

Executive Summary

The objective of this IMM support request is to provide a medical risk assessment for medical risk posture for long duration Mars DRMs, specifically an Accelerated Mars Mission (AMM) of 426 days with 30 four-person EVAs and a Standard Mars Mission (SMM) of 923 days with 401 four-person EVAs. The IMM was modified to simulate a Mars mission with partial-gravity EVAs. The simulation results are as follows:

- **Average number of Total of Medical Events (TME):**
 - For the (AMM) (426-day DRM): 156.45 events.
 - For the (SMM) (923-day DRM): 603.03 events.
- **Average Crew Health Index (CHI):**
 - For the AMM DRM: 91.56.
 - For the SMM DRM: 72.52.
- **Probability of consideration for Evacuation (EVAC):**
 - For the AMM DRM: 0.0625.
 - For the SMM DRM: 0.2940.
- **Probability of Loss of Crew Life (LOCL):**
 - For the AMM DRM: 0.0057.
 - For the SMM DRM: 0.0158.

Background

The IMM is a stochastic model that uses Monte Carlo methodology to simulate medical outcomes during spaceflight missions. The IMM consists of a three-step process. First, mission and crew member characteristics are specified to define a particular mission profile, or design reference mission (DRM). Next, medical events and outcomes during the space flight mission are randomly generated based on pre-defined incidence values and probability distributions. Finally, total crew health and mission impact outcomes are summarized. For this report, the primary outcomes of interest are average number of total medical events (TME), crew health index (CHI), need for evacuation (EVAC) and loss of crew life (LOCL).

The IMM is most useful for comparing risks across multiple mission profiles based on probable events and resource availability. Biased results may be incurred due to limitations of the model, but the bias will be consistent across mission profiles within the same service request.

Methods

Crew and Mission Parameters

The DRMs were configured using the crew profile shown in Table 1. The outcomes of certain IMM medical conditions are influenced by pre-existing medical history including: coronary artery calcium score (CAC), dental crowns, contact lenses, and history of prior abdominal surgery. Pre-existing conditions, as defined here, are consistent with historical U.S. crew data.

Table 1: DRM crew profile

	Sex	Crowns	EVA	CAC	Contacts	Prior Abdominal Surgery
Crew 1	Male	Yes	Yes	No	No	No
Crew 2	Male	No	Yes	Yes	No	No
Crew 3	Female	No	Yes	No	Yes	No
Crew 4	Female	No	Yes	No	No	Yes

Medical Conditions and Resources

The one hundred medical conditions currently included in the IMM are shown in Appendix B. However, to better approximate long duration missions with EVAs and partial gravity environments, the set of conditions was modified for this request as described in Appendix C. The incidence of IMM medical events occurring during simulated missions are based on historical mission and cohort data contained within the Integrated Medical Evidence Database (iMED). For each condition the percentage of “best case” and “worst case” scenarios are specified, as well as a defined set of medical resources that are used to treat the condition. The iMED entry for each condition details the specific medical resources and quantity necessary for treatment in both the best and worst-case scenarios. In-flight medical treatment is assumed to follow a specified protocol [5] or clinical practice guidelines for each medical condition and is constrained by resource availability on the ISS.

Model outcomes can be given for the all-treated (continuous resupply, e.g. ISS in low earth orbit), all-untreated (no Medkit) and baseline MedCap (Medkit without resupply). For exploration missions, the MedCap state should most closely resemble a real-world deep space mission where resupply is not possible but where utilization of partial and alternative treatment can occur.

For this service request, the “MedCap” results for the DRMs correspond to the set of resources baselined to ISS according to current iMED data.

Main Outcomes

The IMM primary medical outcomes include the number of total medical events (TME), crew health index (CHI), probability of Evacuation (EVAC), probability of Loss of Crew Life (LOCL), and required resources.

CHI is a calculated percentage using the quality-adjusted mission time lost (QAMTL) due to in-flight medical events and resources available to treat those conditions [2].

$$\text{CHI} = (1 - (\text{QAMTL} \div \text{Mission Length})) \times 100$$

For a given condition, QAMTL is determined by summing the product of functional impairment and duration for all three clinical phases of that condition: i) diagnosis and initial treatment, ii) ongoing treatment, and iii) end-state. CHI percent values range from 0-100, where zero represents complete crew impairment and one hundred represents a completely functional crew.

EVAC in the context of IMM means that medical evacuation from the ISS would be considered for

definitive treatment of the afflicted crew member(s). EVAC is considered an end state result if any of the following criteria are met: 1) potential LOCL; 2) potential significant permanent impairment; or 3) potential intractable pain. When EVAC is calculated by the IMM, no consideration has been given to the availability of a return vehicle or the likelihood of a successful clinical outcome should a return vehicle be available.

LOCL in the context of IMM should be interpreted to mean that the clinical scenario resulted in death of the affected crew member(s). In version 4.1 of the IMM, the simulation usually assigns each crew member only one end state of EVAC or LOCL. In rare instances a crewmember can get a condition that will go to EVAC or LOCL, and then develop another condition that will also go to EVAC or LOCL in the time between the onset of first condition and the EVAC or LOCL time. Both events are recorded as EVAC or LOCL outcomes. These assumptions should result in more accurate IMM forecasts for the occurrence of EVAC and LOCL as compared to the prior versions of the model. Catastrophic vehicle failures such as the Challenger and Columbia accidents, and MMOD (micrometeorite and orbital debris) are not considered as possible causes of EVAC and LOCL.

Required resources for treatment are tracked for each simulated mission trial. The number of each resource that is used to treat a given condition is decremented from available resources. If more of any particular resource is used than is available, then that resource is considered “depleted” in the MedCap (no resupply) scenario. Events that require a “depleted” resource are considered “partially treated” if only a portion of the required resources are available. If there are sufficient available alternate resources in the MedCap, the event is considered “fully treated.” If none of the resources are available to treat the event, the event is considered “untreated.” The initial quantities for medical resources are baselined to a fully stocked ISS medical kit (MedCap) for one simulation, a 5 lb.-constrained set of resources generated for this service request for the second simulation, and the summation of the optimized medical kit from IMM SR-201808-406 and the previously mentioned 5 lb.-constrained set of resources for the third simulation. Note that when an event is partially treated, its outcomes are based on a weighted average of the treated and untreated values. For example, if a condition has a 0% chance of going to EVAC in the best case treated scenario and a 0-100% chance of going to EVAC in the best case untreated scenario, then under best case partial treatment, it is possible the condition will go to EVAC.

