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# Extravehicular Activity on the Lunar Surface: Mapping Mitigation Risk Consequence for Crew Needing Assistance or Rescue

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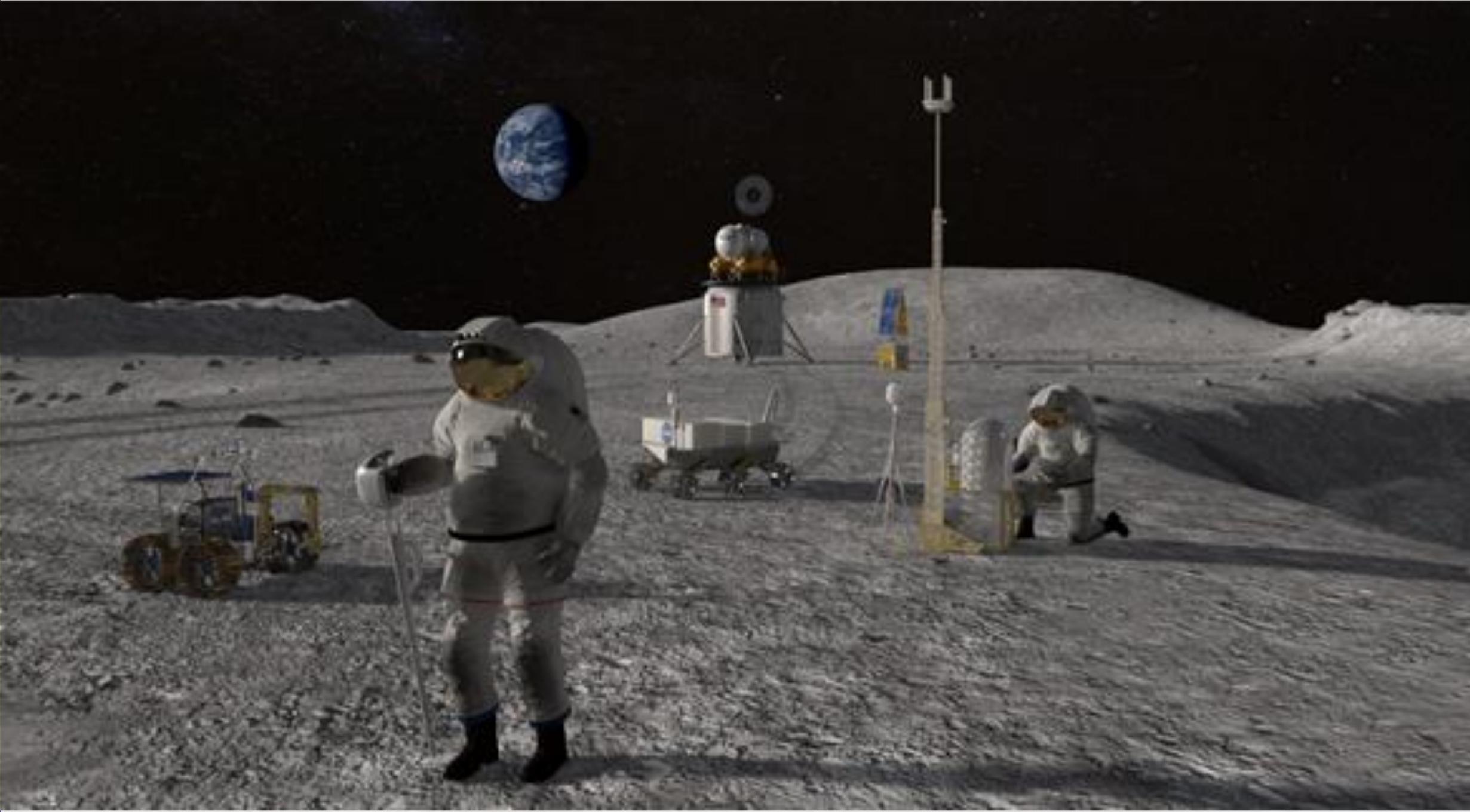
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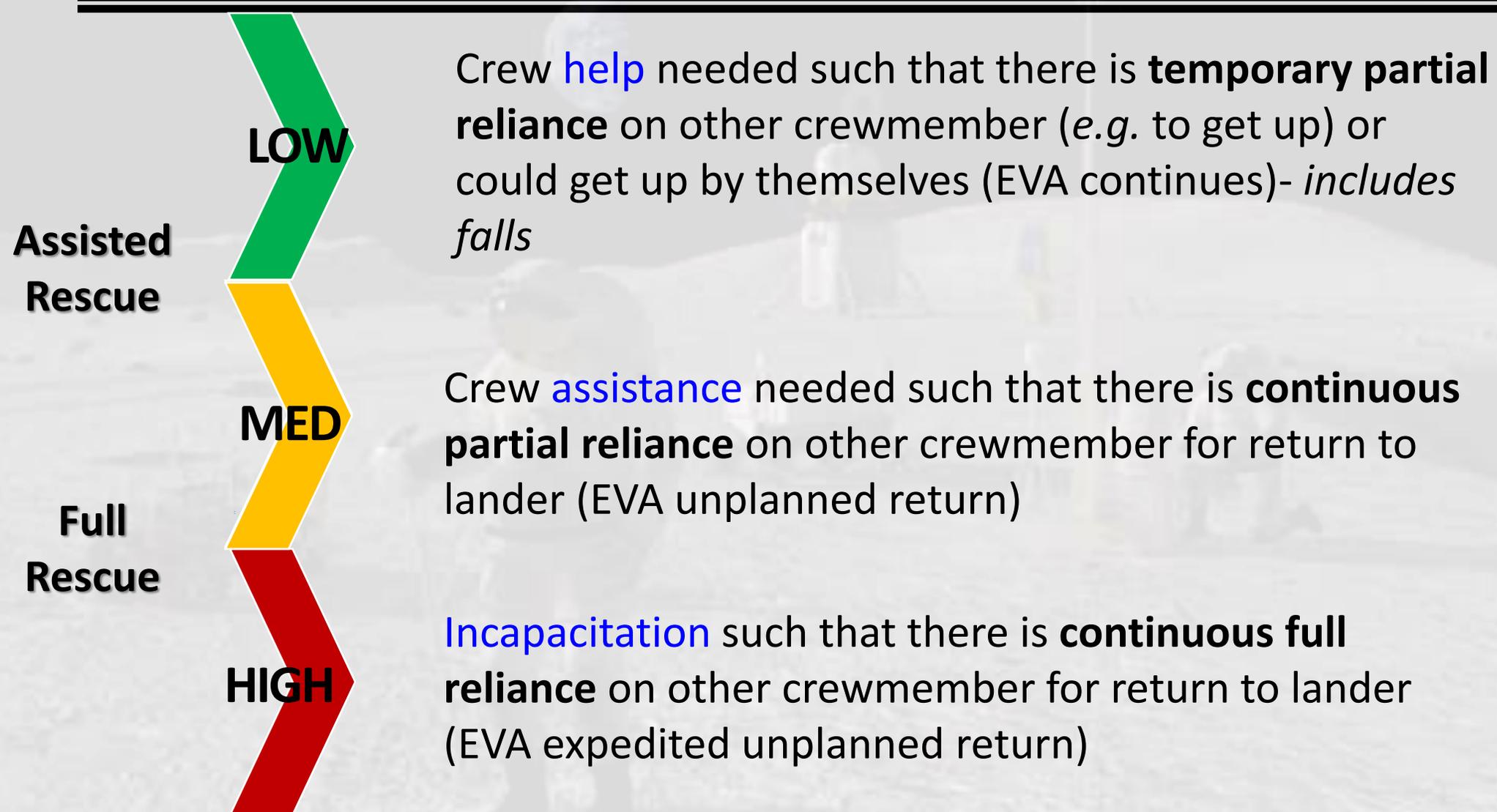
*Scott Ross*

