

The following document contains data and analyses developed by the NASA Human Research Program Integrated Medical Model (IMM) v3.0, which has undergone rigorous testing and review within the NASA medical community per NASA Procedural Requirement 7150.2 and NASA Standard 7009, but still requires review by the external space flight medical community. Outstanding elements for review include: assessing the applicability of the IMM v3.0 outcomes, the relevance of stated assumptions, and clearly defining limitations. Given this, it is strongly recommended that care be taken when using the results of the simulation and the output should be weighted appropriately for its level of credibility with respect to informing any decision making. If you have questions regarding remaining review activities, please contact the IMM team. The scheduled release of IMM V4.0 in FY2017 follows completion of a full internal review against NASA standards as well as the successful external review from the appropriate medical and modeling communities.

EXECUTIVE SUMMARY

This service request determined the CHI, probability of EVAC and probability of LOCL for the given design reference mission (DRM) using a medical capability (MedCap) that is baselined to ISS. These outcomes are reported in Tables 2-4. The top 10 influential conditions for EVAC and LOCL for both the Treated and MedCap scenarios are reported in Tables 5-10.

BACKGROUND

The Integrated Medical Model (IMM) simulates medical events during space flight missions and estimates the impact of these events on crew health. The IMM is a stochastic model that uses Monte Carlo methodology to simulate missions. The IMM consists of a three-step process:

1. Design Reference Mission (DRM) and crew member characteristics are specified.
2. Medical events, treatment and outcomes for the DRM are randomly generated based on pre-defined probability distributions.
3. The crew health index, evacuation and loss of crew life outcomes, and resource utilization outcomes are summarized in a post-processing procedure.

METHODS

Crew and Mission Parameters

The DRM was configured using a standard crew profile, with mission length and number of EVAs established by the requestor. Table 1 below shows the crew profile for this service request. The DRM with a duration of 350 was specified with 1 female and 3 male crewmembers.

The outcomes of certain IMM medical conditions are sex-specific and influenced by crew medical history. Pre-existing conditions that influence IMM outcomes include: coronary artery calcium score (CAC), dental crowns, contact lenses, and history of any prior abdominal surgery. Pre-existing conditions, as defined here, are consistent with historical U.S. crew data. The number of extravehicular activity (EVA) excursions influences the probability of EVA-dependent medical conditions.

Table 1: Crew Profile.

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

Medical Conditions and Resources

The incidence of IMM medical events occurring during simulated missions are based on historical mission and cohort data from the Integrated Medical Evidence Database (iMED). For each condition, the percentage of “best case” and “worst case” scenarios are also specified, as well as a defined set of medical resources that is required to treat the medical condition. All medical condition data inputs to the model are pulled from the iMED by an SQL query written in MATLAB scripts. 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 (*i.e.* the ISS medical capabilities (MedCap)).

In the current version of IMM, medical conditions are not treated unless all essential medical resources are available. Resources are classified as essential or non-essential, and as consumable, or non-consumable. Consumable resources are decremented as required to treat medical events; if an item is essential, but has been depleted, then the given medical condition will go untreated.

Main Outcomes

The IMM primary medical outcomes include: 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 [3].

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

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 is 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 the current version of the IMM, it is possible for crew members to be assigned more than one endstate of EVAC and/or LOCL. These assumptions should result in slightly high (conservative) IMM forecasts for the occurrence of EVAC and LOCL. Determining the probability of LOCL for the given DRM is the main objective of this service request.

Required resources for treatment are tracked for each DRM. The number of each resource that is needed from the given available resource quantities to treat all medical events is recorded. If more of any particular resource is used than is available, then that is recorded as a “depleted” resource. The initial quantities for the available resources are baselined to the ISS environment with 6 month resupply.

Modeling Approach

A simulation was run the provided DRM using IMM version three (v3). One hundred thousand (100,000) trials were run for the DRM, where each trial can be considered an individual “mission”. This ensures that the distribution of outcomes meets 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 two - 1,000 mission increments. This last step is performed manually by the modelers using the IMMV3ConvergenceReport.