Modeling Approach

One hundred thousand (100,000) trials were run for each DRM where each trial can be considered an individual “mission”. This ensures that the distribution of outcomes meet convergence criteria. Convergence criteria are met when there is less than or equal to a 5% change in the average standard

deviation of the CHI, EVAC, and LOCL primary model outcomes in the last 2 - 1,000 mission

increments. This last step is performed manually by the modelers using the IMM4ConvergenceReport.

IMM outcomes were determined for the DRMs using the ISS MedCap scenario where all conditions are treated, partially treated or untreated based on the available resources of the ISS MedCap without resupply. CHI is calculated as a percentage, with 95% confidence intervals (CIs) for the associated distributions. EVAC and LOCL are probabilities, with 95% CI for EVAC and LOCL obtained using bootstrap resampling of the simulation output [3]. In this report, TME, CHI, EVAC and LOCL results are presented. Features, assumptions and limitations pertinent to this report are described in a separate section below.

The IMM is baselined to ISS and does not simulate EVAs in partial-gravity environments. For this service request, in accordance with the assumption that crewmembers would perform EVAs in partial gravity environments, the set of conditions listed in Appendix C were invalidated outside the requested EVA windows (i.e. could only occur during the EVAs). These conditions are unlikely to occur during flight within the space vehicle due to normal ambient pressure and limited vehicle size consisting of a single module with limited movement of crew. However, these conditions could occur during EVAs in a partial-gravity environment with decreased ambient pressure. In this case, invalid means that an event cannot and did not occur. During the course of the simulation, an event might normally be considered invalid under items 2 and 3 listed below in “Features, Assumptions and Limitations of IMM Version 4.1.” That is, all events are considered valid when the occurrence is generated, but might become invalid as the simulation processed each event. To meet the assumption that the list of conditions in Appendix C could not occur outside the specified EVA windows, script that deems all the necessary events invalid immediately after event occurrence generation was written into the IMM MATLAB code. Once the necessary events were invalidated, the simulation continued as normal. To be clear, the script is not currently a feature of the IMM and was written specifically for this request.

For the Accelerated Mars Mission (AMM) (426-day DRM), EVAs were scheduled for 30 days, days 181 to 210, of the mission with 4 crew performing one EVA per day, for a total of 30 four-person EVAs. For the Standard Mars Mission (SMM) (923-day DRM), EVAs were scheduled as 5 days on, 2 days off, every week from days 181 to 741 of the mission with 4 crew performing one EVA per day on days with scheduled EVAs, for a total of 401 four-person EVAs.

Features, Assumptions and Limitations of IMM Version 4.1 [3]

1. All non-space adaption (SA) and non-extravehicular activity (EVA) related conditions have a uniform likelihood of occurring throughout the mission duration. With the exception of VIIP, Space Adaptation Syndrome conditions occur in the first 5 days of the mission, with a peak occurrence at 48 hours.
2. Individuals cannot get the same condition for which they are currently being treated (i.e. during Clinical Phase (CP) I and II).
3. EVAC and LOCL are generated for each medical event, and then the timing of the EVAC or LOCL is generated according to a specified distribution.
4. Individuals are no longer at risk for further conditions once their status changes to either EVAC or LOCL. From the start time of the EVAC or LOCL, the functional impairment of the crew member is assumed to be 100%.
5. When the status of a crew member changes to EVAC, only one crew member is evacuated.
6. The IMM assumes that, per crew member, the first condition requiring a specific therapy utilizes all resources required for treating that condition before a second condition has access to those resources.
7. Most medical conditions, with exceptions including acute radiation syndrome (triggered by Solar Particle Events) and EVA-linked conditions (triggered by EVA events), occur independently of the occurrence of mission events and other medical conditions. Currently there is no correlation or association within or between crew members for most medical conditions.
8. The model assumes another crew member is available to act as caregiver but does not track the time impact of providing this care.
9. Medical procedures are accurately followed and successful; no mistakes occur in executing medical procedures.
10. Crew medical skill level and preflight/inflight training is not modeled.
11. All diagnoses are 100% accurate.
12. All pharmaceuticals maintain maximum efficacy.
13. All medical events receive the appropriate treatment.
14. All medical events respond to the treatment as expected terrestrially.
15. All medical equipment is 100% reliable.
16. For each of the medical conditions specified in iMED, all crew members with the same characteristics (sex, presence of CAC, crowns, contacts, history of abdominal surgery) have the same likelihood distribution of experiencing the condition.
17. All crew members are assumed to have all intrinsic body parts intact (i.e. appendix, gall bladder, and uterus or prostate, etc.).
18. IMM assumes ISS power, potable water and oxygen resources are always available in unlimited supply.
19. No Russian medical capabilities aboard the ISS are available to US crew members in this model.

20. Medical capabilities do not include the use of personal crew carry-on items contained in the Individual Medical Accessories Kit, (IMAK).
21. If a crew member is undergoing treatment for concurrent medical conditions requiring the same consumable resource, the crew member will only utilize resources at the level required by the condition that requires the most resources.
22. If the primary resource required for treating a medical condition is unavailable, one or more alternative resources are considered, if appropriate. One example might be using acetaminophen in place of ibuprofen.
23. Total quantities of a consumable medical resource requiring a daily dose will be adjusted if a dosage schedule runs past the end of the mission.
24. If a solar particle event causes acute radiation sickness in one or more crew members, IMM assumes the condition begins identically in all affected crew members at the beginning of the solar particle event.
25. The IMM does not decrement non-consumable items and allows all non-consumable items to be used simultaneously by multiple astronauts (e.g. blood pressure cuff).

Results

The IMM MedCap results for TME, CHI, EVAC, and LOCL for the simulated DRMs are presented in the tables below. Table 2 and Figure 1 show the average number of total medical events (TME) during the mission across all the DRMs. Table 3 and figure 2 show the average CHI across all the DRMs. Table 4 along with Figure 3 and Figure 4 show the probability of EVAC and LOCL across all of the DRMs. Note that in the figures cc corresponds to cm^3 .