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# ICR/Acute Injury Scenario Definitions



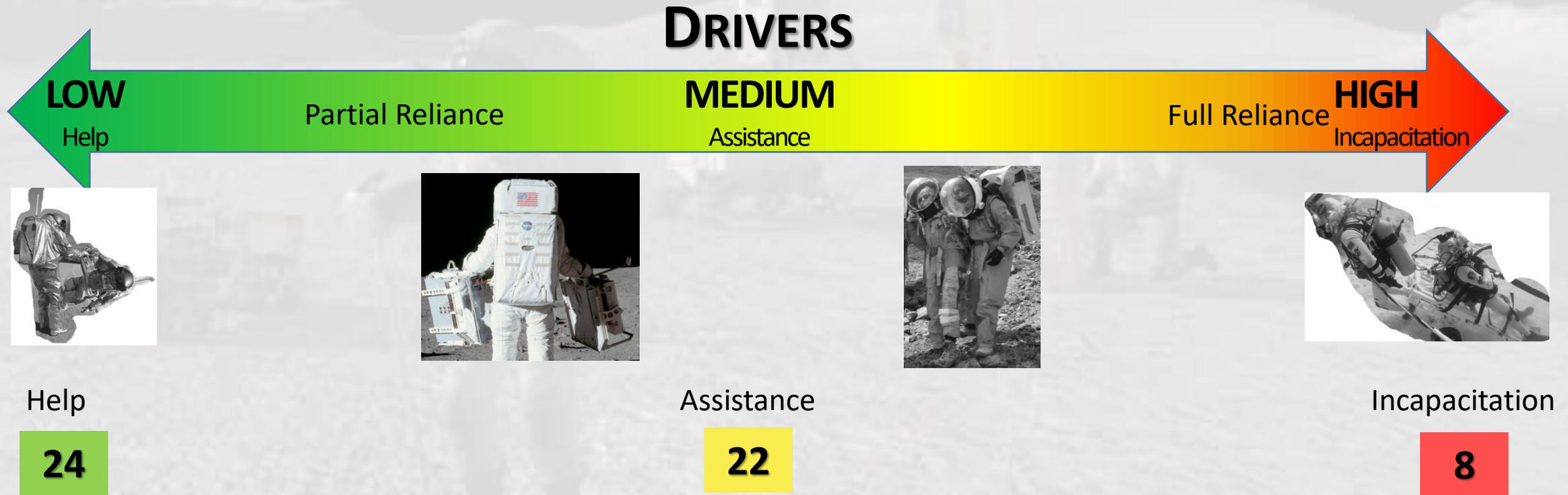
# Causes of Incapacitation/Acute Injury





# Causes of Incapacitation/Acute Injury

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



# Data Caveats and Assumptions

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- **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)
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# 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
- Probabilities do not include preventions nor hazard controls (forward work)

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

**Probabilities associated with early Artemis mission, not individual EVA**

# Risk by Condition: Continuous Reliance Focus



## ICR/ACUTE INJURY SCENARIO (BC- best case; WC – worst case)

**PROBABILITY**

<p><b>Very high</b> (<math>1/200 &lt; P</math>)</p>	<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</p>	<p>Blisters wc; DCS Secondary to EVA bc; Heat Related Illness bc; Paresthesias Secondary to EVA wc; Skin Abrasion wc</p>	
<p><b>High</b> (<math>1/1000 &lt; P \leq 1/200</math>)</p>	<p>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</p>	<p>Eye: Extraocular Foreign Body wc; Finger Pain/Sprain/Strain wc; Hand Pain/Sprain/Strain wc</p>	
<p><b>Moderate</b> (<math>1/10,000 &lt; P \leq 1/1000</math>)</p>	<p>Finger Dislocation bc; Lower Extremity Fracture (stress) bc; Nose Bleed (not Space Adaptation) bc</p>		<p>Back Sprain/Strain wc</p>
<p><b>Low</b> (<math>1/100,000 &lt; P \leq 1/10,000</math>)</p>	<p>Dental: Tooth Fracture bc; Wrist Fracture bc</p>	<p>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</p>	<p>Ankle Fracture wc; Ankle Sprain/Strain wc; Acute Stress Response wc; Lower Extremity Fracture (pathological/traumatic) bc</p>
<p><b>Very low</b> (<math>P \leq 1/100,000</math>)</p>	<p>Acute Neurapraxia bc; Head Injury bc</p>	<p>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</p>	<p>Head Injury wc; Herniated Disc wc; Hip/Proximal Femur Fracture bc</p>

# Risk Assessment: Mapping and Criteria



LIKELIHOOD	5	10	16	20	23	25
	4	7	13	18	22	24
	3	4	9	15	19	21
	2	2	6	11	14	17
	1	1	3	5	8	12
		1	2	3	4	5
	CONSEQUENCE					

Safety Consequence	Criteria
1	Minor injury not requiring first aid treatment, minor discomfort
2	Injury requiring first aid treatment, moderate discomfort
3	Terrestrial injury or occupational illness requiring medical treatment
4	In-flight injury or illness that requires medical intervention from a second crewmember and/or Flight Surgeon and is not treatable by first aid alone; ground personnel occupational injury or illness requiring definitive/specialty hospital/medical treatment
5	Loss of crew life (LOC) or permanent, disabling injury

# Ground Rules and Assumptions – Mitigation Assessment

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1. Considered worst of worse case for assessment- there are no data to back these up!
  2. Considered each Driver condition as independent event
  3. Prevention – lowering the likelihood of ever getting to the scenario where the event occurs (Driver condition)
  4. Mitigation – event has occurred; we are now trying to reduce the consequence and/or likelihood of LOC
  5. Mitigation device performs as designed or capability works as planned for consequence scoring
  6. Mitigation may not lead to a full or complete medical or mission resolution for a given event
  7. Single fault failure captured for each mitigation
  8. **Only assessed for Artemis III, but should be thinking towards Artemis IV+**
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# Continuous Reliance 5 x 5: Catastrophic Focus



## ICR/ACUTE INJURY CONDITIONS (BC- best case; WC – worst case)

**LIKELIHOOD**

<p><b>5-Very high</b> (1/200 &lt; P)</p> <p><b>4-High</b> (1/1000 &lt; P ≤ 1/200)</p> <p><b>3-Moderate</b> (1/10,000 &lt; P ≤ 1/1000)</p> <p><b>2-Low</b> (1/100,000 &lt; P ≤ 1/10,000)</p> <p><b>1-Very low</b> (P ≤ 1/100,000)</p>	10	Heat Related Illness bc 16	DCS bc 20	Blisters wc; Paresthesias wc; Skin Abrasion wc 23	25
	7			Eye: Extraocular Foreign Body wc 22	24
	4				<b>Back Sprain/Strain wc</b> 21
	2			Dental: Avulsion (Tooth Loss) bc; Knee Sprain/Strain wc; Herniated Disc bc 14	Ankle Fracture wc; Ankle Sprain/Strain wc; <b>Acute Stress Response wc</b> ; Lower Extremity Fracture (pathological/traumatic) bc; Hip Sprain/Strain wc 17
	1			Ankle Fracture bc; Lumbar Spine Fracture bc; Dental: Tooth Fracture wc; Elbow Dislocation bc; Shoulder Dislocation bc; Nose Bleed (not Space Adaptation) wc 8	<b>Head Injury wc</b> ; Herniated Disc wc; Hip/Proximal Femur Fracture bc; Acute Neurapraxia wc 12