IMM outcomes were determined for the DRM under three scenarios: 1) ISS MedCap scenario where all conditions are treated until the essential resources of the ISS MedCap are depleted; 2) All Treated scenario where supplies are limitless and all conditions are fully treated; and 3) Untreated scenario where none of the conditions are treated. Total medical events (TME) and CHI are calculated as means, with 95% confidence intervals (CIs) for the associated distributions. EVAC and LOCL are probabilities, with 95% confidence intervals (CI) for EVAC and LOCL obtained using bootstrap resampling of the simulation output [3].

RELEVANT IMM ASSUMPTIONS AND LIMITATIONS

1. The IMM is baselined to the ISS environment including medical capabilities.
2. All medical conditions are correctly diagnosed and all treatments are effective.
3. Conditions are treated in order of decreasing incidence and increasing crew member count (*i.e.* crew member one is treated before crew member two for any given condition) with Space Adaptation conditions treated first.
4. When there are insufficient *essential* medical resources to treat a condition, all available resources are consumed and the medical condition is considered untreated.
5. The IMM does not include a mission timeline. All conditions occur at launch on day one.
6. Medical conditions are independent of each other; i) a mission could end in more than one evacuation or loss of crew life being considered for the same crew member, and ii) additional medical conditions can occur in a crew member assigned an end state of EVAC or LOCL.
7. IMM source data in the iMED database undergo periodic updates to ensure best alignment to the real world system; this may affect the inclusion or exclusion of certain resources from the optimized MedCap, which would also effect resulting mass and volume.
8. Mass and volume for MedCap does not consider packaging materials.

RESULTS AND Discussion

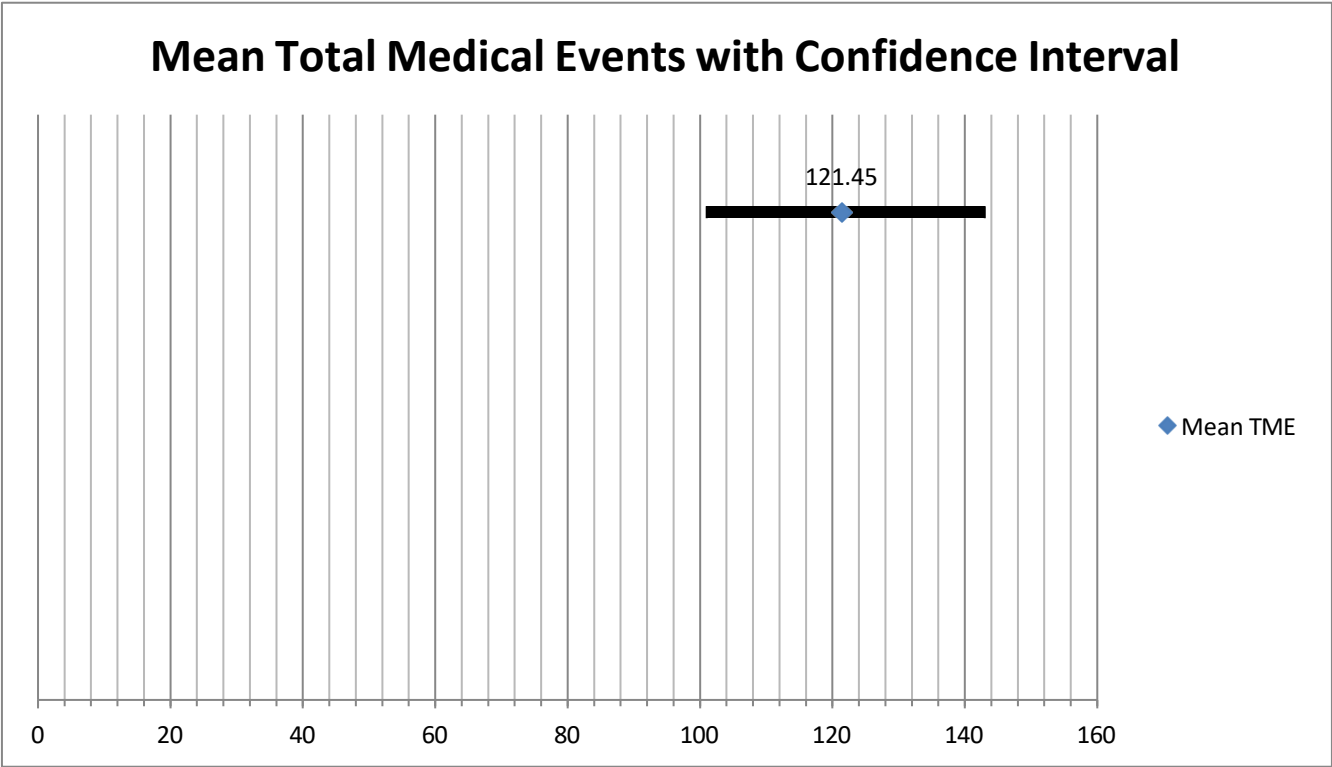
The specified DRM was assessed using the IMM as described above in the Methods section above. One hundred thousand trials were simulated for the DRM with ISS MedCap to forecast IMM primary outcomes and resources required to treat each condition. The ISS MedCap is baselined to the ISS environment with 6 month resupply. Results of the main outcomes are reported in Tables 2-4 with the numbers for fully treated and completely untreated as reference. The top 10 influential conditions for EVAC and LOCL for the DRM are provided in Tables 5-10. Note the absence of Fingernail Delamination Secondary to EVA, Decompression Sickness Secondary to EVA, Paresthesias Secondary to EVA not included because no EVAs were performed. Also, the total number of EVACs and LOCLs is over all 100,000 trials of the simulation.