Table 2: Average Number of TME for the DRMs

		TME	95% CI	
AMM - 426-day DRM	MedCap	156.45	130	182
SMM - 923-day DRM	MedCap	603.03	482	673

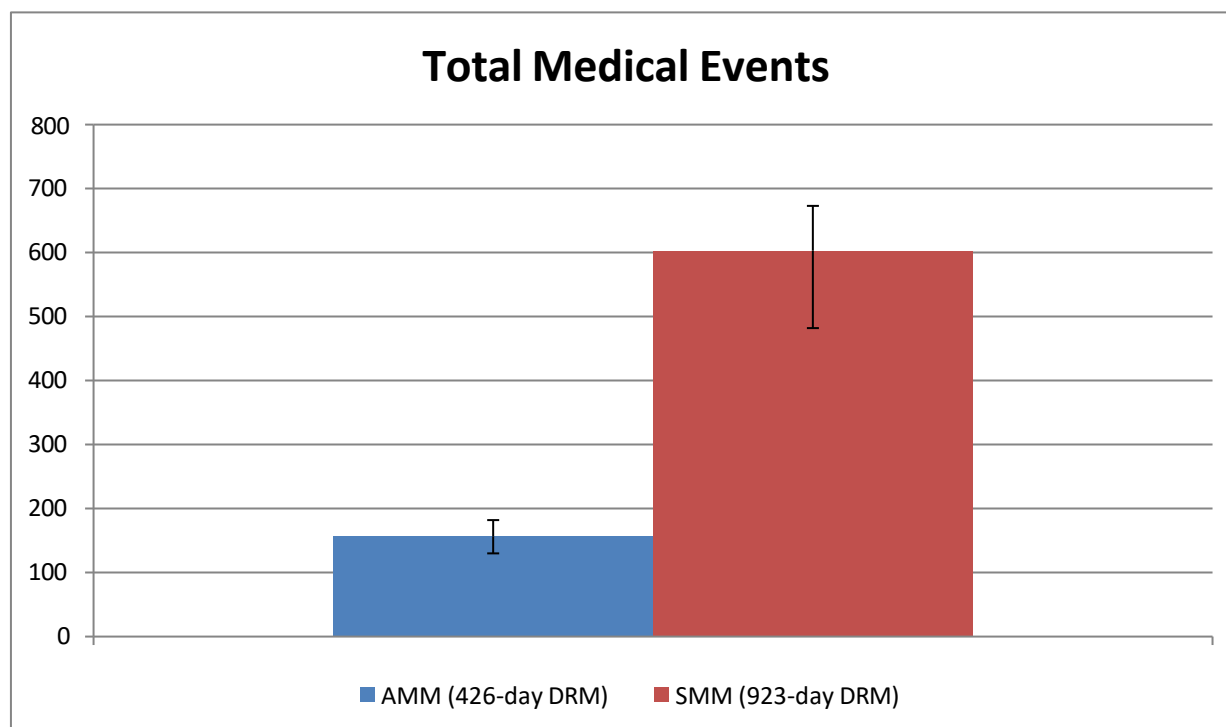


Figure 1: Average Number of TME for the DRMs

Table 3: Average CHI for the DRMs

		CHI	95% CI	
AMM - 426-day DRM	MedCap	91.56	75.87	97.76
SMM - 923-day DRM	MedCap	72.52	56.33	84.24

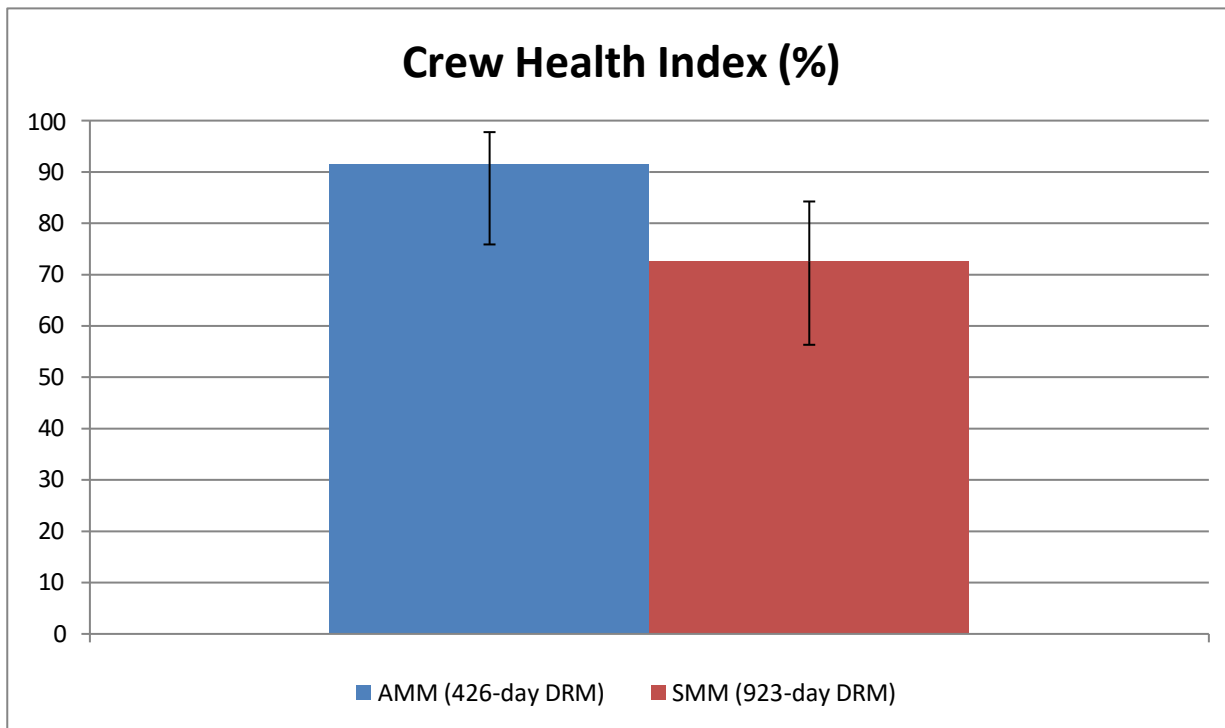


Figure 2: Average CHI for the DRMs

Table 4: Probability of EVAC and LOCL for the DRMs

		EVAC			LOCL		
		Probability	95% CI		Probability	95% CI	
AMM - 426-day DRM	MedCap	0.0625	0.0610	0.0641	0.0057	0.0053	0.0062
SMM - 923-day DRM	MedCap	0.2940	0.2911	0.2967	0.0158	0.0151	0.0166

