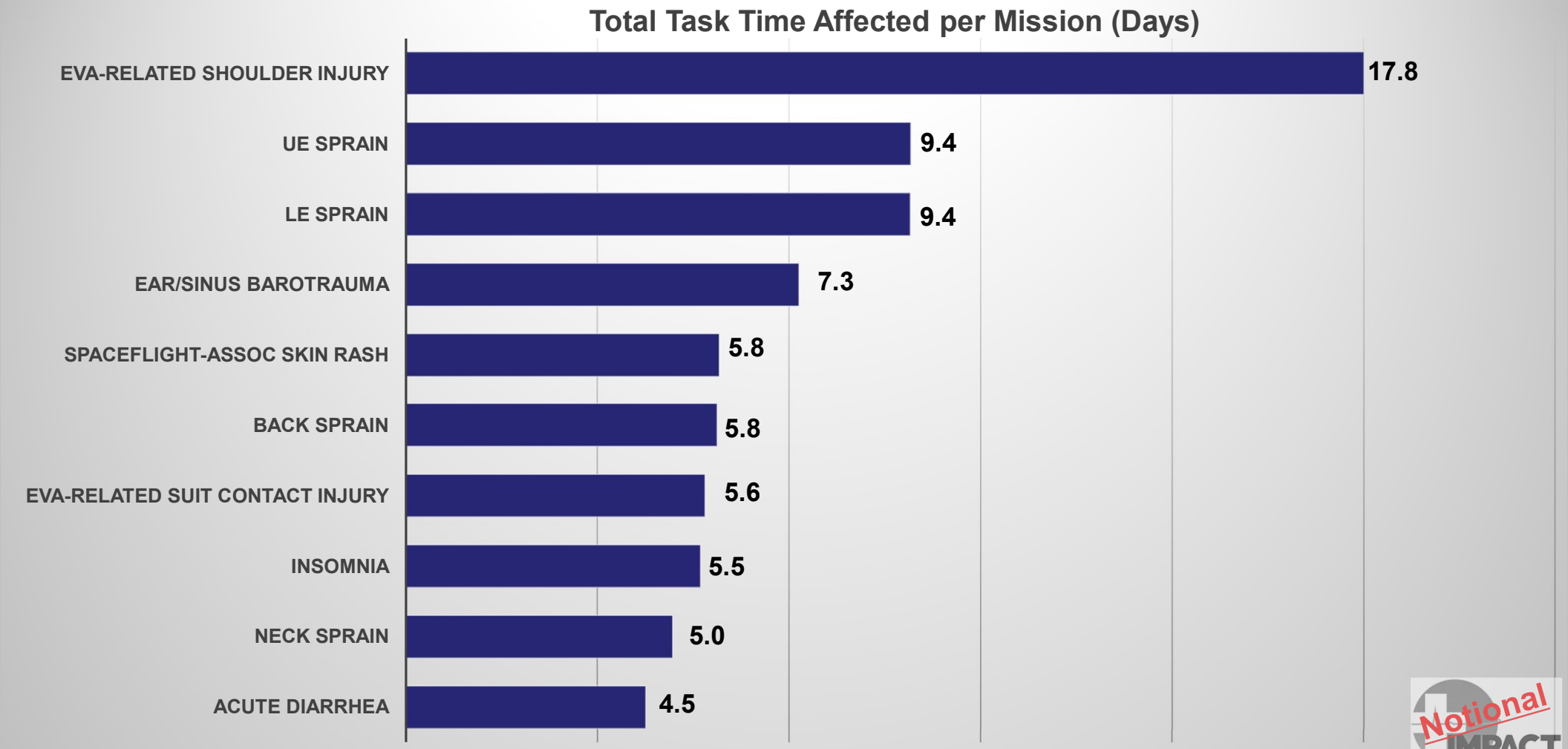
LOCL – Events Per Mission



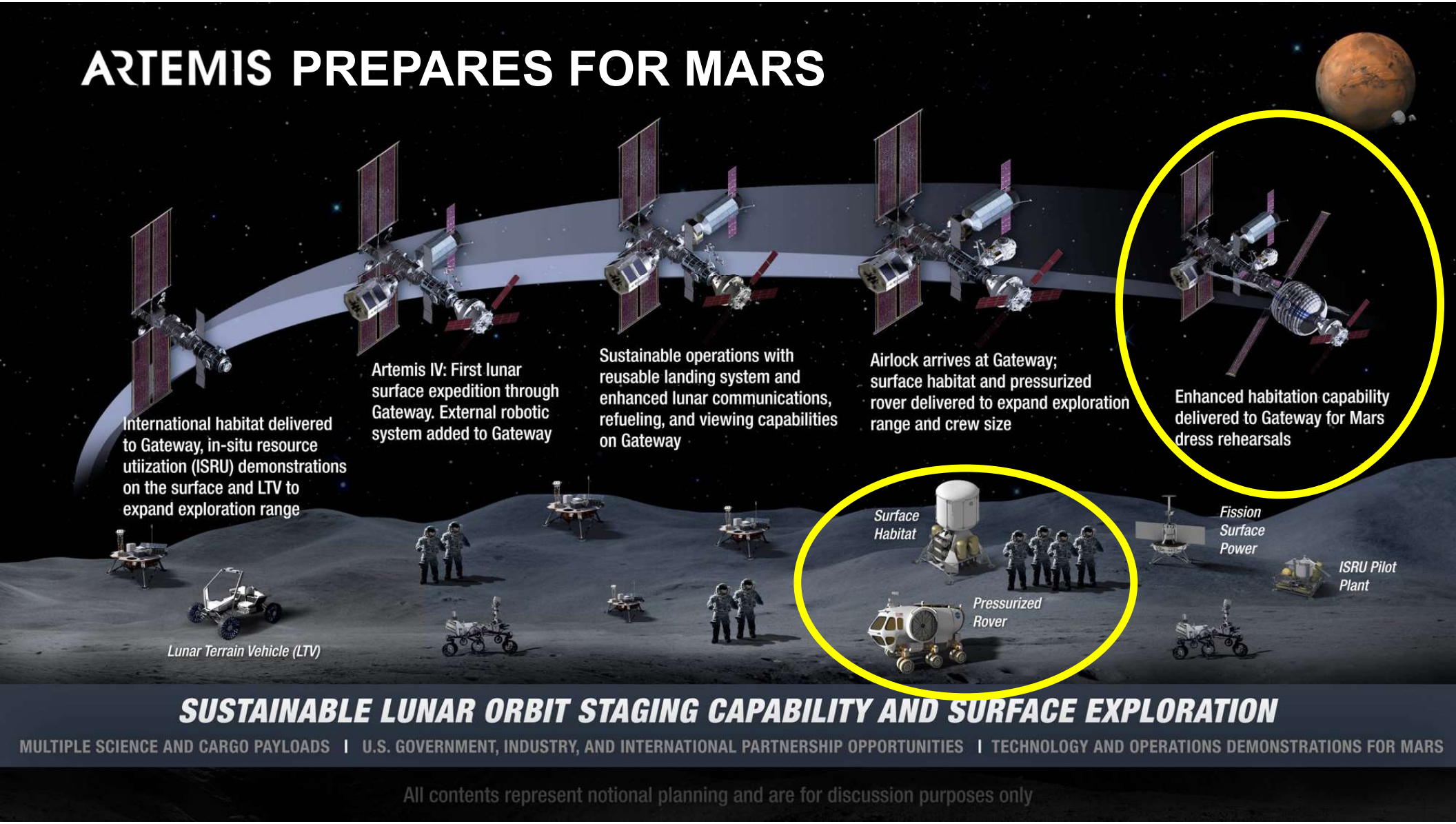
Consideration of MedEvac – Events/Mission



TTA – Crewmember Days per Mission



Notional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Thank you!

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“Expanding the Boundaries of Space Medicine and Technology”

BACK-UP/EXTRA SLIDES

AGENDA

- What is IMPACT
- How was IMPACT built
- IMPACT inputs & outputs
- Example of notional data
- Next Steps

Integrated Medical Model (IMM)

- **Current risk analysis tool for Low Earth Orbit Missions**

- **Limitations**
  - Considers only microgravity
  - No tradespace analysis capability
  - Heavy computational resources
  - Evidence base not updated since 2017

Step 2 – CRT example

Name	Best Case							Worst Case						
	Contribution	Necessity	Equivalence	Rank	Efficacy	Frequency	Quantity	Contribution	Necessity	Equivalence	Rank	Efficacy	Frequency	Quantity
CP1 - Interpretation - Ultrasound - MSK Absolute	100	0	0	0	100	N/A		100	0	0	0	100	N/A	
CP1 - Interpretation - Ultrasound - MSK	100	100	0	0	100	Event	1.00	100	100	0	0	100	Event	1.00
CP1 - Physical Exam - Vital Signs - Periodic Absolute								100	0	0	0	100	N/A	
CP1 - Physical Exam - MSK Absolute	100	0	0	0	100	N/A		100	0	0	0	100	N/A	
CP1 - Physical Exam - MSK	100	100	0	0	100	Event	1.00	100	100	0	0	100	Event	1.00
CP1 - Physical Exam - Neurologic Exam - MSK Absolute	100	0	0	0	100	N/A		100	0	0	0	100	N/A	