Although it did not contribute to the top 10 influential conditions, during a review of the simulation results, it was observed that Otitis Media was contributing to LOCL when it went to the untreated worst case scenario. The untreated worst case LOCL is the result of this condition progressing into two other conditions. Otitis Media should have 0% LOCL. A change request (C2-20170309-384) has been entered to make the changes in iMED.

Table 2. Total Medical Events(TME) and CHI

2a. TME

Mission Length	TME	95% CI
350 days	121.45	(101 , 143)



2b. CHI

	CHI (%)	95% CI
Treated	91.20	(74.56 , 98.23)
MedCap	84.83	(60.66 , 97.13)
Untreated	0.62	(0 , 6.62)

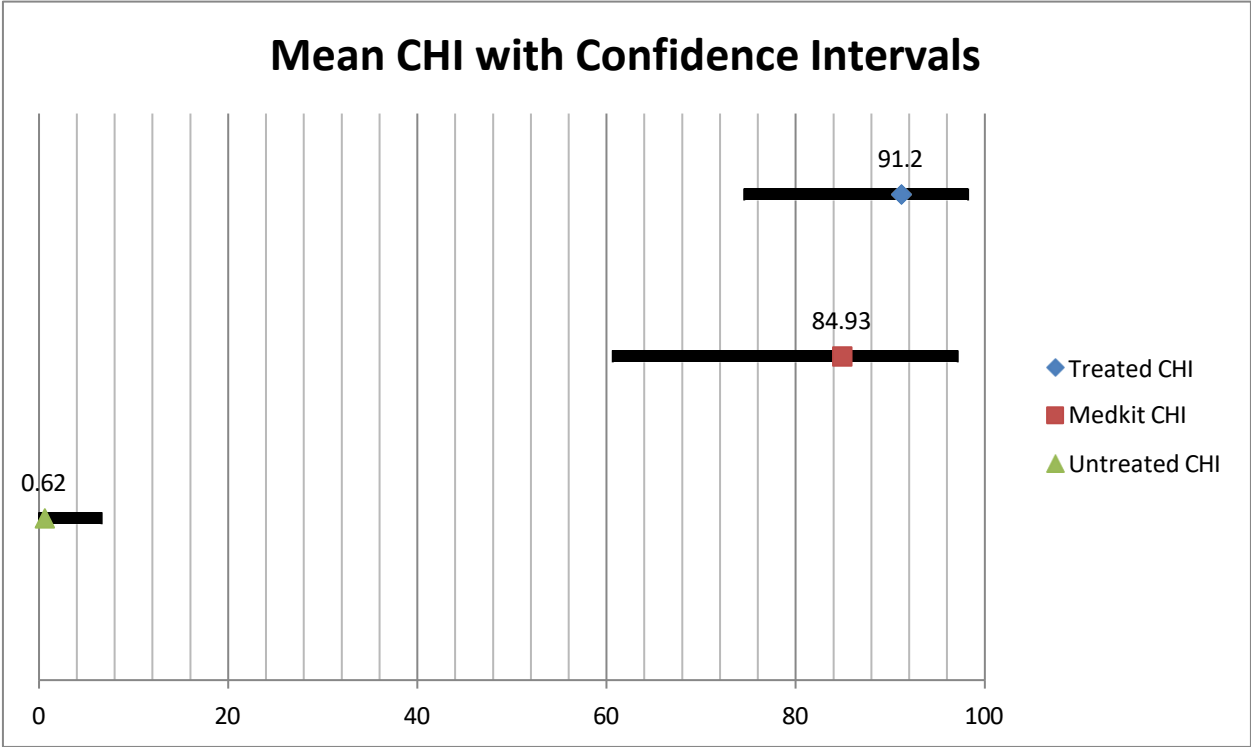


Table 3. Probability of EVAC

	pEVAC	95% CI	Odds
Treated	0.0507	(0.0492 , 0.0520)	1 in 20
MedCap	0.2263	(0.2238 , 0.2288)	1 in 4
Untreated	0.7073	(0.7047 , 0.7102)	1 in 1