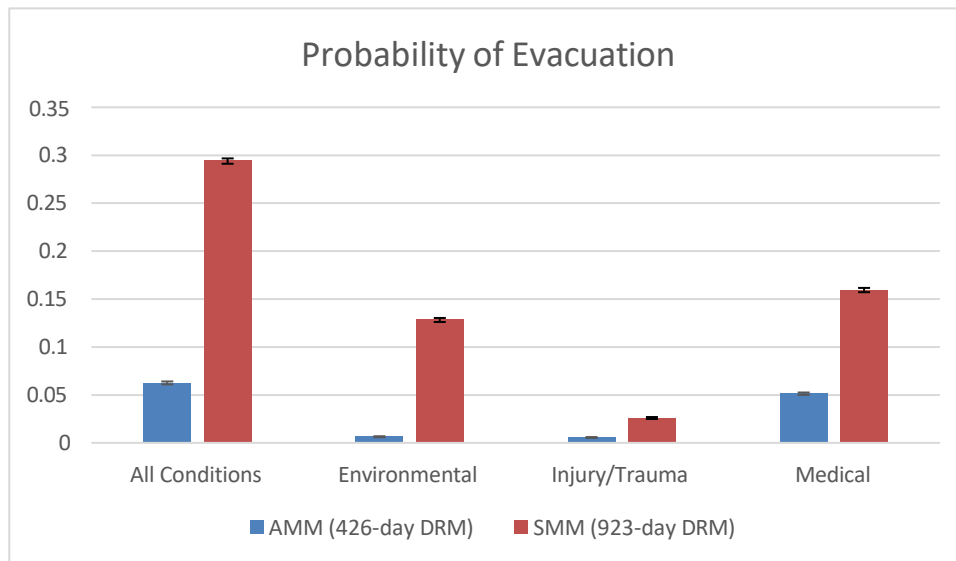


Figure 3: Probability of EVAC for the DRMs

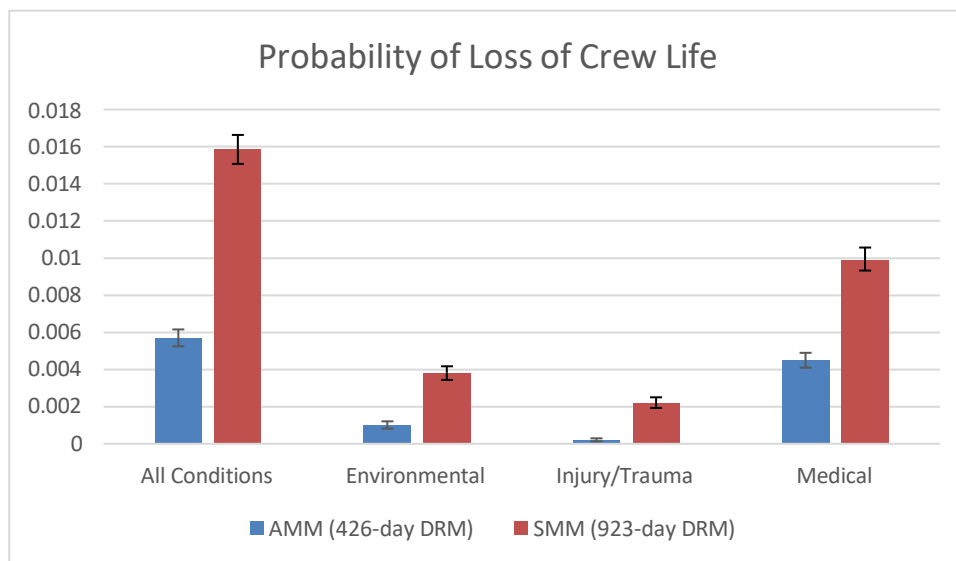


Figure 4: Probability of LOCL for the DRMs

Table 5 and Table 6 show the top ten influential conditions for EVAC the AMM and SMM DRMS respectively.

Table 7 and Table 8 present the top ten influential conditions for LOCL for those same two missions

respectively. Combined instances of influential conditions (i.e. independent of best or worst

case, treated, partially treated or untreated) for EVAC and LOCL for both DRMs are shown in Appendix D.

Table 5: AMM (426-day) DRM; Top Ten Influential Conditions for EVAC

Scenario	Treated	Medical Condition	Category	Total EVAC	Percent Contribution	Cumulative Percent
WORST CASE	PARTIAL	HERPES ZOSTER REACTIVATION (SHINGLES)	MEDICAL	991	15.36	15.36
WORST CASE	TREATED	NEPHROLITHIASIS	MEDICAL	460	7.13	22.49
WORST CASE	TREATED	SEPSIS	MEDICAL	367	5.69	28.18
WORST CASE	PARTIAL	NEPHROLITHIASIS	MEDICAL	283	4.39	32.57
WORST CASE	PARTIAL	URINARY TRACT INFECTION	MEDICAL	273	4.23	36.80
BEST CASE	PARTIAL	EYE CHEMICAL BURN	ENVIRONMENTAL	261	4.05	40.85
WORST CASE	TREATED	DENTAL ABSCESS	MEDICAL	237	3.67	44.52
WORST CASE	TREATED	STROKE (CEREBROVASCULAR ACCIDENT)	MEDICAL	233	3.61	48.13
BEST CASE	TREATED	SMALL BOWEL OBSTRUCTION	MEDICAL	212	3.29	51.42
WORST CASE	TREATED	WRIST FRACTURE	INJURY/TRAUMA	204	3.16	54.58

Table 6: SMM (923-day) DRM; Top Ten Influential Conditions for EVAC

Scenario	Treated	Medical Condition	Category	Total EVAC	Percent Contribution	Cumulative Percent
BEST CASE	PARTIAL	DECOMPRESSION SICKNESS SECONDARY TO EXTRAVEHICULAR ACTIVITY	ENVIRONMENTAL	10406	30.78	30.78
WORST CASE	PARTIAL	HERPES ZOSTER REACTIVATION (SHINGLES)	MEDICAL	3886	11.49	42.27
WORST CASE	PARTIAL	URINARY TRACT INFECTION	MEDICAL	2719	8.04	50.32
BEST CASE	PARTIAL	EYE CHEMICAL BURN	ENVIRONMENTAL	2165	6.40	56.72
WORST CASE	PARTIAL	NEPHROLITHIASIS	MEDICAL	973	2.88	59.60
WORST CASE	PARTIAL	EYE INFECTION	MEDICAL	787	2.33	61.92
WORST CASE	PARTIAL	SKIN LACERATION	INJURY/TRAUMA	629	1.86	63.78
BEST CASE	PARTIAL	EYE CORNEAL ULCER	MEDICAL	617	1.82	65.61
WORST CASE	PARTIAL	DENTAL ABSCESS	MEDICAL	594	1.76	67.37
WORST CASE	TREATED	NEPHROLITHIASIS	MEDICAL	569	1.68	69.05

