Boots on the Moon
Incapacitated Crew Rescue (ICR) and Acute Injury

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Disclosure Information

92nd Annual Scientific Meeting

Marlei Walton

I have no financial relationships to disclose.

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

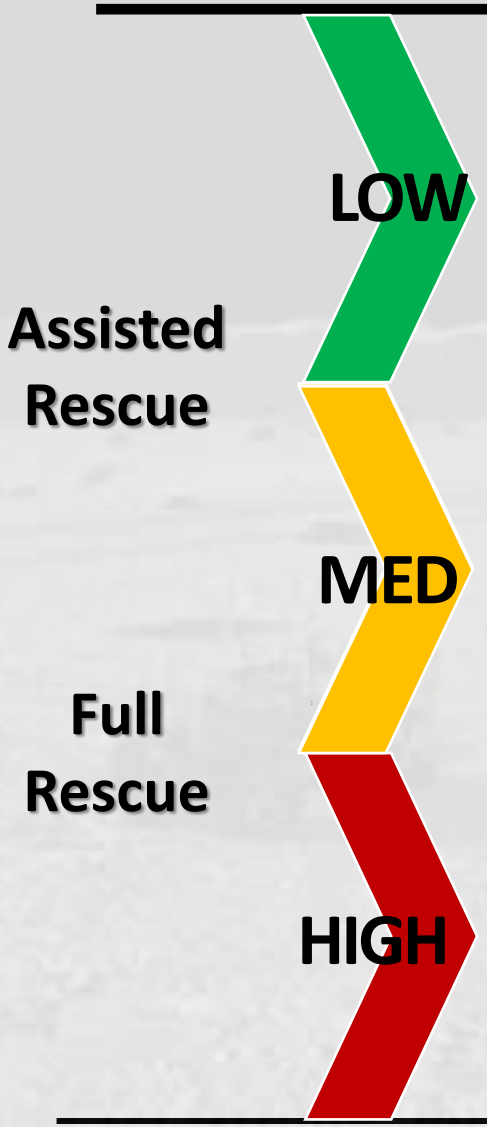
EVA Injury on the Lunar Surface

What are the credible causes of incapacitation, including organic problems and orthopedic injury due to falls, on a planetary surface?

Definitions

- **Credible cause**- an event or series of events leading to an incapacitated EVA crewmember that is
  - likely to happen based on past spaceflight data, or
  - is of SME concern to potentially happen based on past spaceflight and/or analog data
- **Organic problem**- medical event that may occur during EVA due to crewmember being human
- **Falls on planetary surface**- current considerations do not include details of HLS egress/ingress scenarios or rover designs

ICR/Acute Injury Scenario Definitions



Assisted Rescue

Crew help needed such that there is **temporary partial reliance** on other crewmember (*e.g.* to get up) or could get up by themselves (EVA continues)- *includes nominal falls*

Crew assistance needed such that there is **continuous partial reliance** on other crewmember for return to lander (EVA unplanned return)

Full Rescue

Incapacitation such that there is **continuous full reliance** on other crewmember for return to lander (EVA expedited unplanned return)