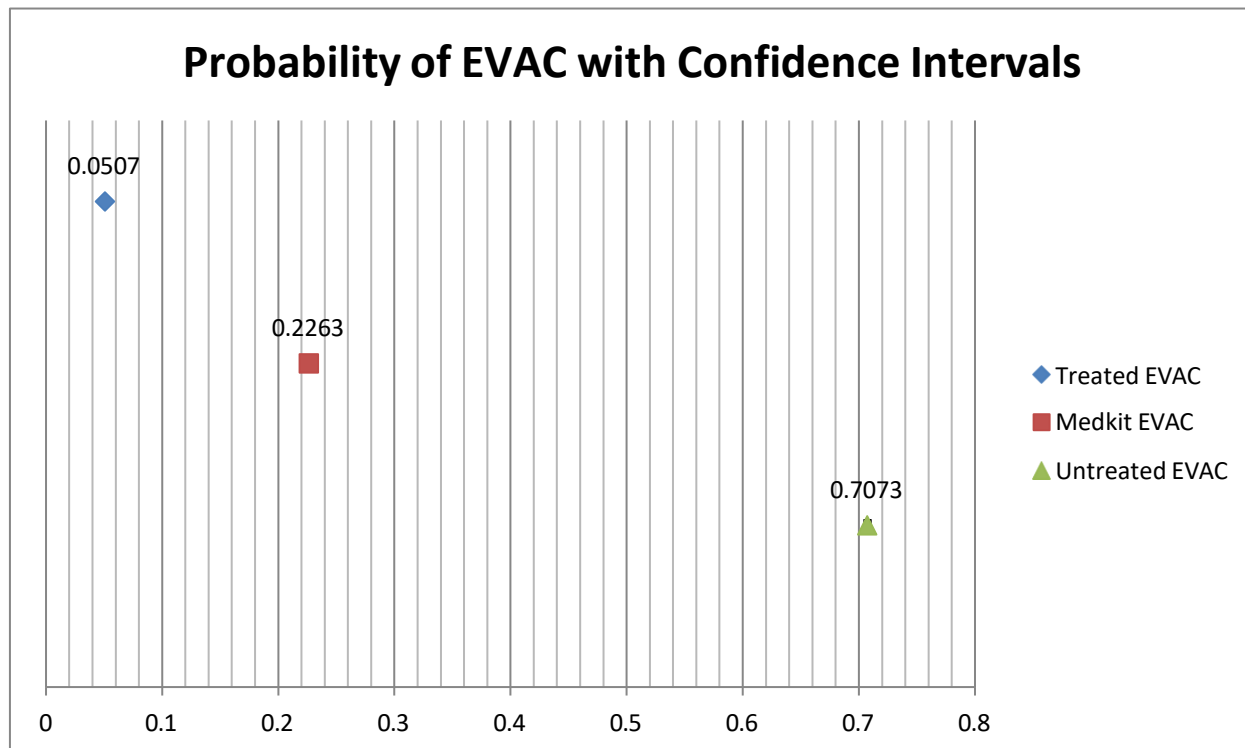


Table 4. Probability of LOCL

	pLOCL	95% CI	Odds
Treated	0.0062	(0.0057 , 0.0066)	1 in 161
MedCap	0.0078	(0.0072 , 0.0083)	1 in 128
Untreated	0.0271	(0.0261 , 0.0281)	1 in 37

