17th Hypervelocity Impact Symposium
HVIS2024
September 9-13, 2024, Tsukuba, Japan

HVIS2024-062

A REVIEW OF INTERNATIONAL SPACE STATION EXTRAVEHICULAR ACTIVITY MICROMETEOROID & ORBITAL DEBRIS RISK

Dana M. Lear[1,*], Kevin D. Hoffman[2], James L. Hyde[2], Cameron M. Collins[2]

[1] NASA Johnson Space Center, Mail Code XI5, Houston, TX 77058, USA
[2] Jacobs, NASA Johnson Space Center, Mail Code XI5, Houston, TX 77058, USA

ABSTRACT

Nearly 300 spacewalks have been conducted over the last 25 years to support the construction and maintenance of the International Space Station (ISS). During the nearly 2,000 hours of extra-vehicular activity (EVA), crew wore extra-vehicular mobility unit (EMU) "spacesuits" to help mitigate hazards of the space environment including impacts from micrometeoroid and orbital debris (MMOD) particles. The National Aeronautics and Space Administration (NASA) conducts detailed EMU MMOD risk analyses as part of the ISS EVA review and approval process. This paper provides a general historical overview of the ISS EVA MMOD risks and the associated risk assessment process. The NASA Johnson Space Center (JSC) Hypervelocity Impact Technology (HVIT) Team produces the ISS EVA MMOD risk analyses using the Bumper MMOD risk analysis code in conjunction with detailed information about the EVA including crew member EVA work sites, crew translation paths, suit orientation, and durations. Detailed physical models of the EMU spacesuit and the ISS are included and tailored for each EVA analysis. Two types of MMOD risk are included: (1) Penetration, and (2) Catastrophic. Penetration risk is for any size leak in the EMU suit. Catastrophic risk is a subset of Penetration Risk and only includes penetrations that cause a 4mm diameter hole (or larger) in the pressure-maintaining "bladder" layer of the EMU suit. This size hole will exceed the ability of the EMU suit to compensate. The MMOD risk analyses also utilize the latest orbital debris environment and meteoroid environment models including additional transient factors to account for recent satellite break-ups and annual meteor storms. These additional factors and the associated increase in EVA MMOD risk are considered when scheduling EVAs to reduce EMU MMOD risk.

1. INTRODUCTION

For nearly 35 years, the National Aeronautics and Space Administration (NASA) Johnson Space Center (JSC) Hypervelocity Impact Technology (HVIT) facility has been conducting micrometeoroid and orbital debris (MMOD) risk assessments of spacecraft including the International Space Station (ISS), Space Shuttle, Orion, Gateway, and commercial spacecraft. The results of these assessments are used to help meet MMOD design and operations safety requirements [1].

During preparations for ISS in the late-1990s, HVIT conducted MMOD risk assessments of the Extravehicular Mobility Unit (EMU) "spacesuits" that would be used during the hundreds of future Extravehicular Activity (EVA) "spacewalks" needed for ISS assembly and maintenance [2].

Preparations for initial EMU MMOD risk assessments included characterizing how the spacesuit materials would respond to high-speed MMOD particle impacts. Two initial "hypervelocity impact" (HVI) test series were conducted in 1997 to provide data for development of ballistic limit equations (BLE) used in the assessment [2],[3],[4]. In parallel with the testing effort, a special type of three-dimensional model of the EMU was developed specifically for MMOD risk analysis. This EMU model was produced in early-1997 and first used for MMOD risk assessments in July 1997.

These initial EMU assessments examined free-flying suit orientation MMOD risk sensitivities. Other assessments examined the effects on EMU risk when working near large space structures such as the ISS, Mir Space Station, and Space Shuttle. EMU MMOD risk assessments were provided to the EVA Project Office for Space Shuttle Transportation System (STS) missions STS-81, STS-82, STS-87, as well as EVAs hosted from the Mir Space Station in 1997. These early assessments led the way to more complex EVA timeline-specific MMOD risk assessments that included crewmembers working at multiple worksite locations, suit orientations and on specific timelines.

Following the loss of the Space Shuttle Columbia in 2003 and subsequent Return-to-Flight (RTF) in mid-2005, HVIT began producing EVA-specific MMOD risk assessments for each ISS EVA starting with those on the STS-116 mission to ISS in late-2006.

The following is an overview of the ISS EVA MMOD risk assessment process and a historical review of the ISS EVA MMOD assessed risks since STS-116. Note that ISS EVAs prior to STS-116 and those using Russian Orlan Suits are not included in this review.

2. GENERAL RISK ASSESSMENT PROCESS

The general MMOD risk assessment process is shown in Figure 1. The centerpiece of this process is the "Bumper" MMOD risk assessment code [5].

The iterative process begins with defining the spacecraft "geometry" (i.e., physical shape), MMOD environment models, operating parameters, and failure criteria. Bumper uses these to calculate the probability of not exceeding the failure criteria for each spacecraft surface.