ICR/Acute Injury Spectrum

LOW
Help

Partial Reliance

MEDIUM
Assistance

Full Reliance

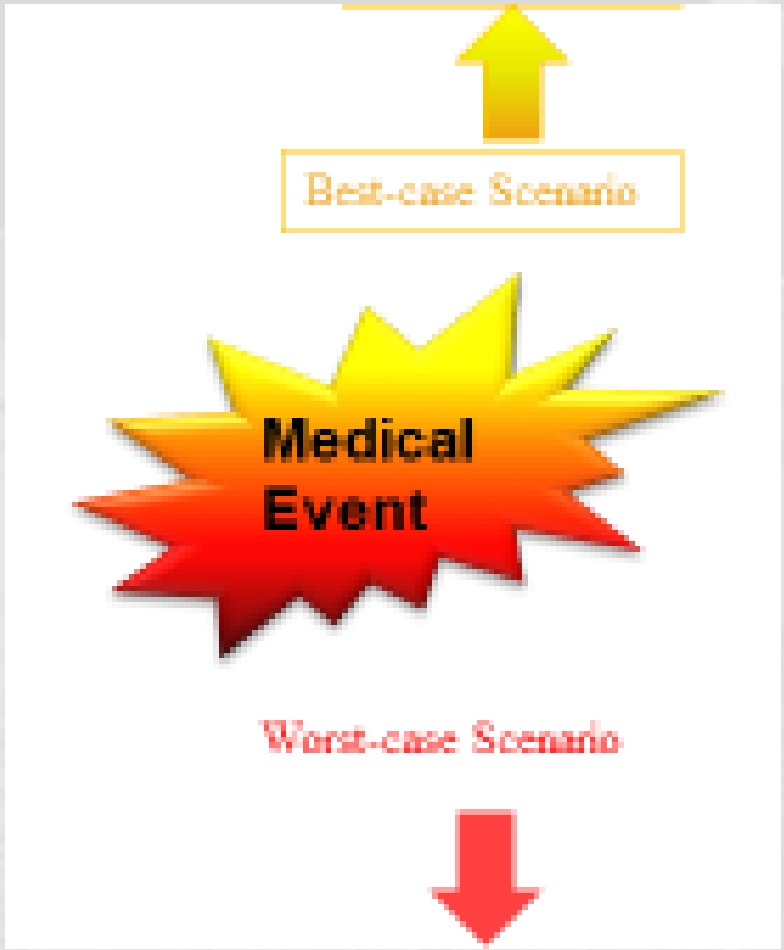
HIGH
Incapacitation

Help

Assistance

Incapacitation

Conditions- Best/Worst Case Scenarios



Boots on the Moon Drivers

Credible Causes of Incapacitation/Acute Injury

(Total conditions= 264 → Credible causes = 157 → ***Drivers= 54****)*

DRIVERS

LOW Help — Partial Reliance — **MEDIUM** Assistance — Full Reliance — **HIGH** Incapacitation

Help	Assistance	Incapacitation
24	22	8

Driver Data Caveats and Assumptions

- **Suit**: Not exploration EVA suit, not suited
- **Lunar surface**: Apollo, micro-g, terrestrial analogs
- **Population**: US/USOS astronaut, astronaut analog, general population
- **Fall data not quantified**: not a medical condition per se
- **Incidence, Probability**: assumed all driver conditions are completely independent (no consideration of correlating conditions or prior EVA events)

Analysis Caveats and Assumptions

- Data analysis does not link directly to outcomes/mission impacts
  - No consideration of EVA-specific tasks (*e.g.* longer walkback versus shorter-range geology)
  - No integrated risk priority/hierarchy of probability thresholds and ICR spectrum categorization
  - ICR = acute injury- *e.g.* no account of cumulative (minor) injury → mission limiting injuries for subsequent EVAs *(Suited Injury Risk Matrix)*
- Probabilities associated with early Artemis mission, not individual EVA

Early Artemis Mission Assumptions (Probability)

- **ONLY lunar surface EVA**
- No lunar transport vehicle (LTV), pressurized rover (PR)
- Generic Human Landing System (HLS)
- Medical diagnostic and treatment resources not considered
- Max back-to-back EVAs =2
- Suit capable of single rescuer assisted doff of incapacitated crewmember (assumes self-doff suit capability)

EARLY ARTEMIS DESIGN REFERENCE MISSION (DRM)
(Used for probability calculations)

Two crew members on each EVA:

Artemis 3 EVA 1 (6 hr)

Artemis 3 EVA 2 (6 hr)

Artemis 3 EVA 3 (8 hr)

Artemis 3 EVA 4 (6 hr)

Artemis 3 EVA 5 (1 hr)

https://wiki.jsc.nasa.gov/exploration/index.php/Artemis_3

Credible Causes Drivers Exist and Are Likely to Happen…

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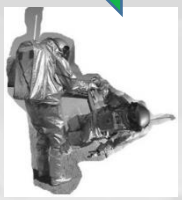

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ICR/ACUTE INJURY SCENARIO

PROBABILITY

	Low — Help	Medium — Assistance	High — Incapacitation
Very high (1/200 < P)	10	5	
High (1/1000 < P ≤ 1/200)	7	3	
Moderate (1/10,000 < P ≤ 1/1000)	3		1
Low (1/100,000 < P ≤ 1/10,000)	2	7	4
Very low (P ≤ 1/100,000)	2	7	3