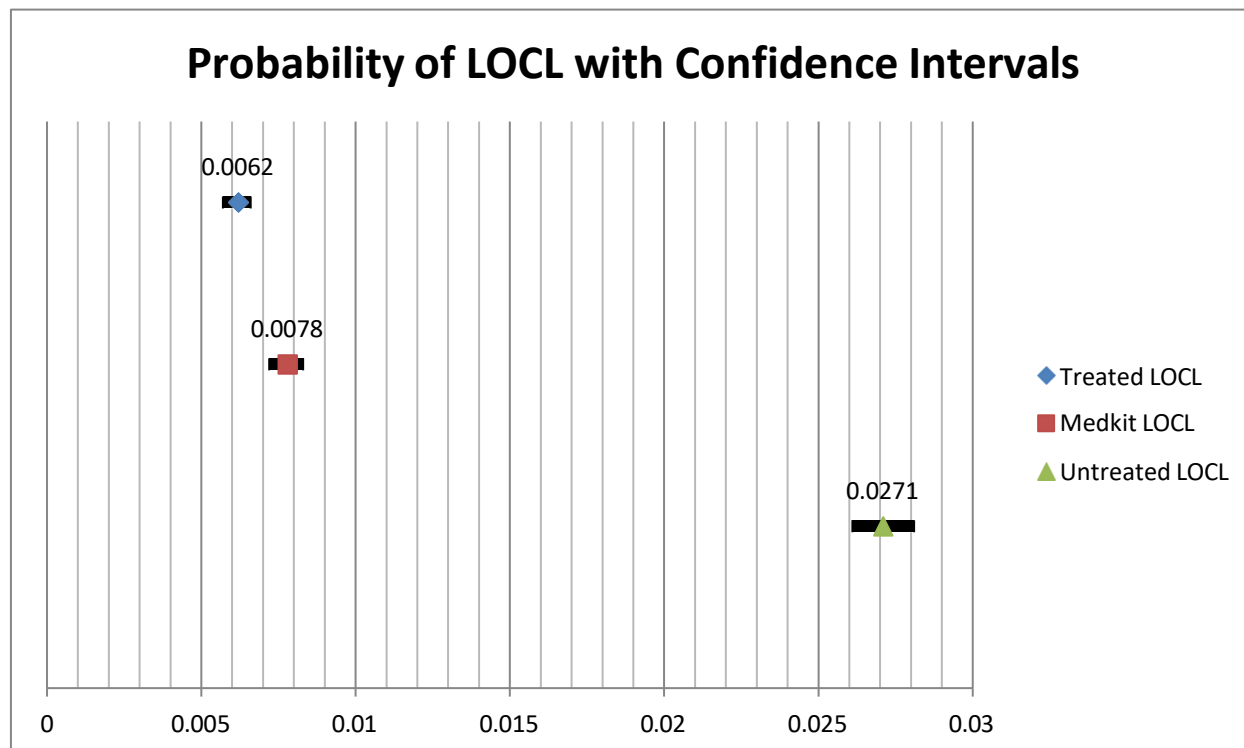


Table 5. DSH 350 Days Influential Conditions for EVAC – Treated

Scenario	Treated	Medical Condition	Total EVAC	Percent Contribution	Cumulative Percent
WORST CASE	TREATED	VISUAL IMPAIRMENT AND/OR INCREASED INTRACRANIAL PRESSURE (VIIP)(SPACE ADAPTATION)	966	18.57	18.57
WORST CASE	TREATED	NEPHROLITHIASIS	586	11.27	29.84
WORST CASE	TREATED	DENTAL ABSCESS	324	6.23	36.07
WORST CASE	TREATED	SEPSIS	317	6.09	42.16
WORST CASE	TREATED	SMOKE INHALATION	295	5.67	47.84
BEST CASE	TREATED	SMALL BOWEL OBSTRUCTION	200	3.85	51.68
WORST CASE	TREATED	WRIST FRACTURE	179	3.44	55.12
WORST CASE	TREATED	HIP/PROXIMAL FEMUR FRACTURE	136	2.61	57.74
WORST CASE	TREATED	BACK SPRAIN/STRAIN	134	2.58	60.32
WORST CASE	TREATED	STROKE (CEREBROVASCULAR ACCIDENT)	120	2.31	62.62

Table 6. DSH 350 Days Influential Conditions for EVAC – MedCap

Scenario	Treated	Medical Condition	Total EVAC	Percent Contribution	Cumulative Percent
BEST CASE	UNTREATED	EYE CHEMICAL BURN	9052	32.23	32.23
WORST CASE	UNTREATED	SKIN INFECTION	3220	11.47	43.70
WORST CASE	UNTREATED	EYE CHEMICAL BURN	2371	8.44	52.14
BEST CASE	UNTREATED	FINGER DISLOCATION	1118	3.98	56.12