Bumper was developed in the mid-1980s by Boeing for use on the Space Station Freedom program. In 1991, NASA HVIT group updated the code to "Bumper-II" for use on the ISS and Space Shuttle programs. Bumper has been under software configuration control continuously since that time. The HVIT Bumper Configuration Control Board (CCB) is responsible for all aspects of the code. The latest version (Bumper 3) is available for use on U.S. Government-related programs through the NASA Johnson Space Center (JSC) Technical Transfer Office (TTO).

The MMOD risk results from Bumper are then compared to the overall protection requirement for the spacecraft. If the requirement is not met, then the inputs are reviewed and modified if necessary. If changes were made to any of the inputs, then Bumper is run again and another comparison is made to the requirement. The process is repeated until the requirement is met and no additional input changes are necessary.

If the damage equations were preliminary, then impact test data on samples representative of the spacecraft hardware may be necessary to verify the damage equations.

If the overall MMOD protection requirement still has not been met after all input modifications and iterations have been conducted, then hardware modifications to enhance the impact resistance of higher-risk MMOD shielding is necessary. This "shielding enhancement" often consists of including ballistic fabrics within or on high-risk hardware but can also consist of a wide variety of other solutions such as operational changes to reduce MMOD impacts via attitude adjustment [14].

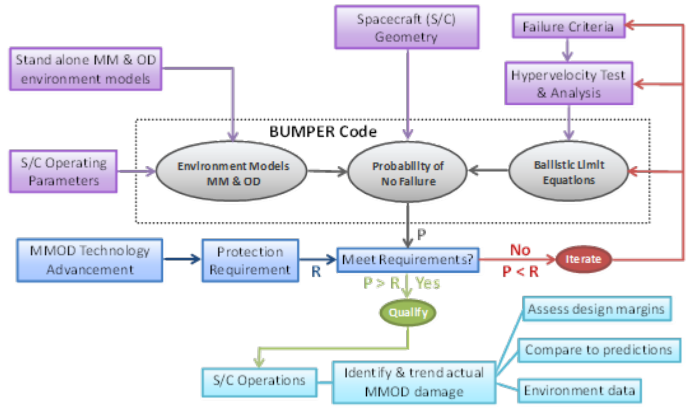

FIGURE 1: General MMOD Risk Assessment Process [5],[14]

3. EVA MMOD RISK ASSESSMENT

3.1 EMU Finite Element Model

The physical shape of the EMU is specified using a special type of Finite Element Model (FEM) as shown in Figure 2. The FEM consists of thin triangular and quadrilateral polygons that collectively define the entire outer surface of the EMU. Bumper essentially uses these polygons as MMOD particle impact targets.

Bumper can deliver risk results for a single polygon or groups of polygons. Each polygon is assigned a unique "element" identification (EID) number. The analyst uses EID numbers to specify to Bumper which regions of the EMU suit to include in the assessment. A contiguous range of EID numbers is assigned to each hardware item to make requesting results for that item easier. Each element also has 3 or 4 corner "nodes" each with 3-dimensional coordinates that provide Bumper with the location and orientation of the outer polygon surface. Each element is also assigned a material "Property Identification" (PID) number. The PID number is linked to a specific BLE and associated inputs. A single PID number can be assigned to multiple elements. The BLE allows Bumper to determine if an impacting MMOD particle will cause damage that exceeds the failure criteria for that surface.

FEM element colors are not used by Bumper but are instead assigned and used by the modeler to aid in visually identifying different hardware regions. Regions that share the same BLE are often assigned the same color, but not always. The current EMU FEM has 41 of these regions. By convention, PID #1 is reserved for FEM regions that represent hardware that is present in the assessment but that will not carry any MMOD risk. For the EVA MMOD risk assessment, PID #1 is primarily assigned to the ISS FEM.

The EMU BLEs fall into two general categories of "soft goods" and "hard goods." Soft goods are represented by the fabric portions of the suit including the Thermal Micrometeoroid Garment (TMG), gloves, and boots. The hard goods include the helmet, connection rings, Hard-Upper Torso (HUT), Display and Control Module (DCM), Primary Life Support System

(PLSS), Simplified Aid for EVA Rescue (SAFER), helmet mounted lights, and cameras.

