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.

Executive Summary

The objective of this IMM support request is to support a continued dialogue between the ISS PRA and IMM teams to provide updated results of medical risk assessment due to updates made in the iMED database and the IMM model after the last delivery of risk assessment results from IMM to the ISS Probabilistic Assessment (PRA) team, and to aid in accurate interpretation of IMM data. This report compares simulation results from the last simulation delivered to the ISS PRA Model group in 2016 (S-20151123-341 RevA) to a more recent simulation from 2020 (S-20200330- 426). From the more recent S-20200330-426, for the fully treated scenario, the probability of evacuation of one or more crew members was 3.24% (1 in 31) and the probability of loss of crew life of one or more crew members was 0.49% (1 in 204). The probability of emergent evacuation of one or more crew members was 1.83% (95% confidence interval bounds of 1.74% to 1.91%) in the fully treated scenario (1 in 55). This report also includes a list of top ten influential conditions for probability of medical evacuation (EVAC) and probability of medical loss of crew life (LOCL), and a list of conditions that contribute ~75% of the emergent evacuations in the S-20200330-426 simulation.

Contents

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 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

There were some slight differences between the crew profile in S-20151123-341 RevA and S-20200330-426. The differences are reported in Table 1 and Table 2. The outcomes of certain IMM medical conditions are influenced by crew pre-existing medical history including coronary artery calcium score (CAC), dental crowns, contact lenses, and history of prior abdominal surgery. Pre-existing conditions for both crew profiles, as defined here, are consistent with historical U.S. crew data. The slight difference between the two crew profiles does not have a significant effect on results.

Table 1: 6 month ISS PRA DRM crew profile S-20151123-341 RevA

	Sex	Crowns	EVA	CAC	Contacts	Prior Abdominal Surgery
Crew 1	Female	Yes	No	No	No	No
Crew 2	Male	No	Yes (3)	No	No	No
Crew 3	Male	No	Yes (3)	Yes	No	No
Crew 4	Male	No	No	Yes	No	No
Crew 5	Male	No	No	No	Yes	No
Crew 6	Male	No	No	Yes	No	No

Table 2: 6 month ISS PRA DRM crew profile S-20200330-426

	Sex	Crowns	EVA	CAC	Contacts	Prior Abdominal Surgery
Crew 1	Female	Yes	No	No	No	No
Crew 2	Male	No	Yes (3)	No	Yes	No
Crew 3	Male	No	Yes (3)	No	No	No
Crew 4	Male	No	No	Yes	No	No
Crew 5	Male	No	No	No	No	Yes
Crew 6	Male	No	No	Yes	No	No

Medical Conditions and Resources

The one hundred medical conditions currently included in the IMM are shown in Appendix B. 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 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 this service request, the Fully Treated timeline results are reported as they represent ISS capabilities and resupply.

Appendix C shows all updates made to the iMED between the time of delivery of IMM Request S-20151123-341 RevA and S-20200330-426.

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].

CHI = (1- (QAMTL ÷ Mission Length)) x 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 resources quantities for both comparison simulations are baselined to ISS medical capabilities contained in iMED at the time of those requests. 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 IMMV4ConvergenceReport.

IMM outcomes were determined for the DRMs using the Fully Treated timeline where all conditions are considered fully treated based on the available resources of the ISS Medical Capabilities contained in iMED, at the time of the respective comparison requests, with 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, EVAC and LOCL results are presented. Features, assumptions and limitations pertinent to this report are described in a separate section below.

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).

Assumptions and Limitations of IMM Version 3.0

1. The IMM does not include a mission timeline – all conditions occur at launch on day one.

2. Medical conditions are independent of each other – a mission could end in more than one evacuation or loss of crew life being considered for the same crew member.

3. Conditions are treated in order of incidence and crew member count with Space Adaptation conditions treated first (i.e. crew member one is treated before crew member two for any given condition and all instances of the highest incidence condition is treated before the next highest incidence).

4. When there are insufficient essential medical resources to treat a condition, all available resources are consumed to reflect a partial treatment, and the condition is considered untreated.

5. The IMM ISS medical capability scenario does not take into account the availability of Russian medical resources or the ability to resupply depleted medical resources.