WORST CASE	UNTREATED	LOWER EXTREMITY (LE) STRESS FRACTURE	1049	3.74	59.85
WORST CASE	TREATED	VISUAL IMPAIRMENT AND/OR INCREASED INTRACRANIAL PRESSURE (VIIP)(SPACE ADAPTATION)	934	3.33	63.18
WORST CASE	UNTREATED	SKIN LACERATION	842	3.00	66.18
WORST CASE	UNTREATED	HERPES ZOSTER REACTIVATION (SHINGLES)	685	2.44	68.62
BEST CASE	UNTREATED	BURNS SECONDARY TO FIRE	591	2.10	70.72
BEST CASE	UNTREATED	NEPHROLITHIASIS	429	1.53	72.25

Table 7. DSH 350 Days Influential Conditions for EVAC – Untreated

Scenario	Treated	Medical Condition	Total EVAC	Percent Contribution	Cumulative Percent
BEST CASE	UNTREATED	EYE CHEMICAL BURN	39035	31.41	31.41
BEST CASE	UNTREATED	FINGER DISLOCATION	7122	5.73	37.14
WORST CASE	UNTREATED	EYE CHEMICAL BURN	6280	5.05	42.19
WORST CASE	UNTREATED	SKIN LACERATION	5269	4.24	46.43
WORST CASE	UNTREATED	BACK SPRAIN/STRAIN	4507	3.63	50.06
WORST CASE	UNTREATED	URINARY TRACT INFECTION	4430	3.56	53.62
BEST CASE	UNTREATED	URINARY RETENTION (SPACE ADAPTATION)	3844	3.09	56.71
WORST CASE	UNTREATED	RESPIRATORY INFECTION	3516	2.83	59.54
WORST CASE	UNTREATED	DIARRHEA	3484	2.80	62.34
WORST CASE	UNTREATED	ACUTE SINUSITIS	3319	2.67	65.01