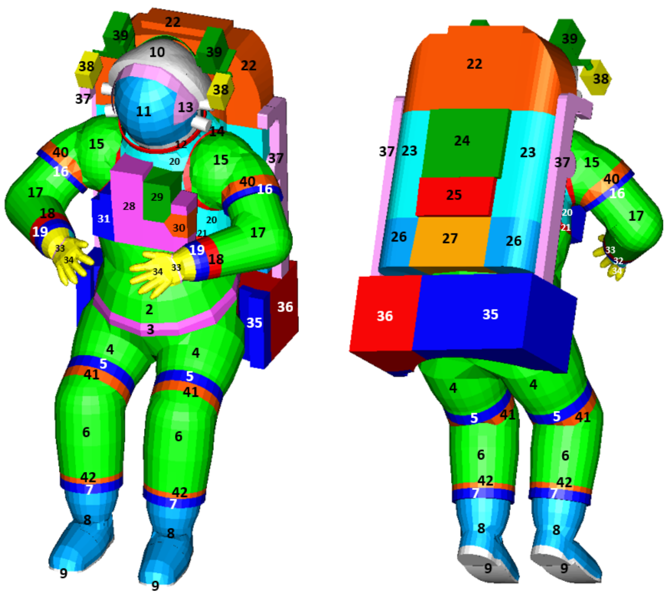

FIGURE 2: EMU MMOD Risk Assessment Finite Element Model

PID #	EID Range		Region Description
2	1	220	Lower Torso - SSA TMG
3	221	254	Lower Torso - Bearings/Sizing Rings
4	255	532	Lower Torso - SSA TMG
5	533	628	Lower Torso - Bearings/Sizing Rings
6	677	1062	Lower Torso - SSA TMG
7	1111	1206	Lower Torso - Bearings/Sizing Rings
8	1207	1642	Boot TMG
9	1643	1824	Boot - Heel & Sole
10	1825	3106	Helmet - EVVA Shell
11	3107	3410	Helmet - Face Plate
12	3411	3602	Helmet - Bearings/Sizing Rings
13	3603	3778	Helmet - Eyeshades
14	3779	3842	Arms - Bearings/Sizing Rings
15	3843	4248	Arms - SSA TMG
16	4363	4458	Arms - Bearings/Sizing Rings
17	4459	4858	Arms - SSA TMG
18	4859	4906	Arms - Gauntlet/SSA TMG
19	4907	5050	Arms - Gauntlet/Wrist Connect
20	5051	5526	Upper Torso - HUT
21	5527	5568	Upper Torso - Bearings/Sizing Rings
22	5569	6504	PLSS - Other PLSS Equipment
23	6505	7396	PLSS - Primary O2
24	7397	7672	PLSS - METOX CCC
25	7673	7832	PLSS - Advanced Battery
26	7833	8384	PLSS - Secondary O2
27	8385	8613	PLSS - Other PLSS Equipment
28	8614	8633	DCM
29	8634	8638	DCM - Controls and Display
30	8639	8645	DCM - Multiple Connector
31	8646	8656	DCM
32	8657	8798	Gloves - Palm
33	8799	8858	Gloves - Gimbals and Palm bar
34	8859	10160	Gloves - Glove Back and Fingers
35	10161	11050	Safer - Base - Non-tank
36	11051	11452	Safer - Base - Tank
37	11453	12596	Safer - Thruster Supports
38	12597	13014	Head Lights - Lights
39	13015	14566	Head Lights - Light Base & Head Mount
40	4249	4362	Arms - SSA TMG Overlap
41	629	676	Thigh TMG Overlap
42	1063	1110	Ankle TMG Overlap

FIGURE 3: EMU Finite Element Model Suit Regions

3.2 ISS Finite Element Model

The ISS provides a degree of incidental protection to the EMU suit by blocking some potential MMOD impacts. This MMOD "shadowing" effect can significantly reduce EMU MMOD risk. The effect is included in the EVA EMU risk assessment by including the ISS model with the EMU FEM.

The ISS portion of the FEM includes all large ISS modules and truss but not the large ISS solar arrays nor radiators. The ISS FEM shown in Figure 4 is of sufficient fidelity to represent the shadowing effect for the EVA MMOD risk assessments.

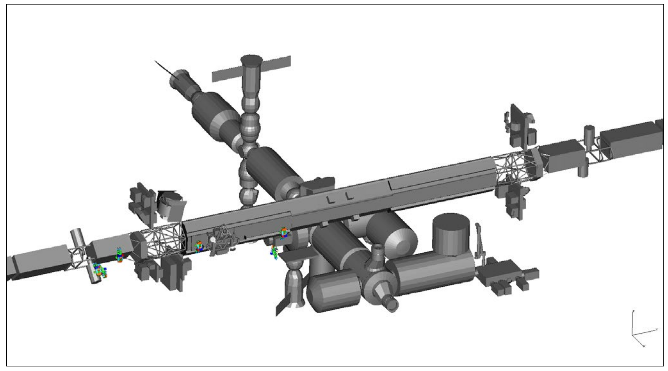

FIGURE 4: ISS EVA MMOD Risk Assessment FEM

3.3 Combined ISS & EMU Finite Element Model

Multiple instances of the EMU FEM are positioned around the ISS FEM. These instances represent the EVA timeline-specific worksite locations and suit orientations. An ISS-EVA FEM is produced for each EVA since changes in the EVA worksite locations, EMU suit orientation, and the time spent at each worksite location changes and affects the MMOD risk results. Figure 5 shows a close-up of the ISS EVA MMOD risk assessment FEM. Translation paths between worksite locations are typically not included in the FEM due to the short duration that the EMU suit is located along the translation path.