**CONSEQUENCE**



# Mitigations to Catastrophic Drivers

Catastrophic Event	Mitigations								
	Transport Device	Walking Assist Devices	Crew Assistance Only	Suit Design Options	EVA Tool Design*	Reduced EVAs/Hours	Restrict EVA Operations	EVA Con Ops	Work Hardening
Back Sprain/Strain (WC)	x								
Acute Stress Response (WC)	x								
Ankle Sprain/Strain (WC)	x	x	x						
Lower Extremity Fracture (BC)	x	x	x						
Ankle Fracture (WC)									
Hip Sprain/Strain (WC)	x	x	x						
Head Injury (WC)									
Hip/Proximal Femur Fracture (BC)									
Herniated Disc (WC)									
Acute Neurapraxia (WC)	x	x	x						

Acronyms	
BC	Best Case
WC	Worst Case

x box-box change

\*EVA Tool design not accounted for in other columns



# Mitigations to Catastrophic Drivers

Catastrophic Event \ Mitigations	Transport Device	Walking Assist Devices	Crew Assistance Only	Suit Design Options	EVA Tool Design*	Reduced EVAs/Hours	Restrict EVA Operations	EVA Con Ops	Work Hardening
	Back Sprain/Strain (WC)	x							
Acute Stress Response (WC)	x								
Ankle Sprain/Strain (WC)	x	x	x						
Lower Extremity Fracture (BC)	x	x	x						
Ankle Fracture (WC)									
Hip Sprain/Strain (WC)	x	x	x						
Head Injury (WC)									
Hip/Proximal Femur Fracture (BC)									
Herniated Disc (WC)									
Acute Neurapraxia (WC)	x	x	x						

Acronyms	
BC	Best Case
WC	Worst Case

x box-box change

\*EVA Tool design not accounted for in other columns

# Mitigation Analysis: Process Overview (box-box change)



## Capability: notional

- Mitigations

- Mitigation point 1
- Mitigation point 2
- Mitigation point 3

LIKELIHOOD

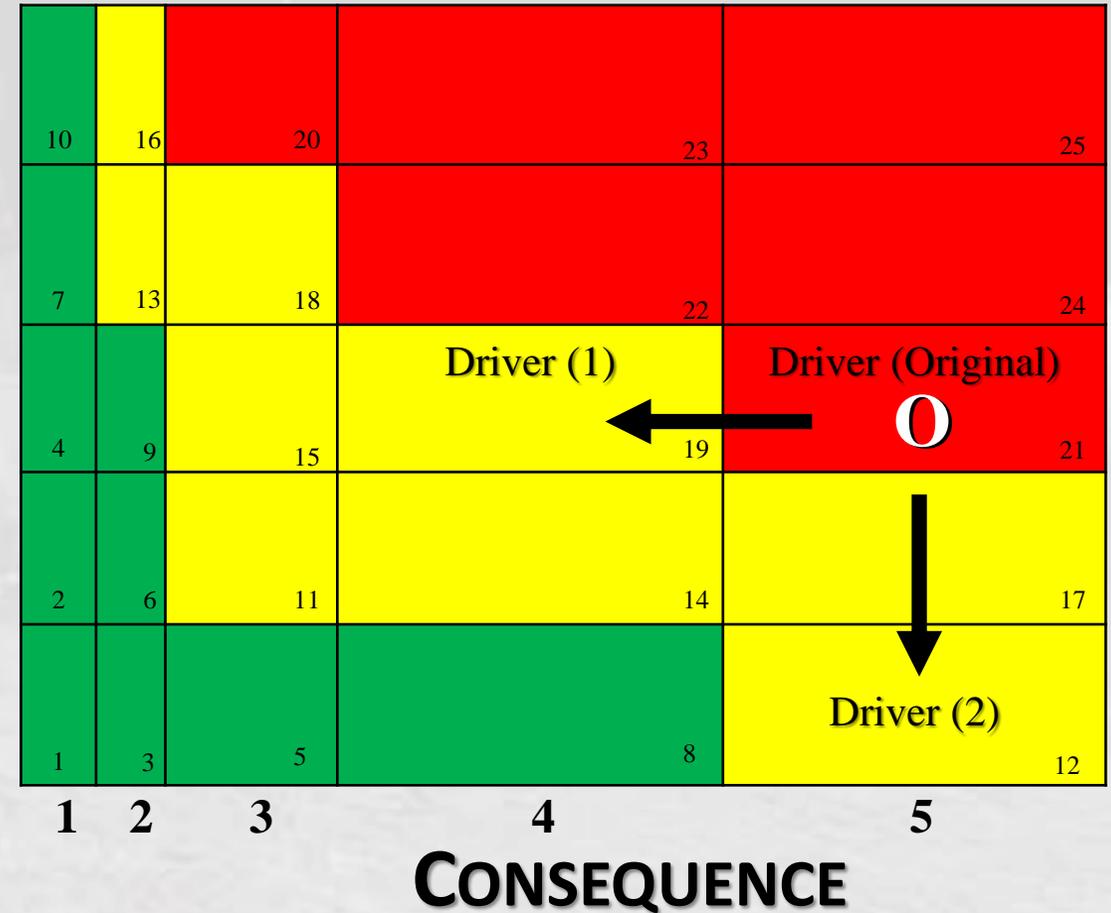
**5-Very high**  
( $1/200 < P$ )