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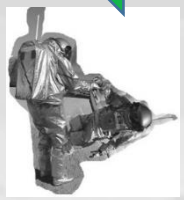

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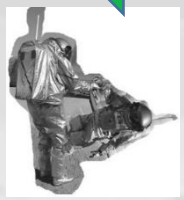

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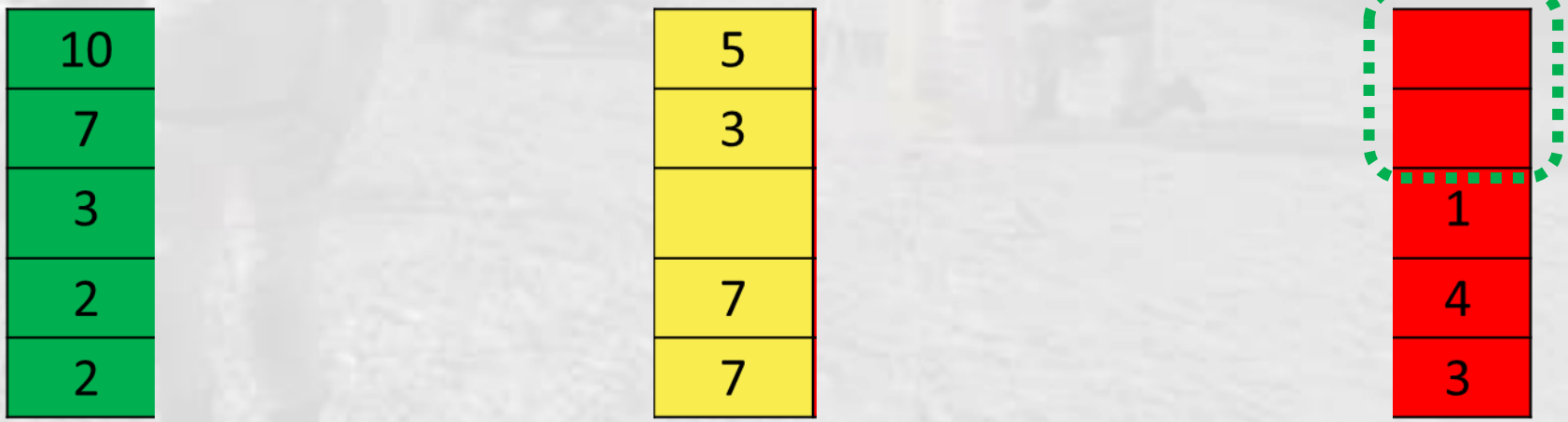

Low Help — **Medium** Assistance — **High** Incapacitation

Risk by Condition

ICR/Acute Injury Scenario (BC- best case; WC – worst case)

PROBABILITY			
Very high (1/200 < P)	Back Sprain/Strain bc; Blisters bc; Dehydration bc; Eye: Extraocular Foreign Body bc; Finger Pain/Sprain/Strain bc; Hand Pain/Sprain/Strain bc; Paresthesias Secondary to EVA bc; Shoulder Sprain/Strain bc; Skin Abrasion bc; Skin Laceration bc	Blisters wc; DCS Secondary to EVA bc; Heat Related Illness bc; Paresthesias Secondary to EVA wc; Skin Abrasion wc	
High (1/1000 < P ≤ 1/200)	Ankle Sprain/Strain bc; Acute Stress Response bc; Elbow Sprain/Strain bc; Hip Sprain/Strain bc; Knee Sprain/Strain bc; Neck Sprain/Strain bc; Wrist Sprain/Strain bc	Eye: Extraocular Foreign Body wc; Finger Pain/Sprain/Strain wc; Hand Pain/Sprain/Strain wc	
Moderate (1/10,000 < P ≤ 1/1000)	Finger Dislocation bc; Lower Extremity Fracture (stress) bc; Nose Bleed (not Space Adaptation) bc		Back Sprain/Strain wc
Low (1/100,000 < P ≤ 1/10,000)	Dental: Tooth Fracture bc; Wrist Fracture bc	Dental: Avulsion (Tooth Loss) bc; Elbow Sprain/Strain wc; Herniated Disc bc; Hip Sprain/Strain wc; Knee Sprain/Strain wc; Shoulder Sprain/Strain wc; Wrist Sprain/Strain wc	Ankle Fracture wc; Ankle Sprain/Strain wc; Acute Stress Response wc; Lower Extremity Fracture (pathological/traumatic) bc
Very low (P ≤ 1/100,000)	Acute Neurapraxia bc; Head Injury bc	Acute Neurapraxia wc; Ankle Fracture bc; Dental: Tooth Fracture wc; Elbow Dislocation bc; Lumbar Spine Fracture bc; Nose Bleed (not Space Adaptation) wc; Shoulder Dislocation bc	Head Injury wc; Herniated Disc wc; Hip/Proximal Femur Fracture bc