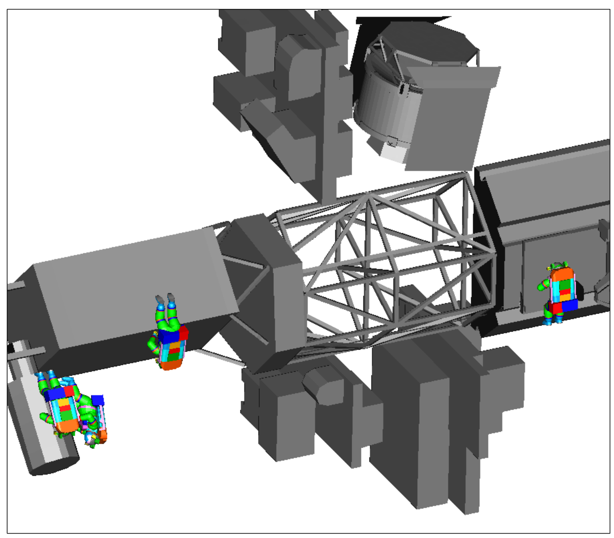

FIGURE 5: Combined ISS & EMU FEM with multiple EMU worksite locations on ISS truss

4. MMOD ENVIRONMENT MODELS

The ISS EVA MMOD risk assessment uses the latest available NASA MMOD environment models. Note that these models represent dynamic environments and as such are updated over time. Model updates are unscheduled but generally occur approximately every 2 to 6 years. Major orbital debris events such as satellite collisions and breakups can influence when an environment model is updated.

The NASA Meteoroid Engineering Model (MEM) is the responsibility of the Meteoroid Environment Office (MEO) at the NASA Marshall Space Flight Center (MSFC). These models represent the latest and best characterization of the meteoroid environment.

The latest version - MEM 3 – has been used for ISS EVA MMOD risk assessments since October 2019. Bumper currently includes three historical meteoroid reference models, two lunar surface meteoroid "secondaries" models, and MEM3. The meteoroid velocities can be extremely high as shown in Figure 6. A detailed description of MEM3 can be found in [6].

An additional meteoroid shower factor is included in the ISS EVA MMOD risk assessment to account for any last-minute changes in meteoroid flux estimates. An initial estimate of these factors is provided by MEO annually as well as the shower factor estimate within a month or so of the EVA. This final shower factor is used in the ISS EVA MMOD risk assessment.

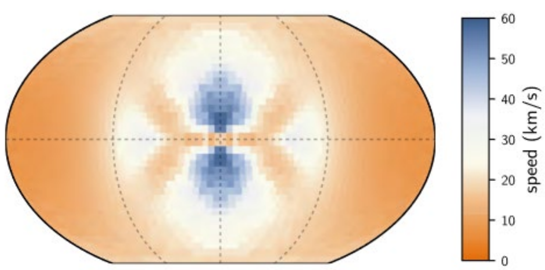

FIGURE 6: MEM3 Showing Average Interplanetary Meteoroid Speed [6]

4.1 Orbital Debris Environment

The NASA Orbital Debris Engineering Model (ORDEM) is the responsibility of the Orbital Debris Program Office (ODPO) at the NASA Johnson Space Center (JSC). Four orbital debris environment models have been used for ISS EVAs. The latest version – ORDEM3.2 – has been used for ISS EVA MMOD risk assessments since November 2022. A detailed description of the similarly-structured ORDEM3.1 model can be found in [7],[8],[9].

An additional orbital debris factor is included in the ISS EVA MMOD risk assessment to account for satellite collisions and breakups. This factor is provided by the ODPO prior to the EVA and is used in the ISS EVA MMOD risk assessment.

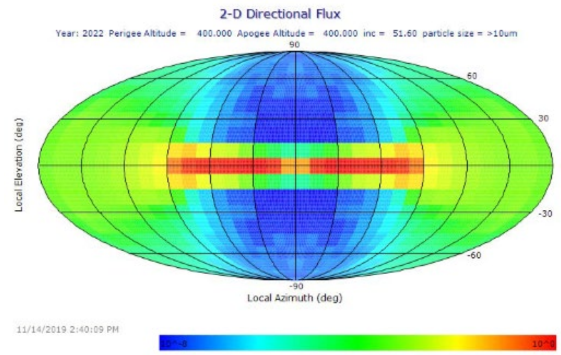

FIGURE 7: ORDEM 3.1 2-D Directional Flux Projection [10]

4.2 General Comparison of MM and OD

While they may seem to be somewhat similar threats to spacecraft, MM and OD environments are quite different. They are each high-velocity impact threats to spacecraft, but they differ in particle densities, velocities, directionalities, and flux concentrations [6],[7],[8]. Orbital debris particle densities vary considerably and can be much higher than micrometeoroids. Impact velocities for micrometeoroids (Figure 6) can be many times higher than those for orbital debris. While micrometeoroids are present throughout the solar system, orbital debris are currently only present near Earth. In the ISS EVA environment, orbital debris have a more limited set of approach directions (Figure 7) whereas meteoroids can approach from a wider range of directions. Based on all ISS EVA EMU MMOD risk assessments, orbital debris represents about 70% of the total MMOD risk and meteoroids the remaining 30%.