Table 7: AMM (426-day) DRM; Top Ten Influential Conditions for LOCL

Scenario	Treated	Medical Condition	Category	Total LOCL	Percent Contribution	Cumulative Percent
WORST CASE	TREATED	SEPSIS	MEDICAL	181	31.75	31.75
WORST CASE	TREATED	STROKE (CEREBROVASCULAR ACCIDENT)	MEDICAL	121	21.23	52.98
WORST CASE	TREATED	MEDICATION OVERDOSE/ADVERSE REACTION	MEDICAL	46	8.07	61.05
WORST CASE	TREATED	TOXIC EXPOSURE (AMMONIA)	ENVIRONMENTAL	43	7.54	68.60
WORST CASE	TREATED	APPENDICITIS	MEDICAL	31	5.44	74.04
WORST CASE	PARTIAL	BURNS SECONDARY TO FIRE	ENVIRONMENTAL	30	5.26	79.30
WORST CASE	PARTIAL	SEPSIS	MEDICAL	23	4.04	83.33
WORST CASE	TREATED	SUDDEN CARDIAC ARREST	MEDICAL	22	3.86	87.19
WORST CASE	TREATED	CHEST INJURY	INJURY/TRAUMA	9	1.58	88.77
WORST CASE	TREATED	TRAUMATIC HYPOVOLEMIC SHOCK	INJURY/TRAUMA	8	1.40	90.18

Table 8: SMM (923-day) DRM; Top Ten Influential Conditions for LOCL

Scenario	Treated	Medical Condition	Category	Total LOCL	Percent Contribution	Cumulative Percent
WORST CASE	PARTIAL	SEPSIS	MEDICAL	233	14.59	14.59
WORST CASE	TREATED	STROKE (CEREBROVASCULAR ACCIDENT)	MEDICAL	233	14.59	29.18
WORST CASE	TREATED	SEPSIS	MEDICAL	166	10.39	39.57
WORST CASE	PARTIAL	DECOMPRESSION SICKNESS SECONDARY TO EXTRAVEHICULAR ACTIVITY	ENVIRONMENTAL	120	7.51	47.09
WORST CASE	TREATED	DECOMPRESSION SICKNESS SECONDARY TO EXTRAVEHICULAR ACTIVITY	ENVIRONMENTAL	95	5.95	53.04
WORST CASE	TREATED	MEDICATION OVERDOSE/ADVERSE REACTION	MEDICAL	89	5.57	58.61
WORST CASE	TREATED	TRAUMATIC HYPOVOLEMIC SHOCK	INJURY/TRAUMA	85	5.32	63.93
WORST CASE	TREATED	TOXIC EXPOSURE (AMMONIA)	ENVIRONMENTAL	71	4.45	68.38
WORST CASE	TREATED	APPENDICITIS	MEDICAL	67	4.20	72.57
WORST CASE	TREATED	HEAD INJURY	INJURY/TRAUMA	60	3.76	76.33

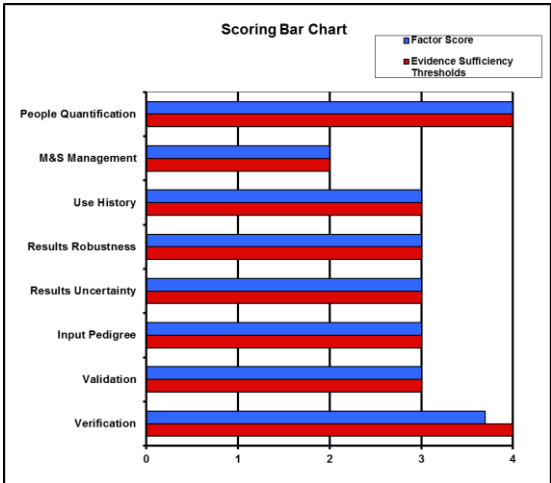
Discussion

The results of this simulation reveal that there are more total medical events in the SMM (923-day) DRM compared to the AMM (426-day) DRM. This significant increase in total medical events in the SMM DRM is due to the longer duration and the increased number of EVAs in this DRM compared to the AMM DRM. The mean CHI for the SMM DRM is lower than the mean CHI for the AMM DRM. This is due to the longer duration of this DRM and the increased number of EVAs in this DRM compared to the AMM DRM resulting in a greater depletion of resources. The probability of consideration for EVAC is greater in the SMM DRM than in the AMM DRM. This is due to the longer duration of this DRM and the increased number of EVAs in this DRM compared to the AMM DRM resulting in a greater depletion of resources. The probability of LOCL is greater in the SMM DRM than in the AMM DRM. This is due to the longer duration of this DRM and the increased number of EVAs in this DRM compared to the AMM DRM resulting in a greater depletion of resources.

References

1. Integrated Medical Model Project. Integrated Medical Model Operations Plan. JSC-66114. 2011. Houston, TX, NASA, Johnson Space Center. *Ref Type: Report*
2. Integrated Medical Model Project. Integrated Medical Model Software Requirements Specification. IMM-SFTWR-008. 2017. Houston, Texas, KBRwyle Integrated Science, Technology and Engineering. *Ref Type: Report*
3. Integrated Medical Model Project. Integrated Medical Model version 4 Assumptions and Limitations. IMM-GEN-300. 2017. Houston, Texas, KBRwyle Integrated Science and Engineering Space Medicine Information Technology. *Ref Type: Report*
4. NASA-STD-7009: Standard for Models and Simulations (2008). NASA: Washington, DC.
5. ISS Medical Checklist (Med CL), 04 June 2014, NASA Johnson Space Center, Medical Operations Group
6. ISS PRA Model v.3.2.0. ISS PRA Fire and Ammonia Model Contributions to the Integrated Medical Model. 2015. Houston, Texas, NASA Johnson Space Center. *Ref Type: Report*