The fully treated scenario provides a more realistic estimate of EVAC and LOCL probabilities for ISS than the baseline scenario of considering only medical capabilities without resupply, and eliminates the limitations associated with assumptions 3 through 5.

Results

IMM simulation results for 100,000 trials of the ISS DRM are displayed in Figure 1. In the fully treated scenario, the probability of evacuation of one or more crew members was 3.24% (1 in 31) and the probability of loss of crew life of one or more crew members was 0.49% (1 in 204). The probability of EVAC for the fully treated scenario in the prior medical update report (S-20151123-341 RevA) of 5.03% does not fall within the 95% confidence interval for this request nor do the 95% confidence intervals overlap.
However, the probability of LOCL with 0.46% does fall within the 95% confidence interval, respectively and the 95% confidence intervals do overlap (Table 4). The probability of emergent evacuation of one or more crew members was 1.83% (95% confidence interval bounds of 1.74% to 1.91%) in the fully treated scenario (1 in 55). Although probability of emergent EVAC was 1.80% in the fully treated scenario from the prior medical update report (S-20151123-341 RevA), the probability of emergent EVAC falls within prior 95% confidence interval bounds of 1.71% to 1.88% (S-20151123-341 RevA) and vice versa.

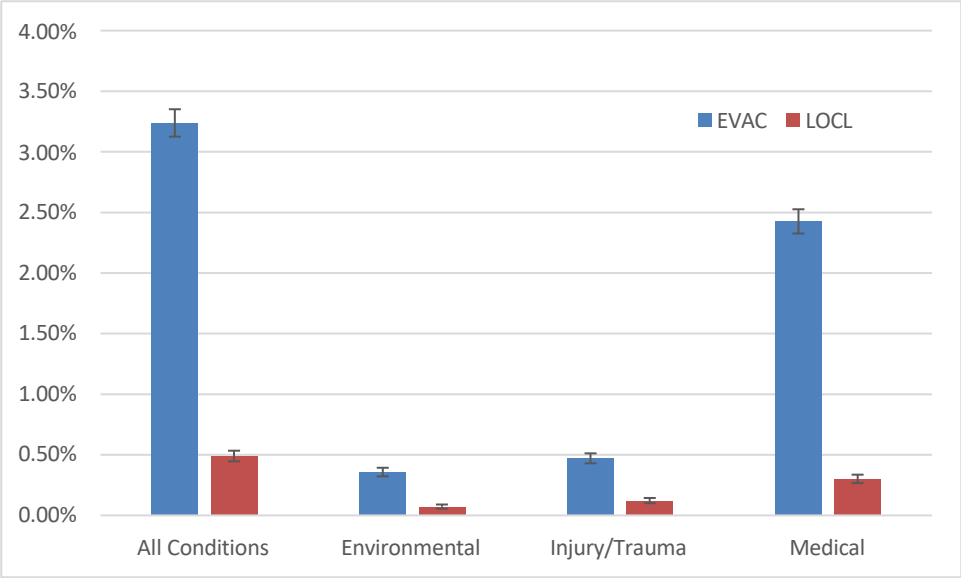

Figure 1: S-20200330-426: Percent of missions with at least one evacuation (EVAC) or loss of crew life (LOCL), by condition category, and 95% confidence intervals (CI). Data from the fully treated scenario are summarized for 100,000 simulated missions.

Table 3: EVAC and LOCL data corresponding to Figure 1. **S-20200330-426**: Percent of missions with at least one evacuation (EVAC) or loss of crew life (LOCL), by condition category, and 95% confidence intervals (CI). Data from the fully treated scenario are summarized for 100,000 simulated missions.

		95% CI			95% CI	
Medical Condition Category	**Probability of EVAC**	**Lower Bound**	**Upper Bound**	**Probability of LOCL**	**Lower Bound**	**Upper Bound**
All Conditions	3.24%	3.13%	3.35%	0.49%	0.45%	0.53%
Environmental	0.36%	0.32%	0.39%	0.07%	0.06%	0.09%
Injury/Trauma	0.47%	0.43%	0.51%	0.12%	0.10%	0.14%
Medical	2.43%	2.33%	2.53%	0.30%	0.27%	0.34%

Table 4: EVAC and LOCL data from **S-20151123-341 RevA**. Percent of missions with at least one evacuation (EVAC) or loss of crew life (LOCL), by condition category, and 95% confidence intervals (CI). Data from the fully treated scenario are summarized for 100,000 simulated missions.

