National Aeronautics and Space Administration

Comparison of Risk from Orbital Debris and Meteoroid Environment Models on the Extravehicular Mobility Unit (EMU)

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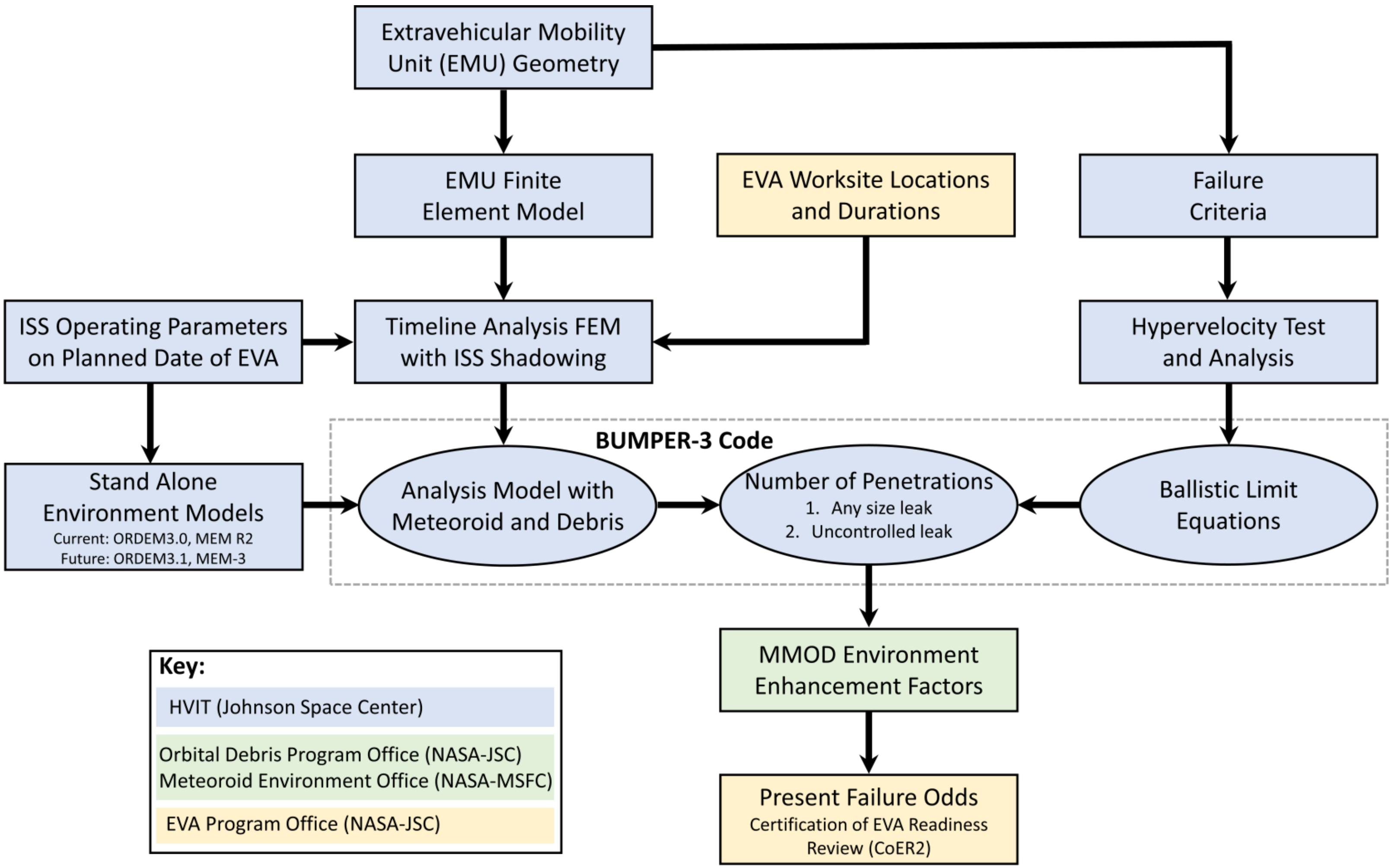
Overview