**4-High**  
( $1/1000 < P \leq 1/200$ )

**3-Moderate**  
( $1/10,000 < P \leq 1/1000$ )

**2-Low**  
( $1/100,000 < P \leq 1/10,000$ )

**1-Very low**  
( $P \leq 1/100,000$ )



# Mitigation Analysis: Process Overview (box-box change)



## Capability: notional

- Mitigations

- Mitigation point 1
- Mitigation point 2
- Mitigation point 3

Crew Mission Assurance Risk (Risk 1):  
 3x4: provided safe crew return,  
 protected affected crew

**LIKELIHOOD**

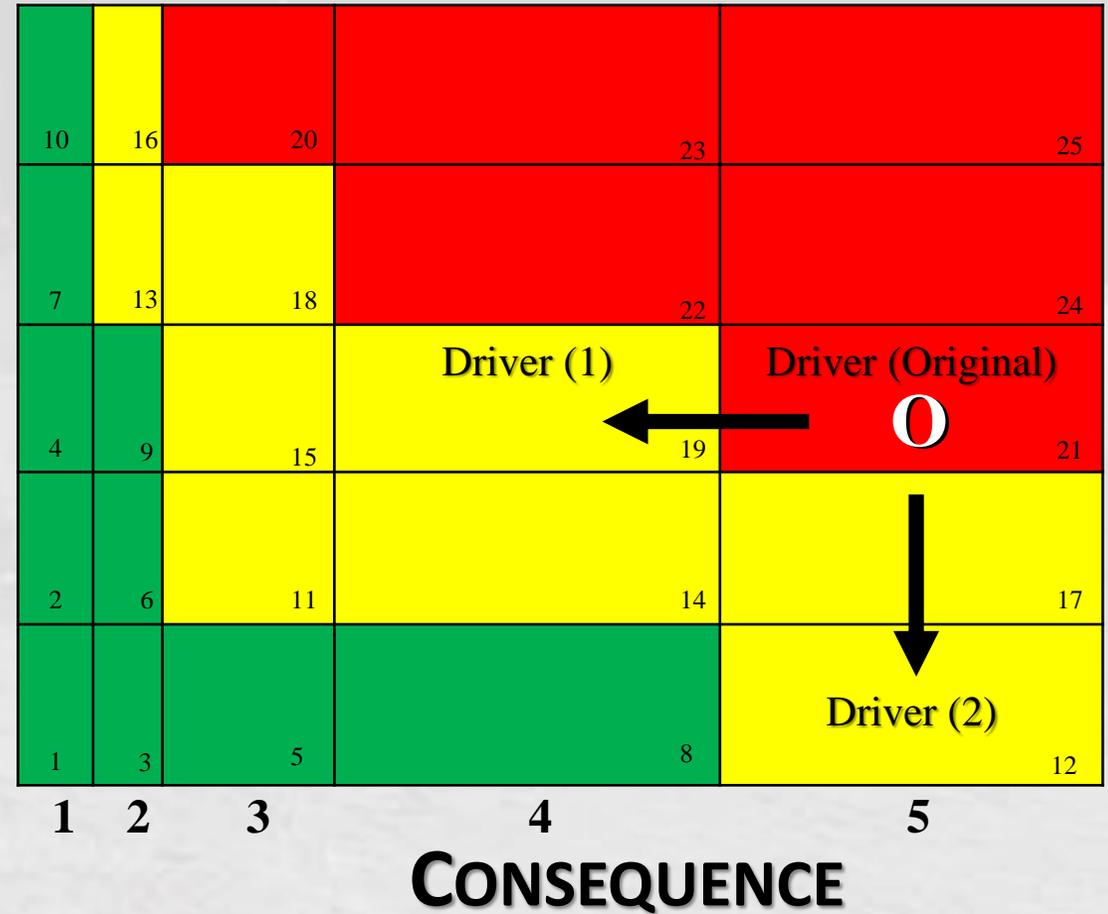
**5-Very high**  
( $1/200 < P$ )