Boots on the Moon Next Steps

Risk – priorities, acceptance, thresholds

- Integration: medical, systems, cross-cutting dependencies, Suited Injury Matrix
- Response: scenario, condition
- Beyond: sustained Artemis missions, other mission phases

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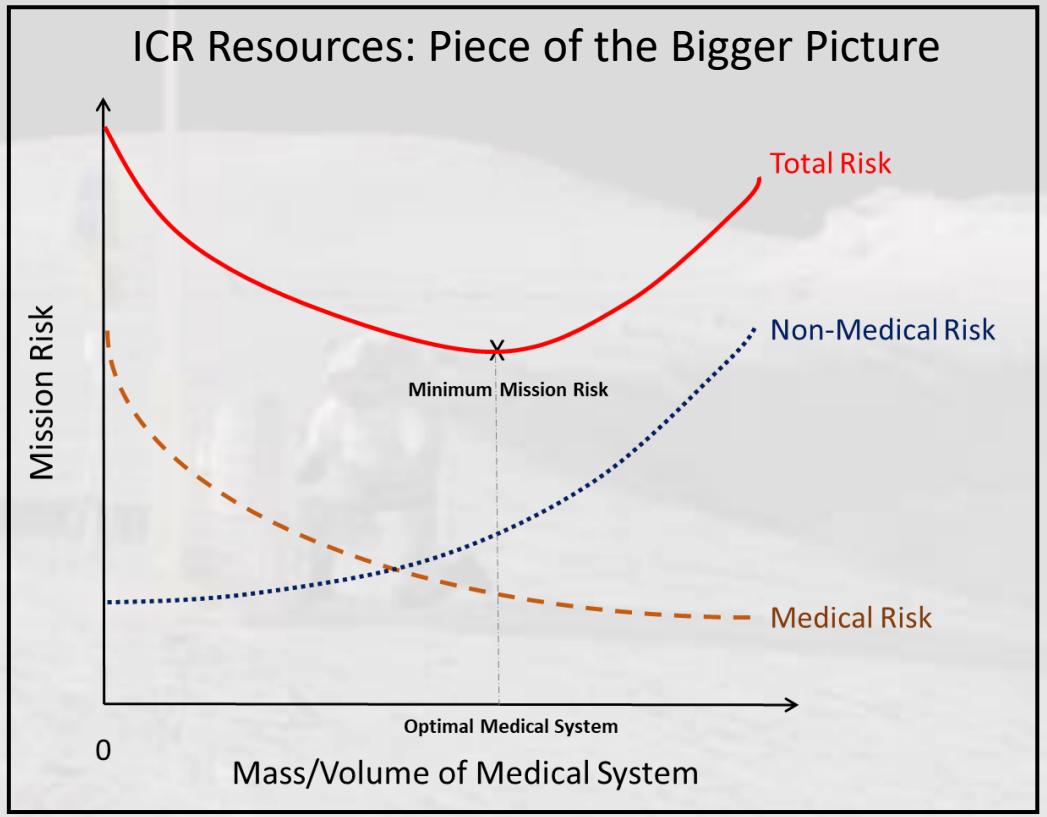
Resources – preventions, mitigations

- Hardware aids (e.g. transport system, walking assistance, lift system)
- Suit (e.g. hand holds, ankle rotation stops)
- Operational planning during training and mission (e.g. work hardening, EVA tasks)