- **A well-known hazard associated with exposure to the space environment is the risk of failure from an impact from a meteoroid and orbital debris (MMOD) particle**
- **An extravehicular mobility unit (EMU) “spacesuit” impact during a US extravehicular activity (EVA) is of great concern as a large leak could prevent an astronaut from safely reaching the airlock in time resulting in a loss of life**
- **A risk assessment is provided to the EVA office at the Johnson Space Center (JSC) by the Hypervelocity Impact Technology (HVIT) group prior to certification of readiness for each US EVA**
- **Need to understand the effect of updated meteoroid and orbital debris environment models to EMU risk**

EVA Risk Assessment Methodology

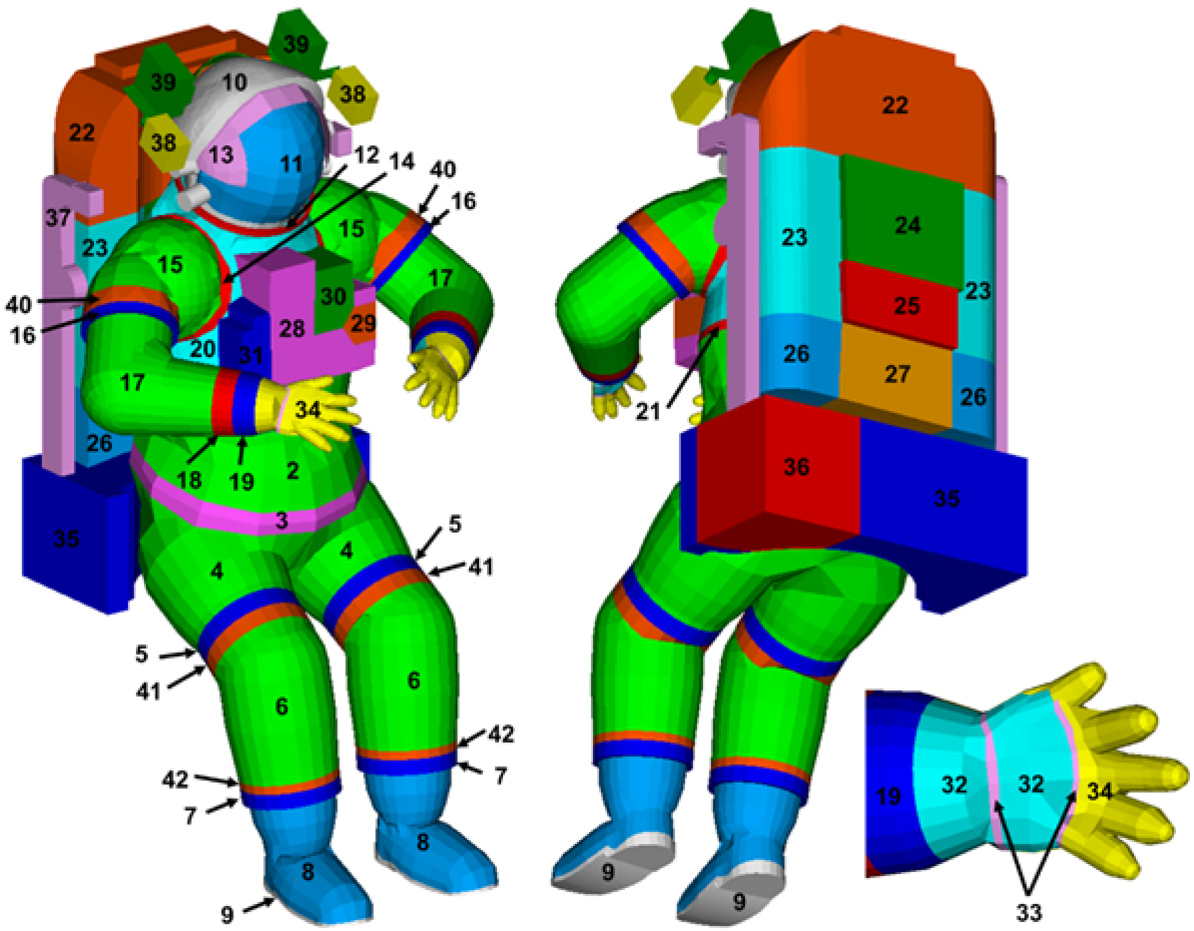


EVA Timeline Risk Assessment Flowchart

EMU Finite Element Model (FEM)