**4-High**  
( $1/1000 < P \leq 1/200$ )

**3-Moderate**  
( $1/10,000 < P \leq 1/1000$ )

**2-Low**  
( $1/100,000 < P \leq 1/10,000$ )

**1-Very low**  
( $P \leq 1/100,000$ )



# Mitigation Analysis: Process Overview (box-box change)



## Capability: notional

- Mitigations

- Mitigation point 1
- Mitigation point 2
- Mitigation point 3

Crew Mission Assurance Risk (Risk 1):  
 3x4: provided safe crew return, protected affected crew

Crew Safety Risk (Risk 2):  
 1x5: capability mitigation- didn't remove all potential for permanent disabling injury

LIKELIHOOD

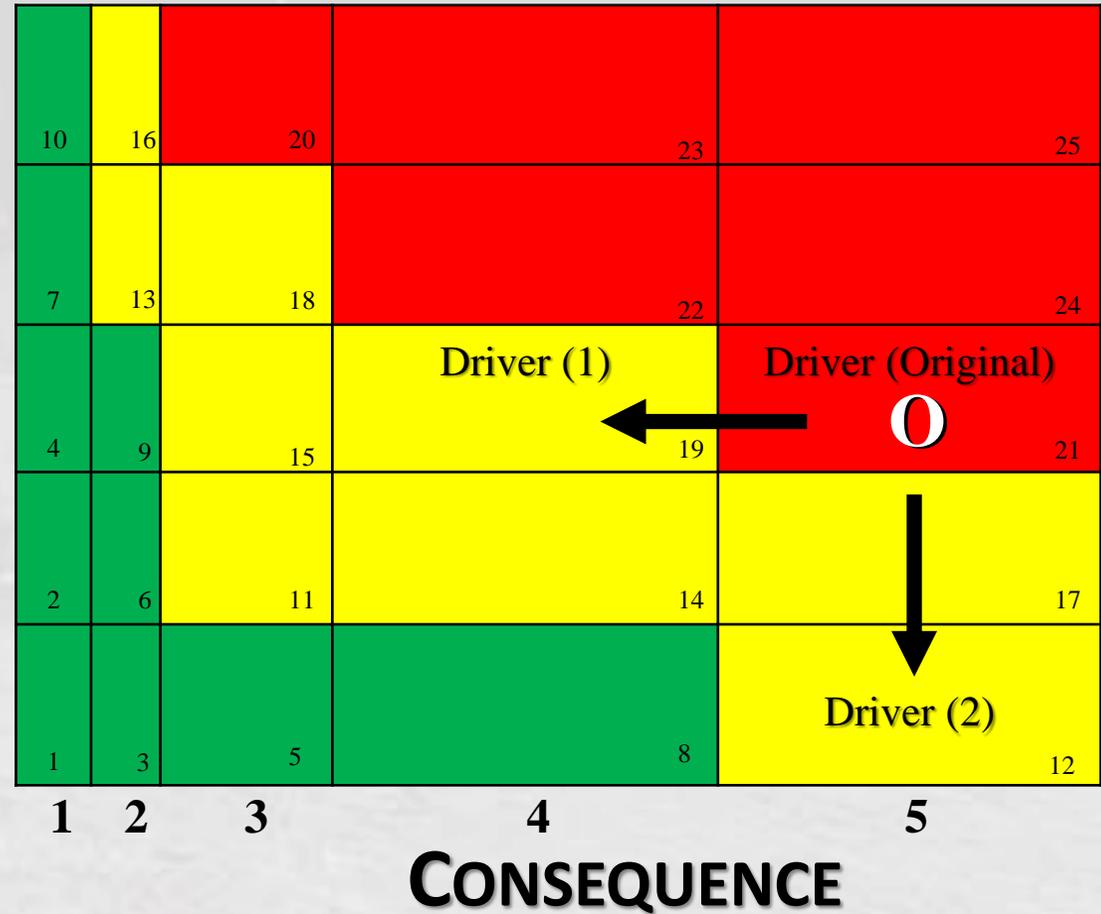
**5-Very high**  
 (1/200 < P)

**4-High**  
 (1/1000 < P ≤ 1/200)

**3-Moderate**  
 (1/10,000 < P ≤ 1/1000)

**2-Low**  
 (1/100,000 < P ≤ 1/10,000)

**1-Very low**  
 (P ≤ 1/100,000)



# Mitigation Analysis: Process Overview (in box change)



## Capability: notional

- Mitigations

- Mitigation point 1
- Mitigation point 2
- Mitigation point 3

Crew Mission Assurance Risk (Risk 1):  
 1x4: provided safe crew return,  
 protected affected crew

Crew Safety Risk (Risk 2):  
 1x5: capability mitigation- didn't remove  
 potential for permanent disabling injury  
 but decreased the severity