Appendix A: IMM Status at Time of Service Request Report

Validation status for IMM	IMM V&V Matrix: The following bar chart shows the IMM v4.1 MATLAB status of IMM validation for each IMM element listed. Scoring Bar Chart <table><thead><tr><th>IMM Element</th><th>Factor Score</th><th>Evidence Sufficiency Thresholds</th></tr></thead><tbody><tr><td>People Quantification</td><td>4</td><td>4</td></tr><tr><td>M&S Management</td><td>2</td><td>2</td></tr><tr><td>Use History</td><td>3</td><td>3</td></tr><tr><td>Results Robustness</td><td>3</td><td>3</td></tr><tr><td>Results Uncertainty</td><td>3</td><td>3</td></tr><tr><td>Input Pedigree</td><td>3</td><td>3</td></tr><tr><td>Validation</td><td>3</td><td>3</td></tr><tr><td>Verification</td><td>3.7</td><td>4</td></tr></tbody></table>	IMM Element	Factor Score	Evidence Sufficiency Thresholds	People Quantification	4	4	M&S Management	2	2	Use History	3	3	Results Robustness	3	3	Results Uncertainty	3	3	Input Pedigree	3	3	Validation	3	3	Verification	3.7	4																															
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Compliance with NASA-Standard-7009 requirements	IMM Compliance Matrix: The IMM has no waivers to any of the requirements in the NASA-Standard-7009 for Models and Simulations (6); however there are certain requirements that are not applicable to the IMM and other requirements where IMM compliance has not yet been fully attained. <table><thead><tr><th>Compliant</th><th>Compliance Incomplete</th><th>Not applicable</th></tr></thead><tbody><tr><td>36</td><td>5</td><td>5</td></tr></tbody></table>	Compliant	Compliance Incomplete	Not applicable	36	5	5																																																				
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Integrated Medical Evidence Database (iMED) code version and date accessed	iMED Lockdown IDs: (62), created on (3/13/2029)																																																										
IMM version and code version	Data analysis for this report was generated using IMM v4.1 with release 2016a of MATLAB software. MATLAB and all other MathWorks product or service names are registered trademarks or trademarks of MathWorks, Natick, MA, USA.																																																										
Modifications made to the code for analysis	None																																																										

Appendix B: Medical Conditions in iMED by Category (iMED_20170221)

ENVIRONMENTAL Acute Radiation Syndrome Altitude Sickness Barotrauma (ear/sinus block) Burns secondary to Fire Decompression Sickness Secondary to EVA Eye Chemical Burn Headache (CO₂ induced) Smoke Inhalation Toxic Exposure: Ammonia INJURY/TRAUMA Abdominal Injury Acute Compartment Syndrome Ankle Sprain/Strain Back Sprain/Strain Chest Injury Dental: Avulsion (tooth loss) Elbow Dislocation Elbow Sprain/Strain Eye Irritation/Abrasion Eye Penetration (foreign body) Finger Dislocation Fingernail Delamination Secondary to EVA Head Injury Hip Sprain/Strain Hip/Proximal Femur Fracture Knee Sprain/Strain Lower Extremity Stress Fracture Lumbar Spine Fracture Neck Sprain/Strain Neurogenic Shock Paresthesias Secondary to EVA Shoulder Dislocation Shoulder Sprain/Strain Skin Abrasion Skin Laceration Traumatic Hypovolemic Shock Wrist Fracture Wrist Sprain/Strain MEDICAL ILLNESS Abdominal Wall Hernia Abnormal Uterine Bleeding Acute Angle-Closure Glaucoma Acute Arthritis Acute Cholecystitis/Biliary Colic Acute Diverticulitis Acute Pancreatitis Acute Prostatitis Acute Sinusitis Allergic Reaction (mild to moderate) Anaphylaxis Angina/Myocardial Infarction	MEDICAL ILLNESS (continued) Anxiety Appendicitis Atrial Fibrillation/Atrial Flutter Back Pain (space adaptation) Behavioral Emergency Cardiogenic Shock Secondary to Myocardial infarction Choking/Obstructed Airway Constipation (space adaptation) Dental: Exposed Pulp Dental Caries Dental: Abscess Dental: Crown Loss Dental: Filling Loss Depression Diarrhea Eye Corneal Ulcer Eye Infection Gastroenteritis Headache (Late) Headache (space adaptation) Hearing Loss Hemorrhoids Herpes Zoster Reactivation (shingles) Hypertension Indigestion Influenza Insomnia (space adaptation) Medication Overdose/Adverse Reaction Mouth Ulcer Nasal Congestion (space adaptation) Nephrolithiasis Nose bleed (space adaptation) Otitis Externa Otitis Media Pharyngitis Respiratory Infection Retinal Detachment Seizures Sepsis Skin Infection Skin Rash Sleep Disorder Small Bowel Obstruction Space Motion Sickness (space adaptation) Stroke (Cerebrovascular Accident) Sudden Cardiac Arrest Urinary Incontinence (space adaption) Urinary Retention (space adaptation) Urinary Tract Infection Vaginal Yeast Infection Visual Impairment and Increased Intracranial Pressure (VIIP) (space adaptation)
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Appendix C: Medical Conditions Excluded or Modified for the AMM (426-day) and SMM (923-day) Long Duration DRMs

Due to limited vehicle size consisting of a single module and limited movement of crew during flight, the following conditions are judged highly unlikely to occur:

- Abdominal Injury
- Acute Compartment Syndrome
- Barotrauma
- Chest Injury
- Elbow Dislocation
- Head Injury
- Hip/Proximal Femur Fracture
- Lower Extremity (LE) Stress Fracture
- Lumbar Spine Fracture
- Shoulder Dislocation
- Neurogenic Shock
- Traumatic Hypovolemic Shock

However, due to the partial gravity environment during the EVA schedule for this request, these conditions were allowed to occur during, but not outside the EVA windows.

Rather than considering the entire ISS volume for application of Fire Model result input to the IMM, ISS Node 3 was used to approximate the size of the Orion vehicle. The corresponding Node 3 Fire Model results (directly from the ISS PRA Fire Model v3.2) were used to update Burns Secondary to Fire and Smoke Inhalation for this request as follows:

- Burns Secondary to Fire:
 - **incidence 0.00613 (events/person year)** - probability one or more crew exposed to response level event (value same as for likelihood for Fire Sustains (response level event) since modeling for single compartment, i.e. Node 3) (v3.2);
 - **worst case scenario = 0-5%** - EVAC (uncontrollable fire- not vehicle) (value = 0.0486; derived from uncontrolled fire event/probability one or more crew exposed to response level event)
- Smoke Inhalation:
 - **incidence 0.00613 (events/person year)** - Fire Sustains (response level event) (v3.2);
 - **worst case scenario = 0-5%** - EVAC (uncontrollable fire- not vehicle) (value = 0.0486; derived from uncontrolled fire event/Fire Sustains (response level event))

Appendix D: Combined instances of influential conditions (i.e. independent of best or worst case, treated, partially treated or untreated) for EVAC and LOCL for both AMM and SMM DRMs

Table 9: Top Ten Combined Influential Conditions for EVAC (Yellow highlighted conditions are those that occurred during the EVAs in the simulation). Values in the “1 in X trials” column are rounded to the nearest integer.