- **A detailed finite element model (FEM) of the EMU was created with regions for the various shielding configurations**
- **42 different surface property ID (PID) types representing the different shielding configurations**
- **Two main groups of shielding configurations:**
  1. Soft goods:
     - TMG over a pressure garment
     - maintains the acceptable atmospheric environment for the astronaut
  2. Hard goods:
     - TMG (except for helmet) over metallic, composite and/or plastic components.

EMU FEM Continued

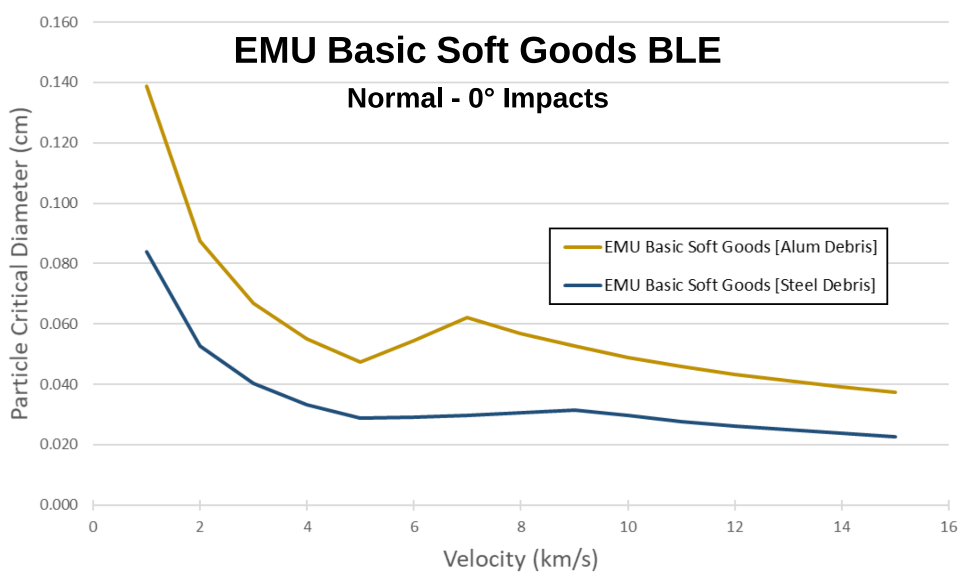


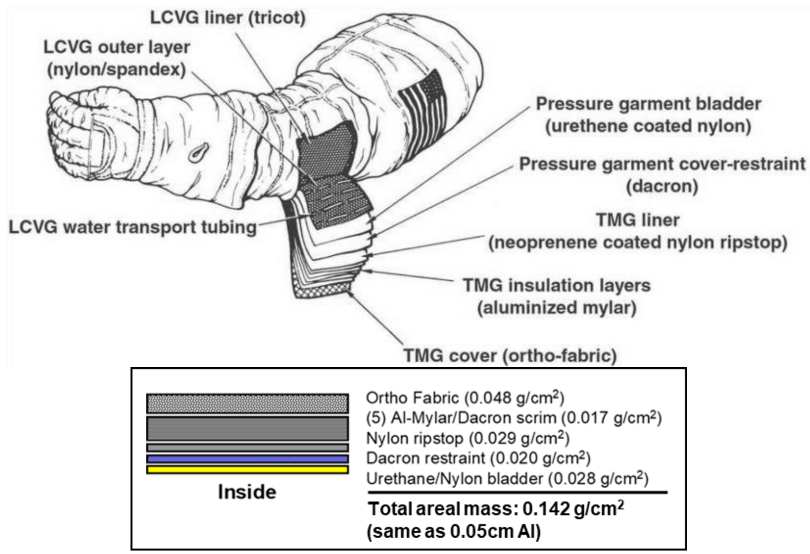
Region *	PID	Code	Region	Color	BLE
Extravehicular Mobility Unit (EMU) FEM					
Lower Torso Assembly	2	L1	Waist TMG	Green	soft goods, 1
	3	L2	Waist Bearings/Sizing Rings	Light Magenta	KE, 39 J
	4	L3	Thigh TMG	Green	soft goods, 1
	5	L4	Thigh Bearings/Sizing Rings	Blue	KE, 39 J
	6	L5	Lower Leg TMG	Green	soft goods, 1
	7	L6	Ankle Bearings/Sizing Rings	Blue	KE, 39 J
	8	L7	Boot TMG	Light Blue	soft goods, 1
	9	L8	Boot Heel & Sole	White	softgoods, 4, AD 5.860
Helmet	10	H1	EVVA Helmet Shell	White	KE, 71 J
	11	H2	Face Plate	Light Blue	KE, 71 J
	12	H3	Helmet Bearings/Sizing Rings	Red	KE, 39 J
	13	H4	Helmet Eyeshades	Pink	KE, 71 J
	38	H1	Helmet Lights	Yellow	shadow
	39	H2	Light Base & Head Mount	Dark Green	shadow
Arms	14	A1	Shoulder Bearings/Sizing Rings	Red	KE, 39 J
	15	A2	Shoulder TMG	Green	soft goods, 1
	16	A3	Upper Arm Bearings/Sizing Rings	Blue	KE, 39 J
	17	A4	Forearm TMG	Green	soft goods, 1
	18	A5	Gauntlet/TMG	Red	softgoods, 3
	19	A6	Gauntlet/Wrist Connect	Blue	KE, 39 J