4.3 MMOD Environment Model Updates

Following updates of either MM or OD model, HVIT conducts assessments to determine the effect of the new model. Following transition from the 1996 orbital debris engineering model (ORDEM1996) to the 2000 orbital debris engineering model (ORDEM2000) in 2002, EMU assessment results indicated that the EMU suit MMOD risk had increased [10]. This observation led to updates to the EMU MMOD risk assessment FEM as well as the need to conduct a series of hypervelocity impact tests to verify current BLEs and evaluate enhanced impact resistant suit material layups. Updates to the MMOD risk assessment FEM as well as refining existing BLEs based on additional test data were sufficient to reduce the risk [10].

4.4 EMU MMOD Failure Criteria

The EMU MMOD failure criterion are: (1) Any Size Leak; and (2) Catastrophic Leak.

Any Size Leak:

For the soft-goods, this failure occurs when a MMOD particle penetrates the suit's pressure-maintaining "bladder" layer shown in Figure 8. For the hard-goods parts of the suit, this is specified using a level of kinetic energy to comparably penetrate the component. This failure criterion includes any size leak in the bladder layer.

Catastrophic Leak:

This failure occurs when a MMOD particle penetrates the bladder layer resulting in a hole measuring 4mm and larger. This failure is a subset of "Any Size Leak" and as such has a lower risk of occurring. The 4mm diameter criterion is related to capabilities of the EMU suit to maintain pressure long enough to move to a safe location.

The above failure criteria are for soft-goods portions of the spacesuit (i.e., arms, legs, and briefs). Failure criteria and ballistic limit equations for other parts of the suit (the "hard-goods" described earlier) are also included in the any-size leak and catastrophic leak calculations.

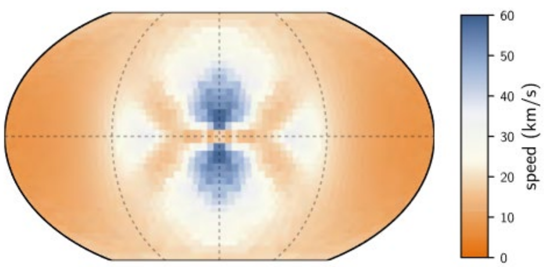

FIGURE 8: Thermal Micrometeoroid Garment Layers [11],[13]

5. ISS EVA MMOD Risk History

5.1 How Many ISS EVAs?

As of August 9th, 2023, there have been a total of 267 ISS EVAs [12]. These amount to almost 1,700 hours of 2-person EVA time or 3,400 hours of individual EMU exposure time. Of the 267 EVAs, 197 (74%) were conducted using EMU suits and the remaining 70 (26%) were conducted using Russian Orlan suits [12]. Of those 197 EMU suit EVAs, 133 have timeline-specific MMOD risk assessment results. These results are shown versus mission and time in Figures 9 & 10. These graphs span from December 2006 to August 2023. The time periods that each MM and OD model was used for the EVA MMOD risk assessments are shown along the bottom of the graph. These figure shows *Any Size Leak* risk and Catastrophic Leak risk by EVA and year.

5.2 Any Size Leak Risks

For nominal 6.5-hour duration 2-person EVAs, odds of suit leak risk ranged from 1 in 2,300 on United States (US) #71 Stage EVA4 (US-71) on 02/28/2021 to 1 in 18,100 (STS-113 EVA3 on 08/15/2007) with the average odds of suit leak risk at 1 in 6,677.

5.3 Catastrophic Leak Risks

Similarly, for nominal 6.5-hour duration 2-person EVAs, odds of suit catastrophic leak risk ranged from 1 in 13,700 (US-24 Stage EVA1 on 12/21/2013) to 1 in 60,525 (STS-120 EVA3 on 10/30/2007) with the average odds of suit leak risk at 1 in 28,586.

5.4 Why the increase in 2020-2022?

Figure 10 shows a noticeable increase in risk on the right side of the graph in the 2020-2022 timeframe. This was due to the change from the ORDEM 3.0 to the ORDEM 3.1 orbital debris environment model in conjunction with EMU BLE updates for higher-density debris particles populations, as well as the high-density meteoroid component that was included for the first time in MEM 3 [13].