From: Engineering, Life Sciences, and Health/Medicine Synergy in Aerospace Human Systems Integration: The Rosetta Stone Project, 2017

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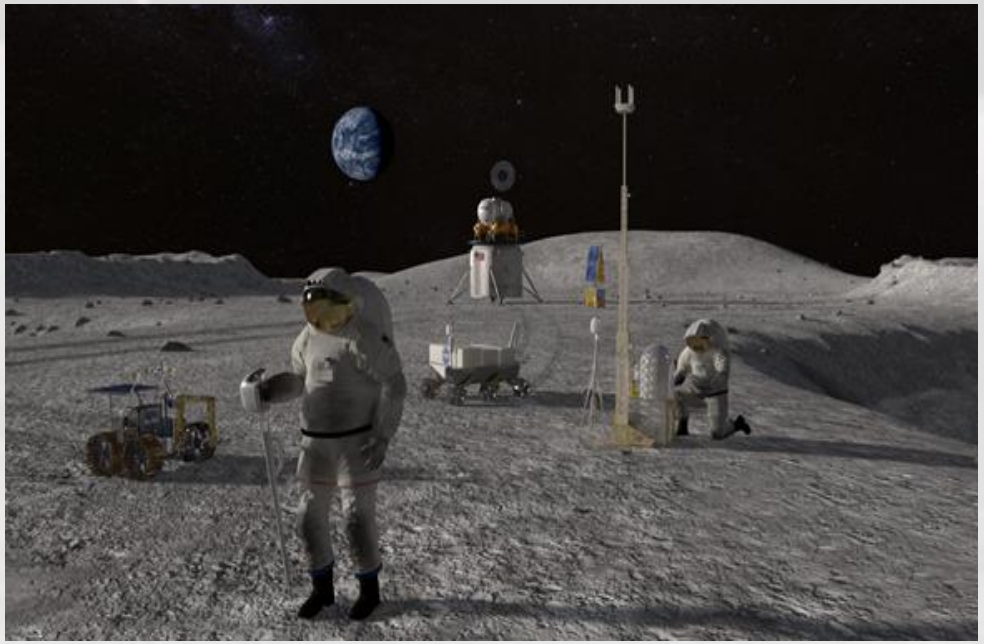
Requirements – specific, integrative



Exploration and DCS Panels Summary

- Panel 1: NASA's Exploration Atmospheres & EVA Strategies
  - VALIDATION OF DECOMPRESSION SICKNESS RISK MITIGATION PROTOCOLS FOR PLANETARY SPACEFLIGHT (Abercromby)
  - REDUCTION OF DECOMPRESSION SICKNESS USING SUITPORTS AND INTERMITTENT RECOMPRESSION (Gernhardt)
  - NITRIC OXIDE SUPPLEMENTATION (Sanders)
  - DEVELOPMENT OF AN EXTRAVEHICULAR ACTIVITY PHYSICAL WORKLOAD SIMULATION FOR USE IN GROUND VALIDATION OF EXPLORATION PREBREATHE PROTOCOLS (Estep)
  - DEVELOPMENT AND TESTING OF A FACILITY TO STUDY SPACECRAFT AND SPACESUIT ATMOSPHERES AND DECOMPRESSION PROTOCOLS (Garbino)
- Panel 2: Management of DCS and Crew Injury During Exploration EVA
  - DCS TREATMENT FOR EXPLORATION ATMOSPHERE STUDY (Sanders)
  - EVALUATION OF DCS TREATMENT CAPABILITIES WHEN PERFORMING EVA FROM REDUCED PRESSURE ENVIRONMENTS (Dervay)
  - REVIEW OF TYPE 1 DECOMPRESSION SICKNESS DISPOSITION POLICIES FROM 18 ORGANIZATIONS (Zamarron)
  - ANALYSIS OF MILD TYPE I DECOMPRESSION SICKNESS RETURN TO ALTERNOBARIC OPERATIONS FOR SHORT DURATION LUNAR MISSIONS (Harman)
  - BOOTS ON THE MOON: INCAPACITATED CREW RESCUE (ICR) AND ACUTE INJURY (Walton)

Thank you!

Questions?