Hard Upper Torso	20	T1	Hard Upper Torso (HUT)	Cyan	KE, 44 J
	21	T2	HUT Bearings/Sizing Rings	Red	KE, 39 J
Primary Life Support System	22	P1	PLSS - Other Equipment (upper)	Orange	KE, 15 J
	23	P2	PLSS - Primary O2	Cyan	KE, 60 J
	24	P3	PLSS METOX CCC	Dark Green	KE, 21.4 J
	25	P4	PLSS Advanced Battery	Red	KE, 3.5 J
	26	P5	Secondary O2	Light Blue	KE, 13.4 J
	27	P6	PLSS - Other Equipment (lower)	Golden Orange	KE, 15 J
Display and Control module	28	D1	DCM	Light Magenta	shadow
	29	D2	DCM Controls & Display	Orange	shadow
	30	D3	DCM Multiple Connector	Dark Green	shadow
	31	D4	DCM Critical Region	Blue	KE, 10 J
Gloves	32	G1	Glove Palm	Cyan	softgoods, 4, AD 1.285
	33	G2	Glove Gimbals & Palm Bar	Pink	KE, 39 J
	34	G3	Glove Back & Fingers	Yellow	softgoods, 2
SAFER Assembly	35	S1	SAFER Base (non-tank)	Blue	shadow
	36	S2	SAFER Base - N2 tank	Red	KE, 20 J
	37	S3	SAFER Thrusters & Supports	Pink	shadow
Overlap Regions	40	O1	Upper Arm SSA TMG Overlap	Orange	KE, 20 J
	41	O2	Thigh SSA TMG Overlap	Orange	KE, 20 J
	42	O3	Ankle SSA TMG Overlap	Orange	KE, 20 J

* Color corresponds to the regional risk breakdown bar charts

Ballistic Limit Equations

- **EMU thermal meteoroid garment (TMG) performs as a mini bumper shield**
  - Ortho-fabric layers induce a shock pulse that breaks up the projectile and creates an expanding debris cloud
  - Inner layers (MLI and ripstop) and the pressure garment restraint layer help with further particle breakup and create spacing for the debris cloud to expand before reaching the bladder or underlying critical component