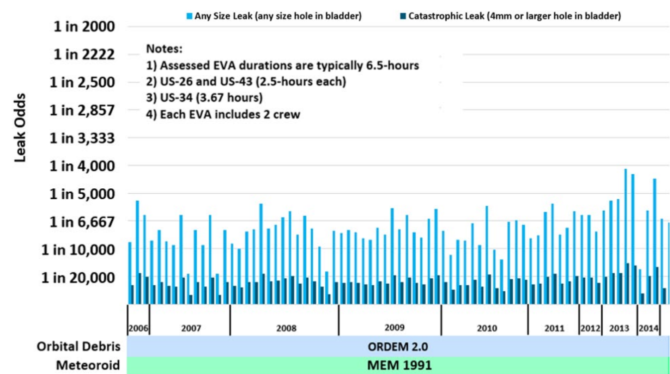

FIGURE 9: ISS EVA MMOD Risks versus Year and MMOD Environment (STS-116 to US-21)

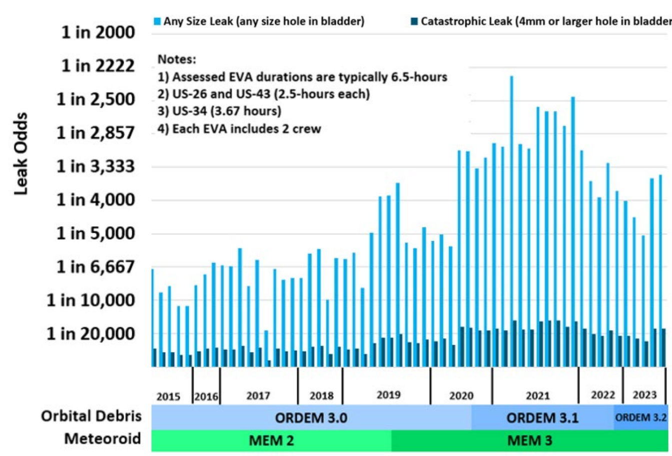

FIGURE 10: ISS EVA MMOD Risks versus Year and MMOD Environment (US-22 to US-88)

6. CONCLUSION

NASA has made significant efforts over the last 30 years to understand, characterize, assess, and reduce MMOD risk to ISS EVA crewmembers. Since 2006, detailed EVA MMOD risk assessments have been produced for all ISS EMU EVAs. These assessments incorporated the latest mission information including the latest MMOD environment models, suit damage equations, ISS altitude and orientation, crewmember worksites, suit orientations, meteoroid shower factors, and orbital debris break-up factors. The results of these assessments have been used by NASA to maintain awareness of the MMOD risks posed to ISS EVA crewmembers and have provided a basis for enhancing EMU suit resistance and improving crew safety.

TABLE 1: ISS EVA MMOD Risks versus Year and MMOD Environment (STS-116 to US-21)