Table 8. DSH 350 Days Influential Conditions for LOCL – Treated

Scenario	Treated	Medical Condition	Total LOCL	Percent Contribution	Cumulative Percent
WORST CASE	TREATED	SEPSIS	163	26.16	26.16
WORST CASE	TREATED	TRAUMATIC HYPOVOLEMIC SHOCK	92	14.77	40.93
WORST CASE	TREATED	MEDICATION OVERDOSE/ADVERSE REACTION	72	11.56	52.49
WORST CASE	TREATED	STROKE (CEREBROVASCULAR ACCIDENT)	57	9.15	61.64
WORST CASE	TREATED	SMOKE INHALATION	53	8.51	70.14
WORST CASE	TREATED	HEAD INJURY	41	6.58	76.73
WORST CASE	TREATED	TOXIC EXPOSURE (AMMONIA)	38	6.10	82.83
WORST CASE	TREATED	CHEST INJURY	37	5.94	88.76
WORST CASE	TREATED	APPENDICITIS	31	4.98	93.74
WORST CASE	TREATED	SUDDEN CARDIAC ARREST	12	1.93	95.67

Table 9. DSH 350 Days Influential Conditions for LOCL – MedCap

Scenario	Treated	Medical Condition	Total LOCL	Percent Contribution	Cumulative Percent
WORST CASE	TREATED	SEPSIS	124	15.82	15.82
WORST CASE	TREATED	MEDICATION OVERDOSE/ADVERSE REACTION	72	9.18	25.00
WORST CASE	UNTREATED	SEPSIS	72	9.18	34.18
WORST CASE	TREATED	TRAUMATIC HYPOVOLEMIC SHOCK	69	8.80	42.98
WORST CASE	TREATED	STROKE (CEREBROVASCULAR ACCIDENT)	56	7.14	50.13
WORST CASE	TREATED	SMOKE INHALATION	51	6.51	56.63
WORST CASE	TREATED	HEAD INJURY	38	4.85	61.48
BEST CASE	UNTREATED	APPENDICITIS	37	4.72	66.20
WORST CASE	TREATED	TOXIC EXPOSURE (AMMONIA)	35	4.46	70.66
BEST CASE	UNTREATED	SEPSIS	33	4.21	74.87

Table 10. DSH 350 Days Influential Conditions for LOCL – Untreated

Scenario	Treated	Medical Condition	Total LOCL	Percent Contribution	Cumulative Percent
WORST CASE	UNTREATED	SMOKE INHALATION	966	35.10	35.10
WORST CASE	UNTREATED	SEPSIS	317	11.52	46.62
BEST CASE	UNTREATED	SEPSIS	312	11.34	57.96
BEST CASE	UNTREATED	APPENDICITIS	131	4.76	62.72
WORST CASE	UNTREATED	STROKE (CEREBROVASCULAR ACCIDENT)	120	4.36	67.08
WORST CASE	UNTREATED	CHOKING/OBSTRUCTED AIRWAY	104	3.78	70.86
BEST CASE	UNTREATED	ANAPHYLAXIS	100	3.63	74.49
WORST CASE	UNTREATED	TRAUMATIC HYPOVOLEMIC SHOCK	92	3.34	77.83
WORST CASE	UNTREATED	HEAD INJURY	79	2.87	80.70
WORST CASE	UNTREATED	MEDICATION OVERDOSE/ADVERSE REACTION	77	2.80	83.50

SUMMARY

This service request provides estimates of the TME, CHI, probability of EVAC and LOCL for the given DRM using a MedCap that is baselined to the ISS. Medical conditions secondary to EVA were not included because EVAs were not included in the DRM. The main outcomes and top 10 Influential Conditions for EVAC and LOCL for the Treated, Untreated, and MedCap scenarios are reported for the DRM. The IMM is baselined to the ISS environment. Therefore, caution should be used when using the IMM to assess DSH medical risk.