EVAC, AMM DRM with 30 four-person EVAs	Total	per Trial	1 in X trials
HERPES ZOSTER REACTIVATION (SHINGLES)	1157	0.01157	86
NEPHROLITHIASIS	767	0.00767	130
DENTAL ABSCESS	515	0.00515	194
URINARY TRACT INFECTION	419	0.00419	239
SEPSIS	416	0.00416	240
EYE CHEMICAL BURN	316	0.00316	316
STROKE (CEREBROVASCULAR ACCIDENT)	309	0.00309	324
SMALL BOWEL OBSTRUCTION	292	0.00292	342
WRIST FRACTURE	205	0.00205	488
SKIN LACERATION	189	0.00189	529
SEIZURES	142	0.00142	704
ATRIAL FIBRILLATION/ ATRIAL FLUTTER	132	0.00132	758
APPENDICITIS	128	0.00128	781
ANGINA/MYOCARDIAL INFARCTION	126	0.00126	794
HEADACHE (CO2 INDUCED)	104	0.00104	962
TOXIC EXPOSURE (AMMONIA)	87	0.00087	1149
DENTAL EXPOSED PULP	82	0.00082	1220
ACUTE DIVERTICULITIS	81	0.00081	1235
EYE INFECTION	81	0.00081	1235
BURNS SECONDARY TO FIRE	72	0.00072	1389
INDIGESTION	67	0.00067	1493
EYE CORNEAL ULCER	58	0.00058	1724
RETINAL DETACHMENT	51	0.00051	1961
VISUAL IMPAIRMENT AND/OR INCREASED INTRACRANIAL PRESSURE (VIIP)(SPACE ADAPTATION)	51	0.00051	1961
ACUTE CHOLECYSTITIS/BILIARY COLIC	50	0.0005	2000
MEDICATION OVERDOSE/ADVERSE REACTION	49	0.00049	2041

EVAC, SMM DRM with 401 four-person EVAs	Total	per Trial	1 in X trials
DECOMPRESSION SICKNESS SECONDARY TO EXTRAVEHICULAR ACTIVITY	10976	0.10976	9
HERPES ZOSTER REACTIVATION (SHINGLES)	4194	0.04194	24
URINARY TRACT INFECTION	2924	0.02924	34
EYE CHEMICAL BURN	2434	0.02434	41
NEPHROLITHIASIS	1691	0.01691	59
DENTAL ABSCESS	1241	0.01241	81
EYE INFECTION	892	0.00892	112
SEPSIS	848	0.00848	118
EYE CORNEAL ULCER	652	0.00652	153
STROKE (CEREBROVASCULAR ACCIDENT)	647	0.00647	155
SKIN LACERATION	629	0.00629	159
SMALL BOWEL OBSTRUCTION	623	0.00623	161
WRIST FRACTURE	492	0.00492	203
ANGINA/MYOCARDIAL INFARCTION	333	0.00333	300
APPENDICITIS	319	0.00319	313
DENTAL EXPOSED PULP	311	0.00311	322
ACUTE DIVERTICULITIS	279	0.00279	358
NECK SPRAIN/STRAIN	277	0.00277	361
HEADACHE (CO2 INDUCED)	276	0.00276	362
SEIZURES	272	0.00272	368
ATRIAL FIBRILLATION/ ATRIAL FLUTTER	268	0.00268	373
EYE IRRITATION/ABRASION	266	0.00266	376
LOWER EXTREMITY (LE) STRESS FRACTURE	265	0.00265	377
TRAUMATIC HYPOVOLEMIC SHOCK	193	0.00193	518
ACUTE ARTHRITIS	183	0.00183	546
TOXIC EXPOSURE (AMMONIA)	166	0.00166	602

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EVAC, AMM DRM with 30 four-person EVAs	Total	per Trial	1 in X trials
NECK SPRAIN/STRAIN	42	0.00042	2381
ABDOMINAL WALL HERNIA	33	0.00033	3030
EYE IRRITATION/ABRASION	32	0.00032	3125
DIARRHEA	31	0.00031	3226
DECOMPRESSION SICKNESS SECONDARY TO EXTRAVEHICULAR ACTIVITY	30	0.0003	3333
RESPIRATORY INFECTION	29	0.00029	3448
OTITIS MEDIA	26	0.00026	3846
SKIN INFECTION	26	0.00026	3846
ACUTE SINUSITIS	24	0.00024	4167
SMOKE INHALATION	22	0.00022	4545
ACUTE PANCREATITIS	21	0.00021	4762
GASTROENTERITIS	21	0.00021	4762
BACK SPRAIN/STRAIN	19	0.00019	5263
TRAUMATIC HYPOVOLEMIC SHOCK	19	0.00019	5263
CHOKING/OBSTRUCTED AIRWAY	16	0.00016	6250
LOWER EXTREMITY (LE) STRESS FRACTURE	15	0.00015	6667
URINARY RETENTION (SPACE ADAPTATION)	10	0.0001	10000
CHEST INJURY	8	0.00008	12500
OTITIS EXTERNA	8	0.00008	12500
ACUTE ARTHRITIS	7	0.00007	14286
ACUTE ANGLE-CLOSURE GLAUCOMA	6	0.00006	16667
HEAD INJURY	6	0.00006	16667
DEPRESSION	5	0.00005	20000
EYE PENETRATION (FOREIGN BODY)	5	0.00005	20000
HIP SPRAIN/STRAIN	5	0.00005	20000
HIP/PROXIMAL FEMUR FRACTURE	5	0.00005	20000
HYPERTENSION	5	0.00005	20000
SUDDEN CARDIAC ARREST	5	0.00005	20000
SKIN INFECTION	4	0.00004	25000
ACUTE RADIATION SYNDROME	4	0.00004	25000
SKIN RASH	4	0.00004	25000

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EVAC, SMM DRM with 401 four-person EVAs	Total	per Trial	1 in X trials
INDIGESTION	164	0.00164	610
BURNS SECONDARY TO FIRE	157	0.00157	637
BACK SPRAIN/STRAIN	150	0.0015	667
HEAD INJURY	130	0.0013	769
SKIN RASH	126	0.00126	794
ACUTE CHOLECYSTITIS/BILIARY COLIC	115	0.00115	870
DIARRHEA	113	0.00113	885
SKIN INFECTION	112	0.00112	893
RETINAL DETACHMENT	100	0.001	1000
MEDICATION OVERDOSE/ADVERSE REACTION	91	0.00091	1099
OTITIS MEDIA	78	0.00078	1282
ACUTE SINUSITIS	76	0.00076	1316
GASTROENTERITIS	64	0.00064	1563
ACUTE PANCREATITIS	62	0.00062	1613
HIP/PROXIMAL FEMUR FRACTURE	62	0.00062	1613
RESPIRATORY INFECTION	62	0.00062	1613
VISUAL IMPAIRMENT AND/OR INCREASED INTRACRANIAL PRESSURE (VIIP)(SPACE ADAPTATION)	52	0.00052	1923
ABDOMINAL WALL HERNIA	49	0.00049	2041
SMOKE INHALATION	39	0.00039	2564
OTITIS EXTERNA	38	0.00038	2632
CHOKING/OBSTRUCTED AIRWAY	29	0.00029	3448
DEPRESSION	25	0.00025	4000
CHEST INJURY	24	0.00024	4167
ACUTE ANGLE-CLOSURE GLAUCOMA	22	0.00022	4545
HIP SPRAIN/STRAIN	22	0.00022	4545
LUMBAR SPINE FRACTURE	22	0.00022	4545
ABDOMINAL INJURY	20	0.0002	5000
ACUTE RADIATION SYNDROME	18	0.00018	5556
ACUTE COMPARTMENT SYNDROME	15	0.00015	6667
SHOULDER DISLOCATION	14	0.00014	7143
HYPERTENSION	11	0.00011	9091