		95% CI			95% CI	
Medical Condition Category	**Probability of EVAC**	**Lower Bound**	**Upper Bound**	**Probability of LOCL**	**Lower Bound**	**Upper Bound**
All Conditions	5.03%	4.90%	5.16%	0.46%	0.42%	0.51%
Environmental	0.33%	0.29%	0.36%	0.07%	0.05%	0.08%
InjuryTrauma	0.80%	0.75%	0.85%	0.13%	0.11%	0.16%
Medical	3.95%	3.83%	4.07%	0.26%	0.23%	0.30%

The probabilities of both EVAC and LOCL decreased in all three categories of medical conditions due with the iMED updates (Table 3 and Table 4).

It is important to note that in the majority of simulations in which an EVAC or LOCL occurred only one crew member underwent EVAC or LOCL (Figure 2). The greatest percentage of evacuation was due primarily to worst-case scenarios; loss of crew life was due exclusively to worst case scenarios. Once a condition occurs it will follow either a best or a worst-case scenario based on a probability distribution. Worst-case scenarios generally require more resources for treatment and have higher probabilities of ending in evacuation or loss of crew life.

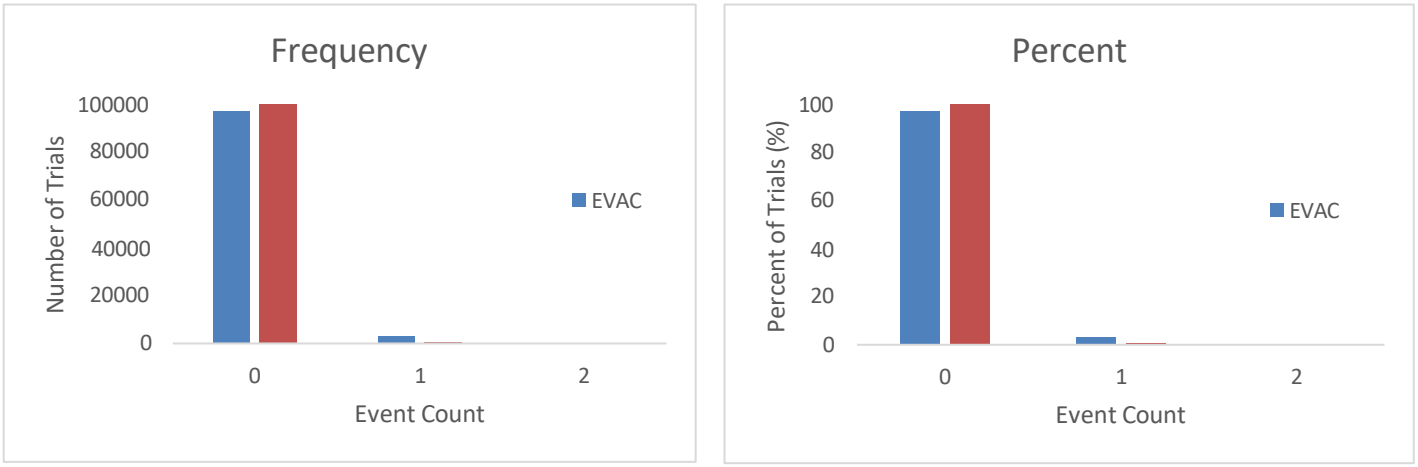

Figure 2: S-20200330-426: Frequency and percent of EVAC and LOCL events in the fully treated scenario.

Table 5: S-20200330-426: Frequency and percent of EVAC and LOCL events in the fully treated scenario.