LIKELIHOOD

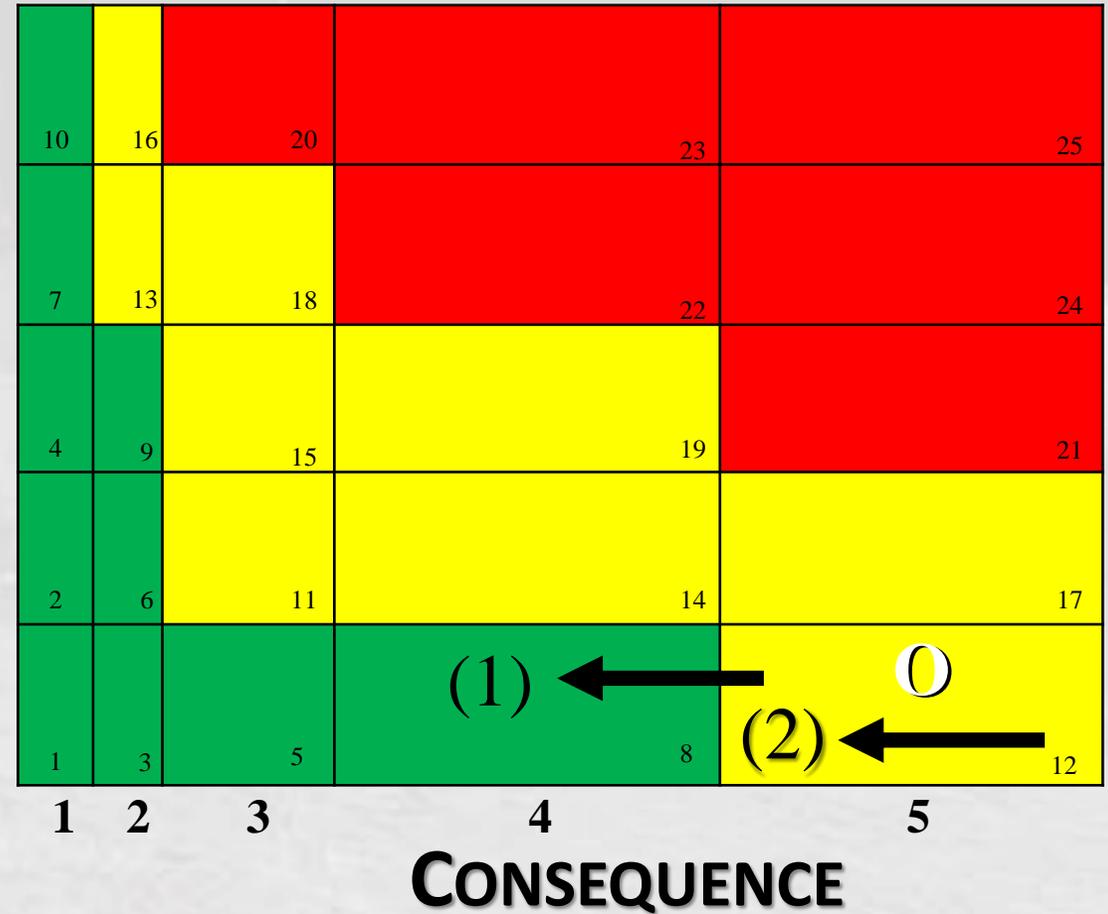
**5-Very high**  
 (1/200 < P)

**4-High**  
 (1/1000 < P ≤ 1/200)

**3-Moderate**  
 (1/10,000 < P ≤ 1/1000)

**2-Low**  
 (1/100,000 < P ≤ 1/10,000)

**1-Very low**  
 (P ≤ 1/100,000)





# Mitigation: Wheeled Transport Device



## Capability: wheeled transport

- Mitigation (consequence)
  - Decrease return timing
  - Decrease progression of injury (protection)
  - Decrease rescuer exertion during return to lander

Driver (wc)	LxC old	L	C	LxC new	Decrease injury progression	Moves risk from LOC	Permanent disabling injury still possible
Back sp/st	21	3	4	19	Possible	Yes	Yes
Acute Stress	17	2	4	14	No	Yes	No
Ankle sp/st	17	2	4	14	Possible	Yes	No
LE Fx	17	2	4	14	Possible	Yes	Yes
<b>Ankle Fx</b>	17	2	5	17	<b>Possible</b>	<b>Yes</b>	Yes
Hip sp/st	17	2	4	14	Possible	Yes	No
<b>Head Injury</b>	12	1	5	12	<b>Possible</b>	<b>Shift</b>	Yes
<b>Hip/pr fm Fx</b>	12	1	5	12	<b>Possible</b>	<b>Yes</b>	Yes
<b>Hern. disc</b>	12	1	5	12	<b>Possible</b>	<b>Shift</b>	Yes
Acute neur.	12	1	4	8	Possible	Yes	Yes