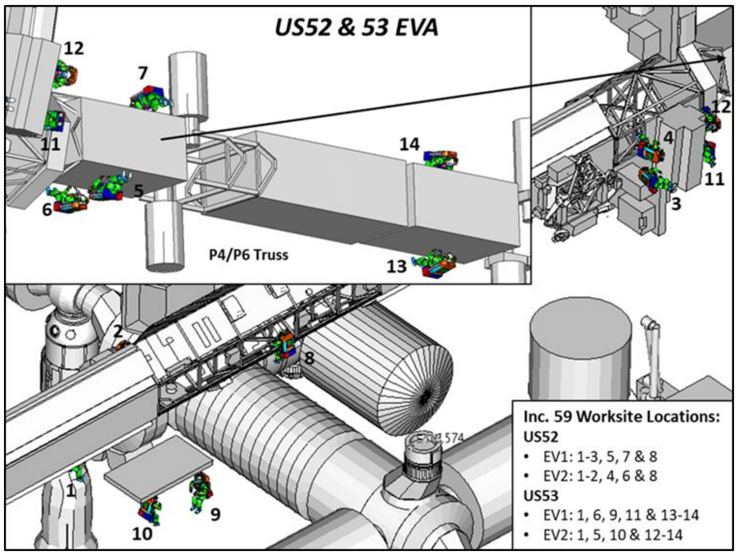
Ref: Christiansen, E.L., Cour-Palais, B.G., and Friesen, L.J., 1998. "Extravehicular Activity Suit Penetration Resistance" Proceedings of the 1998 Hypervelocity Impact Symposium, International Journal of Impact Engineering, Vol. 23.

EMU Failure Modes

- **The risk of a meteoroid or orbital debris particle penetrating the thermal meteoroid garment (TMG) and the pressure garment is determined for two failure modes:**
  1. Perforation threshold (EVA abort): any size leak risk of the bladder layer of the pressure garment
  2. Critical hole size threshold (catastrophic leak): uncontrolled leak risk caused by a >4mm hole in the bladder

EVA Timeline Analysis

- **EVA office provides a summary of EMU positions (including body orientation) for the specific EVA worksite locations on the International Space Station (ISS), and the duration at each location**
  - using detailed EVA summaries/presentations and/or EVA training run videos from the Neutral Buoyancy Lab (NBL)
- **Timeline analysis FEMs are built by orienting an EMU FEM at each worksite location on a simplified ISS FEM. When one or more worksites require multiple body orientations, additional analysis FEMs are built.**



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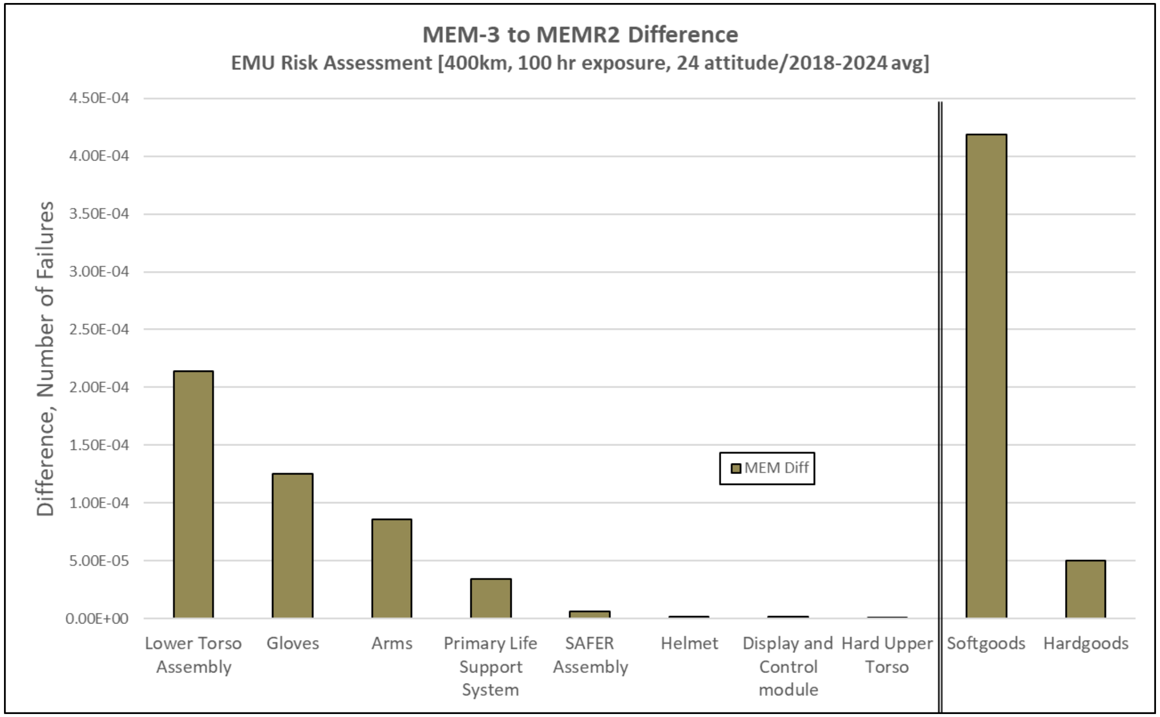
Meteoroid and Orbital Debris Models