EVA Date	EVA Category	Exp EVA	ORDEM Environment	MEM Environment	Odds Any Size	Odds Catastrophic
12/12/2006	STS-116	1	ORDEM2.0	1991	8,887	29,490
12/14/2006	STS-116	2	ORDEM2.0	1991	5,369	17,619
12/16/2006	STS-116	3	ORDEM2.0	1991	6,229	20,086
06/11/2007	STS-117	1	ORDEM2.0	1991	8,735	29,263
06/13/2007	STS-117	2	ORDEM2.0	1991	7,495	25,107
06/15/2007	STS-117	3	ORDEM2.0	1991	8,862	29,686
08/11/2007	STS-118	1	ORDEM2.0	1991	9,500	31,700
08/13/2007	STS-118	2	ORDEM2.0	1991	6,200	20,800
08/15/2007	STS-118	3	ORDEM2.0	1991	18,100	60,500
08/18/2007	STS-118	4	ORDEM2.0	1991	7,500	25,100
10/26/2007	STS-120	1	ORDEM2.0	1991	9,450	31,657
10/28/2007	STS-120	2	ORDEM2.0	1991	6,196	20,755
10/30/2007	STS-120	3	ORDEM2.0	1991	18,068	60,525
11/03/2007	STS-120	4	ORDEM2.0	1991	7,490	25,091
02/11/2008	STS-122	1	ORDEM2.0	1991	9,200	30,800
02/13/2008	STS-122	2	ORDEM2.0	1991	10,000	33,500
02/15/2008	STS-122	3	ORDEM2.0	1991	7,600	25,500
03/14/2008	STS-123	1	ORDEM2.0	1991	7,400	24,700
03/16/2008	STS-123	2	ORDEM2.0	1991	5,500	18,500
03/18/2008	STS-123	3	ORDEM2.0	1991	7,400	24,600
03/21/2008	STS-123	4	ORDEM2.0	1991	7,000	23,300
03/23/2008	STS-123	5	ORDEM2.0	1991	6,400	21,300
06/03/2008	STS-124	1	ORDEM2.0	1991	6,000	20,000
06/05/2008	STS-124	2	ORDEM2.0	1991	8,000	26,700
06/08/2008	STS-124	3	ORDEM2.0	1991	6,300	21,000
11/18/2008	STS-126	1	ORDEM2.0	1991	7,300	24,600
11/20/2008	STS-126	2	ORDEM2.0	1991	9,600	32,200
11/22/2008	STS-126	3	ORDEM2.0	1991	17,100	57,100
11/24/2008	STS-126	4	ORDEM2.0	1991	7,500	25,200
03/19/2009	STS-119	1	ORDEM2.0	1991	7,800	26,100
03/21/2009	STS-119	2	ORDEM2.0	1991	7,500	25,000
03/23/2009	STS-119	3	ORDEM2.0	1991	7,700	25,700
07/18/2009	STS-127	1	ORDEM2.0	1991	8,400	28,100
07/20/2009	STS-127	2	ORDEM2.0	1991	8,700	29,000
07/22/2009	STS-127	3	ORDEM2.0	1991	7,300	24,300
07/24/2009	STS-127	4	ORDEM2.0	1991	7,900	26,600
07/27/2009	STS-127	5	ORDEM2.0	1991	5,800	19,300
09/01/2009	STS-128	1	ORDEM2.0	1991	7,400	24,800
09/03/2009	STS-128	2	ORDEM2.0	1991	6,200	20,800
09/05/2009	STS-128	3	ORDEM2.0	1991	7,700	25,700
11/19/2009	STS-129	1	ORDEM2.0	1991	8,300	27,700
11/21/2009	STS-129	2	ORDEM2.0	1991	6,500	21,700
11/23/2009	STS-129	3	ORDEM2.0	1991	5,800	19,400
02/12/2010	STS-130	1	ORDEM2.0	1991	7,500	25,300
02/14/2010	STS-130	2	ORDEM2.0	1991	11,300	37,800
02/17/2010	STS-130	3	ORDEM2.0	1991	8,700	29,000
04/09/2010	STS-131	1	ORDEM2.0	1991	8,800	29,400
04/11/2010	STS-131	2	ORDEM2.0	1991	6,800	22,900
04/13/2010	STS-131	3	ORDEM2.0	1991	9,400	31,600
05/17/2010	STS-132	1	ORDEM2.0	1991	5,600	18,900
05/19/2010	STS-132	2	ORDEM2.0	1991	10,200	34,300
05/21/2010	STS-132	3	ORDEM2.0	1991	12,300	41,400
08/07/2010	US-15	2	ORDEM2.0	1991	6,700	22,100
08/11/2010	US-16	3	ORDEM2.0	1991	6,600	21,300
08/16/2010	US-17	4	ORDEM2.0	1991	7,000	22,900
02/28/2011	STS-133	1	ORDEM2.0	1991	8,500	28,300
03/02/2011	STS-133	2	ORDEM2.0	1991	8,100	27,100
05/20/2011	STS-134	1	ORDEM2.0	1991	6,000	20,200
05/22/2011	STS-134	2	ORDEM2.0	1991	5,500	18,500
05/25/2011	STS-134	3	ORDEM2.0	1991	8,000	26,800
05/27/2011	STS-134	4	ORDEM2.0	1991	7,200	24,300
07/12/2011	STS-135	1	ORDEM2.0	1991	5,900	19,900
08/30/2012	US-18	2	ORDEM2.0	1991	6,200	20,900
09/05/2012	US-19	3	ORDEM2.0	1991	6,200	20,900
11/01/2012	US-20	1	ORDEM2.0	1991	7,700	25,700
05/11/2013	US-21	2	ORDEM2.0	1991	5,900	20,400

TABLE 2: ISS EVA MMOD Risks versus Year and MMOD Environment (US-22 to US-88)