Crew Safety Risk after mitigation:  
1x5: Transport, injury progression



# Mitigation: Walking Assist Devices

LIKELIHOOD	5	10	16	20	23	25
	4	7	13	18	22	24
	3	4	9	15	19	21
	2	2	6	11	14	17
	1	1	3	5	8	12
	1	2	3	4	5	
	CONSEQUENCE					

**Capability:** dual purposed tools, push-cart, staff

- Mitigation (consequence)
  - Decrease return timing
  - Decrease progression of injury (protection)
  - Provide rescuer stability during assisted walkback

Crew Safety Risk after mitigation:  
 1x5: Device, injury progression, may be insufficient; \*2x5

Driver (wc)	LxC old	L	C	LxC new	Decrease injury progression	Moves risk from LOC	Permanent disabling injury still possible
Back sp/st*	21	3	5	21	No	Shift	Yes
Acute Stress	17	2	5	17	No	No	n/a
Ankle sp/st	17	2	4	14	Possible	Yes	No
LE Fx	17	2	4	14	Possible	Yes	No
Ankle Fx	17	2	5	17	Possible	Yes	Yes
Hip sp/st	17	2	4	14	Possible	Yes	No
Head Injury	12	1	5	12	No	No	n/a
Hip/pr fm Fx	12	1	5	12	No	Shift	Yes
Hern. disc	12	1	5	12	No	Shift	Yes
Acute neur.	12	1	4	8	Possible	Yes	Yes

LIKELIHOOD	5	10	16	20	23	25
	4	7	13	18	22	24
	3	4	9	15	19	21
	2	2	6	11	14	17
	1	1	3	5	8	12
		1	2	3	4	5
		CONSEQUENCE				

# Mitigation: Crew Assistance Only



**Capability:** self or rescuer

- Mitigation (consequence)
  - Decrease return timing
  - Decrease progression of injury (protection)
  - Provide rescuer stability during assisted walk back

Crew Safety Risk after mitigation:  
 1x5: Rescuer, injury progression, may be insufficient; \*2x5

	LxC old	L	C	LxC new	Decrease injury progression	Moves risk from LOC	Permanent disabling injury still possible
<b>Driver (wc)</b>							
<b>Back sp/st*</b>	21	3	5	21	No	Shift	Yes
<b>Acute Stress</b>	17	2	5	17	No	No	n/a
Ankle sp/st	17	2	4	14	Possible	Yes	No
LE Fx	17	2	4	14	Possible	Yes	No
<b>Ankle Fx</b>	17	2	5	17	Possible	Yes	Yes
Hip sp/st	17	2	4	14	Possible	Yes	No
<b>Head Injury</b>	12	1	5	12	No	No	n/a
<b>Hip/pr fm Fx</b>	12	1	5	12	No	Shift	Yes
<b>Hern. disc</b>	12	1	5	12	No	Shift	Yes
Acute neur.	12	1	4	8	Possible	Yes	Yes

# Summary/Next Step Recommendations



Mitigations  Catastrophic Event	Transport Device	Walking Assist Devices	Crew Assistance Only	Suit Design Options	EVA Tool Design*	Reduced EVAs/Hours	Restrict EVA Operations	EVA Con Ops	Work Hardening
	Back Sprain/Strain (WC)	x							
Acute Stress Response (WC)	x								
Ankle Sprain/Strain (WC)	x	x	x						
Lower Extremity Fracture (BC)	x	x	x						
Ankle Fracture (WC)									
Hip Sprain/Strain (WC)	x	x	x						
Head Injury (WC)									
Hip/Proximal Femur Fracture (BC)									
Herniated Disc (WC)									
Acute Neurapraxia (WC)	x	x	x						

\*EVA Tool design not accounted for in other columns

- Feasibility assessment:
  - Dual purpose tools- walking assistance/fall recovery with and without rescuer assist
  - Continued evaluation of human-powered transport system
- Apply Mitigation Analysis Process to other areas
- Identify and target high risk scenarios for reduction
- Mitigation *and* prevention

# Recommendations: A Look at Prevention



Preventions/ Mitigations  Catastrophic Event	Transport Device	Walking Assist Devices	Crew Assistance Only	Suit Design Options	EVA Tool Design*	Reduced EVAs/Hours	Restrict EVA Operations	EVA Con Ops	Work hardening
Back Sprain/Strain (WC)	x								
Acute Stress Response (WC)	x								
Ankle Sprain/Strain (WC)	x	x	x						
Lower Extremity Fracture (BC)	x	x	x						
Ankle Fracture (WC)									
Hip Sprain/Strain (WC)	x	x	x						
Head Injury (WC)									
Hip/Proximal Femur Fracture (BC)									
Herniated Disc (WC)									
Acute Neurapraxia (WC)	x	x	x						

Potential Change in Likelihood  
 Potential Change in Consequence  
**x** box-box change

Assess how LXC risk changes for Artemis IV+

\*EVA Tool design not accounted for in other columns



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Thank you!

*Questions?*

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