- **Meteoroid models (provided by MSFC Meteoroid Environment Office):**
  - MEM R2 – previous meteoroid environment model used from 2014 through August 2019
    - **All meteoroids assumed to be 1.0 g/cm^3**
  - MEM 3 – latest released meteoroid environment model and used in EVA risk assessments starting in August 2019
    - **Meteoroid density in two distributions (low-density and high-density) with density varying from 0.125 g/cm^3 up to 7.975 g/cm^3**
- **Orbital debris models (provided by JSC Orbital Debris Program Office):**
  - ORDEM 3.0 – current approved debris model
  - ORDEM 3.1 – new debris model not yet released
    - **Risk assessments provided here are preliminary, for indication only (may be changed after ORDEM 3.1 is finalized and released)**

Meteoroid Model Comparison MEMR2 to MEM-3

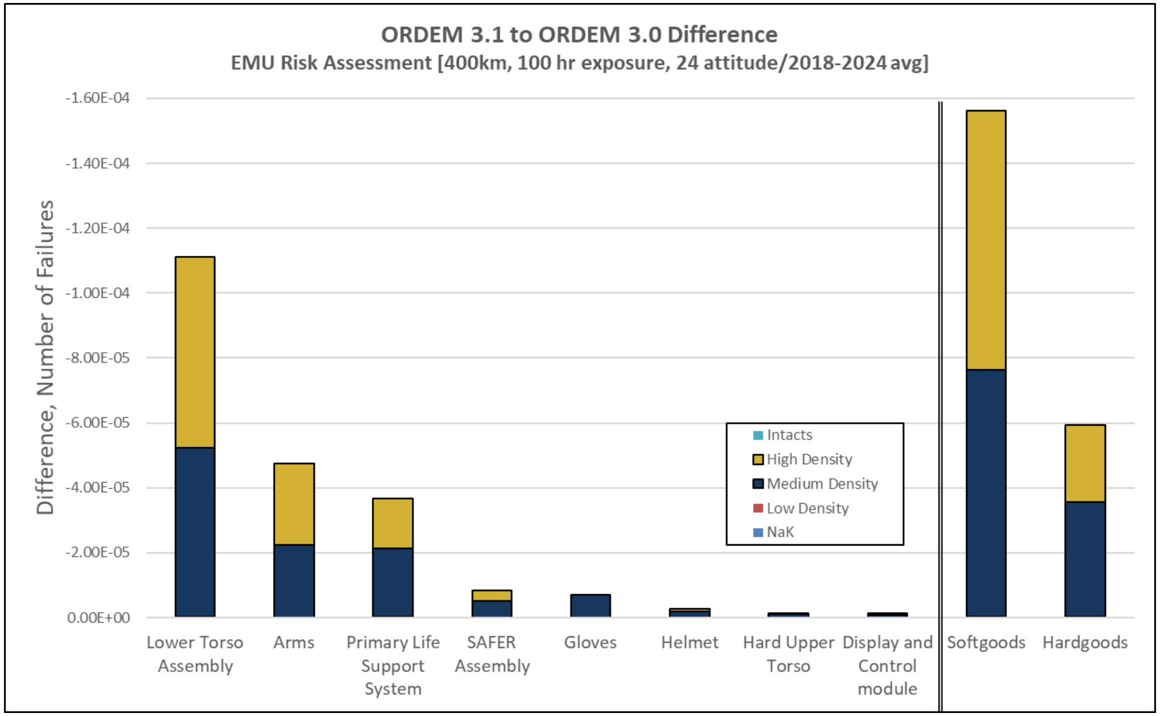


EMU MMOD Study - Risk by Component		
Region	MEM-3 to MEMR2 Factor	% of Total Difference
Lower Torso Assembly	1.9	46%
Gloves	1.8	27%
Arms	1.9	18%
Primary Life Support System	1.3	7%
SAFER Assembly	1.3	1%
Helmet	1.3	0.4%
Display and Control module	1.2	0.3%
Hard Upper Torso	1.3	0.2%
Softgoods	1.9	89%
Hardgoods	1.3	11%
Total	1.7	100%

- **MEM-3 meteoroid environment model contributes <u>71% more risk</u> (any size leak penetration) than MEM-R2**
- **Risk difference is attributable to the addition of high density populations to the MEM-3 meteoroid environment**
- **Softgoods shielding configuration accounts for 89% of the risk difference**

PRELIMINARY

Orbital Debris Model Comparison ORDEM 3.0 vs. ORDEM 3.1



EMU MMOD Study - Risk by Component		
Region	OD3.0 to OD3.1 Factor	% of Total Difference
Lower Torso Assembly	0.9	52%
Arms	0.9	22%
Primary Life Support System	0.8	17%
SAFER Assembly	0.8	4%
Gloves	1.0	3%
Helmet	0.9	1%
Hard Upper Torso	0.9	1%
Display and Control module	0.9	1%
Softgoods	**0.9**	**72%**
Hardgoods	**0.8**	**28%**