REFERENCES

1. Integrated Medical Model Project. Integrated Medical Model Operations Plan. JSC-66114. 2011. Houston, TX, NASA, Johnson Space Center, (document update in progress).
2. Integrated Medical Model Project. Integrated Medical Model Functional Requirements Document. JSC-66110. 2011. Houston, Texas, NASA, Johnson Space Center, (document update in progress).
3. Integrated Medical Model Project. Integrated Medical Model v3 Technical Description Report. JSC-xxxxx. 2015. Houston, TX, NASA JSC, (document update in progress).
4. NASA technical standard for models and simulations 7009 (NASA STD 7009). 1-58. 7-11-2008 (reapproved 7-10-2013). Washington D.C., NASA.
5. ISS Medical Checklist (Med CL), 04 June 2014, NASA Johnson Space Center, Medical Operations Group.

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 v3.0 MATLAB status of IMM validation for each IMM element listed. Scoring Bar Chart Factor Score Evidence Sufficiency Thresholds People Quantification M&S Management Use History Results Robustness Results Uncertainty Input Pedigree Validation Verification 0 1 2 3 4																																																		
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. Compliant Compliance Incomplete Not applicable 36 5 5																																																		
Current NASA-Standard-7009 credibility assessment score	IMM Credibility Matrix: The following table shows the overall IMM v3.0 MATLAB credibility assessment score (CAS), individual factor CAS, customer-specified sufficiency thresholds, and weighted scores. Legend depicts CAS score designated range and color assignments from NASA-Standard-7009. <table><tr><th>Factor</th><th>Sufficiency Thresholds</th><th>Factor Score</th><th>Weighted Scores</th><th>Overall Score</th></tr><tr><td>Verification</td><td>4</td><td>3.7</td><td>0.28</td><td></td></tr><tr><td>Validation</td><td>3</td><td>3</td><td>0.45</td><td></td></tr><tr><td>Input Pedigree</td><td>3</td><td>3</td><td>0.53</td><td></td></tr><tr><td>Results Uncertainty</td><td>3</td><td>3</td><td>0.60</td><td>3.06</td></tr><tr><td>Results Robustness</td><td>3</td><td>3</td><td>0.45</td><td></td></tr><tr><td>Use History</td><td>3</td><td>3</td><td>0.45</td><td></td></tr><tr><td>M&S Management</td><td>2</td><td>2</td><td>0.10</td><td></td></tr><tr><td>People Qualification</td><td>4</td><td>4</td><td>0.20</td><td></td></tr><tr><td></td><td></td><td></td><td></td><td></td></tr></table> Legend from NASA-STD-7009 CAS Score > Threshold Exceeds credibility requirements Threshold ≥ CAS Score ≥ (Threshold-0.5) Ready for use Threshold-0.5 > CAS Score ≥ Threshold-1.0 Use with caution CAS Score < Threshold - 1.0 Use not recommended or to be used with EXTREME CAUTION by subject matter experts only	Factor	Sufficiency Thresholds	Factor Score	Weighted Scores	Overall Score	Verification	4	3.7	0.28		Validation	3	3	0.45		Input Pedigree	3	3	0.53		Results Uncertainty	3	3	0.60	3.06	Results Robustness	3	3	0.45		Use History	3	3	0.45		M&S Management	2	2	0.10		People Qualification	4	4	0.20						
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People Qualification	4	4	0.20																																																
Additional verification and validation information applicable to this analysis	none																																																		
Integrated Medical Evidence Database (iMED) code version and date accessed	iMED Lockdown ID: (26), created on (2/21/2017)																																																		
IMM version and code version	Data analysis for this report was generated using IMM v3.0 with release 2014a 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: LIST OF THE CURRENT 100 MEDICAL CONDITIONS USED IN THE IMM.

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