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EVAC, AMM DRM with 30 four-person EVAs	Total	per Trial	1 in X trials
CARDIOGENIC SHOCK SECONDARY TO MYOCARDIAL INFARCTION	3	0.00003	33333
NOSE BLEED (SPACE ADAPTATION)	3	0.00003	33333
ACUTE PROSTATITIS	2	0.00002	50000
KNEE SPRAIN/STRAIN	2	0.00002	50000
SHOULDER DISLOCATION	2	0.00002	50000
ABDOMINAL INJURY	1	0.00001	100000
ACUTE COMPARTMENT SYNDROME	1	0.00001	100000
ALTITUDE SICKNESS	1	0.00001	100000
ANKLE SPRAIN/STRAIN	1	0.00001	100000
ANXIETY	1	0.00001	100000
LUMBAR SPINE FRACTURE	1	0.00001	100000
SHOULDER SPRAIN/STRAIN	1	0.00001	100000
WRIST SPRAIN/STRAIN	1	0.00001	100000

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EVAC, SMM DRM with 401 four-person EVAs	Total	per Trial	1 in X trials
ELBOW SPRAIN/STRAIN	10	0.0001	10000
ACUTE PROSTATITIS	9	0.00009	11111
CARDIOGENIC SHOCK SECONDARY TO MYOCARDIAL INFARCTION	8	0.00008	12500
FINGER DISLOCATION	8	0.00008	12500
SUDDEN CARDIAC ARREST	8	0.00008	12500
EYE PENETRATION (FOREIGN BODY)	6	0.00006	16667
ELBOW DISLOCATION	5	0.00005	20000
URINARY RETENTION (SPACE ADAPTATION)	5	0.00005	20000
ANXIETY	4	0.00004	25000
KNEE SPRAIN/STRAIN	4	0.00004	25000
ANAPHYLAXIS	3	0.00003	33333
ANKLE SPRAIN/STRAIN	2	0.00002	50000
NOSE BLEED (SPACE ADAPTATION)	2	0.00002	50000
SHOULDER SPRAIN/STRAIN	1	0.00001	100000
WRIST SPRAIN/STRAIN	1	0.00001	100000

Table 10: Top Ten Combined Influential Conditions for LOCL (Yellow highlighted conditions are those that occurred during the EVAs in the simulation). Values in the “1 in X trials” column are rounded to the nearest integer.

LOCL, AMM DRM with 30 four-person EVAs	Total	per Trial	1 in X trials
SEPSIS	206	0.00206	485
STROKE (CEREBROVASCULAR ACCIDENT)	122	0.00122	820
MEDICATION OVERDOSE/ADVERSE REACTION	47	0.00047	2128
TOXIC EXPOSURE (AMMONIA)	47	0.00047	2128
APPENDICITIS	39	0.00039	2564
BURNS SECONDARY TO FIRE	37	0.00037	2703
SUDDEN CARDIAC ARREST	22	0.00022	4545
CHEST INJURY	9	0.00009	11111
DECOMPRESSION SICKNESS SECONDARY TO EXTRAVEHICULAR ACTIVITY	8	0.00008	12500
TRAUMATIC HYPOVOLEMIC SHOCK	8	0.00008	12500
SMOKE INHALATION	5	0.00005	20000
ACUTE DIVERTICULITIS	4	0.00004	25000
CARDIOGENIC SHOCK SECONDARY TO MYOCARDIAL INFARCTION	3	0.00003	33333
SMALL BOWEL OBSTRUCTION	3	0.00003	33333
ACUTE PANCREATITIS	2	0.00002	50000
ACUTE RADIATION SYNDROME	2	0.00002	50000
HEAD INJURY	2	0.00002	50000
ABDOMINAL INJURY	1	0.00001	100000
ABDOMINAL WALL HERNIA	1	0.00001	100000
ALTITUDE SICKNESS	1	0.00001	100000
CHOKING/OBSTRUCTED AIRWAY	1	0.00001	100000

LOCL, SMM DRM with 401 four-person EVAs	Total	per Trial	1 in X trials
SEPSIS	435	0.00435	230
STROKE (CEREBROVASCULAR ACCIDENT)	251	0.00251	398
DECOMPRESSION SICKNESS SECONDARY TO EXTRAVEHICULAR ACTIVITY	215	0.00215	465
APPENDICITIS	125	0.00125	800
TRAUMATIC HYPOVOLEMIC SHOCK	107	0.00107	935
MEDICATION OVERDOSE/ADVERSE REACTION	99	0.00099	1010
TOXIC EXPOSURE (AMMONIA)	87	0.00087	1149
HEAD INJURY	67	0.00067	1493
BURNS SECONDARY TO FIRE	63	0.00063	1587
SUDDEN CARDIAC ARREST	36	0.00036	2778
CHEST INJURY	33	0.00033	3030
ACUTE DIVERTICULITIS	15	0.00015	6667
ABDOMINAL INJURY	13	0.00013	7692
SMOKE INHALATION	9	0.00009	11111
ACUTE RADIATION SYNDROME	8	0.00008	12500
SMALL BOWEL OBSTRUCTION	8	0.00008	12500
CARDIOGENIC SHOCK SECONDARY TO MYOCARDIAL INFARCTION	7	0.00007	14286
CHOKING/OBSTRUCTED AIRWAY	7	0.00007	14286
ANAPHYLAXIS	4	0.00004	25000
ABDOMINAL WALL HERNIA	3	0.00003	33333
ACUTE PANCREATITIS	2	0.00002	50000
SEIZURES	2	0.00002	50000
NEUROGENIC SHOCK	1	0.00001	100000