Medical Instrument - Reflex Hammer	100	100	0	0	100	Event	1.00	100	100	0	0	100	Event	1.00
CP1 - Physical Exam - Neurological - Focused Exam Absolute	100	0	0	0	100	N/A		100	0	0	0	100	N/A	
CP1 - Physical Exam - Neurological - Focused Exam	100	100	0	0	100	Event	1.00	100	100	0	0	100	Event	1.00

Mission Characteristics

Medical system:
- Mass
- Volume

Capabilities/Resources

Risk Metrics
- Loss of Crew Life
- Medical Evacuation
- Task time affected

IMPACT - Medical System Risk Analysis

Step 1 - Scope the System

Step 2 – Identify Inputs & Define Relevant Outputs

Step 3 – Generate Model Data via Computational Engine

Step 4 – Optimize via Tradespace Analysis

Extended Artemis Mission Duration

- **Mission Duration – 9 months, 6 days**
  - Earth orbit and outbound Lunar transit – 3 days
  - Lunar orbit on space station (Gateway) – 3 months
    - No microgravity EVAs
  - Lunar Surface with Habitat – 3 months
    - 36 Lunar surface EVAs (Alternating 2 crew every few days)
  - Lunar orbit on space station (Gateway) – 3 months
    - No microgravity EVAs
  - Return transit – 3 days

Step 3 - Generate Predictions with PRA

What is Probabilistic Risk Analysis?

- **Risk analysis method for complex engineered systems with many variables and complex interactions**
  - What can go wrong?
  - How frequently?
  - What are the consequences?

- **Probabilistic**
  - Uses historical data to inform possibility of events that have not yet occurred

Step 3 - Probabilistic Risk Analysis