Total	**0.9**	**100%**

- **ORDEM 3.1 environment model contributes 13% less risk of (any size leak penetration) than ORDEM 3.0**
- **99.7% of this risk difference comes from the high and medium density populations**
- **Softgoods shielding configuration accounts for 72% of the risk difference**

Combined MMOD Comparison

- **<u>11% more</u> cumulative MMOD penetration risk for MEM-3 and ORDEM 3.1 versus MEMR2 and ORDEM 3.0**
  - Risk decrease from ORDEM 3.1 orbital debris environment offset by risk increase from MEM-3 meteoroid environment
- **78% of the OD3.1/MEM-3 risk is in the softgoods shielding configuration regions**

EMU Risk Assessment	Number of Failures (400km, 100 hour exposure, 24 attitude/2018-2024 average)							
	Orbital Debris						Meteoroid	MMOD
Description	*NaK*	*LD*	*MD*	*HD*	*Intacts*	Total	Total	Total
ORDEM 3.1 and MEM-3	*0.00E+00*	*4.22E-07*	*3.43E-04*	*1.15E-03*	*2.18E-09*	1.50E-03	1.13E-03	2.63E-03
ORDEM 3.0 and MEMR2	*2.71E-09*	*1.01E-06*	*4.54E-04*	*1.26E-03*	*1.18E-09*	1.71E-03	6.63E-04	2.38E-03
Factor	*0.0*	*0.4*	*0.8*	*0.9*	*1.8*	0.9	1.7	1.1

MMOD Risk odds for typical EVA
(6.5 hour duration, 2 crew)

- **MMOD risks are relatively small for typical ISS EVAs, no matter what environment models are used**
  - Example only, MMOD risks vary by location, duration, year of EVA, and other factors

Failure Mode	MMOD Risk Odds	
	MEM R2 and ORDEM 3.0	MEM 3 and ORDEM 3.1
Any size leak	1 in 5,000	1 in 4,500
Critical leak	1 in 28,000	1 in 26,000

Conclusions

- **Assessed the change in risk using updated MMOD environment models (MEM-3 and ORDEM 3.1)**
  - 11% more cumulative MMOD penetration risk due to risk increase from high-density component of MEM-3
- **Soft goods regions of the EMU continue to drive risk, contribute 78% of cumulative MMOD penetration risk**
- **MMOD risks remain small for typical 6.5 hour EVA, no matter what MMOD environments are used**