EVA Date	EVA Descripti	Exp EVA	ORDEM Environmen	MEM Environmen	Odds Any Leak	Odds Catastrophic
07/09/2013	US-22	2	ORDEM2.0	1991	5,400	18,000
07/16/2013	US-23	3	ORDEM2.0	1991	5,300	17,700
12/21/2013	US-24	1	ORDEM2.0	1991	4,100	13,700
12/24/2013	US-25	2	ORDEM2.0	1991	4,300	14,200
04/23/2014	US-26	1	ORDEM2.0	1991	16,000	52,000
10/07/2014	US-27	1	ORDEM2.0	1991	5,900	19,900
10/15/2014	US-28	2	ORDEM2.0	1991	4,400	14,800
02/21/2015	US-29	1	ORDEM3.0	MEM2	6,500	34,500
02/25/2015	US-30	2	ORDEM3.0	MEM2	6,800	36,300
03/01/2015	US-31	3	ORDEM3.0	MEM2	8,900	46,200
10/28/2015	US-32	1	ORDEM3.0	MEM2	8,200	43,900
11/06/2015	US-33	2	ORDEM3.0	MEM2	11,000	56,900
12/21/2015	US-34	1	ORDEM3.0	MEM2	10,900	55,000
01/15/2016	US-35	2	ORDEM3.0	MEM2	8,200	43,400
08/19/2016	US-36	1	ORDEM3.0	MEM2	7,200	36,600
09/01/2016	US-37	2	ORDEM3.0	MEM2	6,400	35,200
01/06/2017	US-38	1	ORDEM3.0	MEM2	6,500	38,100
01/13/2017	US-39	2	ORDEM3.0	MEM2	6,600	38,500
03/24/2017	US-40	3	ORDEM3.0	MEM2	5,600	31,000
03/30/2017	US-41	4	ORDEM3.0	MEM2	8,300	44,400
05/12/2017	US-42	1	ORDEM3.0	MEM2	6,200	34,600
05/23/2017	US-43	2	ORDEM3.0	MEM2	18,200	102,800
10/05/2017	US-44	1	ORDEM3.0	MEM2	6,800	36,400
10/10/2017	US-45	2	ORDEM3.0	MEM2	7,600	41,500
10/20/2017	US-46	3	ORDEM3.0	MEM2	7,500	39,800
01/23/2018	US-47	1	ORDEM3.0	MEM2	7,400	41,900
02/16/2018	US-48	3	ORDEM3.0	MEM2	5,900	32,500
03/29/2018	US-49	1	ORDEM3.0	MEM2	5,600	32,300
05/16/2018	US-50	2	ORDEM3.0	MEM2	10,000	50,200
06/14/2018	US-51	1	ORDEM3.0	MEM2	6,100	32,600
03/22/2019	US-52	1	ORDEM3.0	MEM2	6,200	37,700
03/29/2019	US-53	2	ORDEM3.0	MEM2	5,800	35,600
04/08/2019	US-54	3	ORDEM3.0	MEM2	8,500	49,800
08/21/2019	US-55	1	ORDEM3.0	MEM2	4,900	27,700
10/06/2019	US-56	1	ORDEM3.0	MEM3	3,900	22,700
10/11/2019	US-57	2	ORDEM3.0	MEM3	3,900	22,800
10/18.2019	US-58	3	ORDEM3.0	MEM3	3,600	20,200
11/15/2019	US-59	4	ORDEM3.0	MEM3	5,400	27,000
11/22/2019	US-60	5	ORDEM3.0	MEM3	5,600	27,900
12/02/2019	US-61	6	ORDEM3.0	MEM3	4,800	24,400
01/15/2020	US-62	7	ORDEM3.0	MEM3	5,300	26,300
01/20/2020	US-63	8	ORDEM3.0	MEM3	5,000	23,300
01/25/2020	US-64	9	ORDEM3.0	MEM3	5,500	29,800
06/26/2020	US-65	1	ORDEM3.1	MEM3	3,100	16,600
07/01/2020	US-66	2	ORDEM3.1	MEM3	3,100	17,200
07/16/2020	US-67	3	ORDEM3.1	MEM3	3,400	18,200
07/21/2020	US-68	4	ORDEM3.1	MEM3	3,200	18,200
01/27/2021	US-69	2	ORDEM3.1	MEM3	3,000	17,300
02/01/2021	US-70	3	ORDEM3.1	MEM3	3,000	18,400
02/28/2021	US-71	4	ORDEM3.1	MEM3	2,300	14,200
03/05/2021	US-72	5	ORDEM3.1	MEM3	3,000	17,800
03/13/2021	US-73	6	ORDEM3.1	MEM3	3,100	18,000
06/16/2021	US-74	2	ORDEM3.1	MEM3	2,600	14,700
06/20/2021	US-75	3	ORDEM3.1	MEM3	2,600	14,300
06/25/2021	US-76	4	ORDEM3.1	MEM3	2,600	14,200
09/12/2021	US-77	7	ORDEM3.1	MEM3	2,800	16,700
12/02/2021	US-78	1	ORDEM3.1	MEM3	2,500	14,500
03/15/2022	US-79	3	ORDEM3.1	MEM3	3,100	17,200
03/23/2022	US-80	4	ORDEM3.1	MEM3	3,600	20,100
11/15/2022	US-81	1	ORDEM3.2	MEM3	3,900	21,300
12/03/2022	US-82	3	ORDEM3.2	MEM3	3,300	18,500
12/22/0222	US-83	4	ORDEM3.2	MEM3	3,800	21,300
01/20/2023	US-84	5	ORDEM3.2	MEM3	4,000	21,500
02/02/2023	US-85	6	ORDEM3.2	MEM3	4,400	23,800
04/28/2023	US-86	2	ORDEM3.2	MEM3	5,100	26,200
06/09/2023	US-87	5	ORDEM3.2	MEM3	3,500	17,300
06/15/2023	US-88	6	ORDEM3.2	MEM3	3,500	17,200

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