EVAC Count	Frequency	Percent	LOCL Count	Frequency	Percent
0	96764	96.764	**0**	99510	99.51
1	3180	3.18	**1**	489	0.489
2	56	0.056	**2**	1	0.001

Table 6 and Table 7 provide the percent contribution by category for emergent evacuations and the conditions that contribute ~75% of the total emergent evacuations that occurred during the simulation respectively. Table 8 provides the conditions that contribute ~75% of the total emergent evacuations that occurred during the simulation for S-20151123-341 RevA. Table 9 and Table 10 provide a list of the top ten influential conditions for EVAC and LOCL respectively for S-20200330-426. Table 11 and Table 12 provide a list of the top ten influential conditions for EVAC and LOCL respectively for S-20151123-341 RevA.

Table 6: **S-20200330-426 vs. S-20151123-341 RevA**: The percent of **emergent evacuations** that fall within the three medical condition categories. Note, this is only for emergent evacuations, not the total number of evacuations.

Medical Condition Category	Percent [S-20200330-426]	Percent [S-20151123-341 RevA]
Environmental	15.47%	16.79%
Injury/Trauma	13.20%	16.95%
Medical	71.33%	66.26%

Table 7: **S-20200330-426**: List of medical conditions that contribute approximately 75% to emergent evacuations for this simulation. Although most emergent evacuations are attributable to worst case scenarios, the total EVAC numbers in this table, consist of both best and worst case scenarios.

Medical Condition	Category	Total EVAC	Percent Contribution
NEPHROLITHIASIS	MEDICAL	507	27.42%
SEPSIS	MEDICAL	229	12.39%
SMOKE INHALATION	ENVIRONMENTAL	217	11.74%
STROKE (CEREBROVASCULAR ACCIDENT)	MEDICAL	201	10.87%
HEAD INJURY	INJURY/TRAUMA	73	3.95%
TRAUMATIC HYPOVOLEMIC SHOCK	INJURY/TRAUMA	62	3.35%
APPENDICITIS	MEDICAL	60	3.24%
ACUTE DIVERTICULITIS	MEDICAL	52	2.81%

Table 8: **S-20151123-341**: List of medical conditions that contribute approximately 75% to emergent evacuations for this simulation. The emergent evacuations are attributable to worst case scenarios.

Medical Condition	Category	Total EVAC	Percent Contribution
NEPHROLITHIASIS	MEDICAL	436	24.00%
SEPSIS	MEDICAL	234	12.88%
SMOKE INHALATION	ENVIRONMENTAL	233	12.82%
STROKE (CEREBROVASCULAR ACCIDENT)	MEDICAL	102	5.61%
HIP/PROXIMAL FEMUR FRACTURE	INJURY/TRAUMA	95	5.23%
TRAUMATIC HYPOVOLEMIC SHOCK	INJURY/TRAUMA	78	4.29%
MEDICATION OVERDOSE/ADVERSE REACTION	MEDICAL	66	3.63%
HEAD INJURY	INJURY/TRAUMA	65	3.58%
ACUTE DIVERTICULITIS	MEDICAL	63	3.47%
APPENDICITIS	MEDICAL	47	2.59%

Table 9: Top ten Influential Conditions for EVAC for the Fully Treated timeline (**S-20200330-426**).

Scenario	Treated	Medical Condition	Category	Total EVAC	Percent Contribution
WORST CASE	TREATED	NEPHROLITHIASIS	MEDICAL	507	15.40%
WORST CASE	TREATED	DENTAL ABSCESS	MEDICAL	289	8.78%
WORST CASE	TREATED	SEPSIS	MEDICAL	229	6.96%
WORST CASE	TREATED	SMOKE INHALATION	ENVIRONMENTAL	217	6.59%
WORST CASE	TREATED	STROKE (CEREBROVASCULAR ACCIDENT)	MEDICAL	201	6.11%
WORST CASE	TREATED	HERPES ZOSTER REACTIVATION (SHINGLES)	MEDICAL	144	4.37%
WORST CASE	TREATED	WRIST FRACTURE	INJURY/TRAUMA	134	4.07%
BEST CASE	TREATED	SMALL BOWEL OBSTRUCTION	MEDICAL	94	2.86%

BEST CASE	TREATED	ANGINA/MYOCARDIAL INFARCTION	MEDICAL	89	2.70%
WORST CASE	TREATED	VISUAL IMPAIRMENT AND/OR INCREASED INTRACRANIAL PRESSURE (VIIP)(SPACE ADAPTATION)	MEDICAL	87	2.64%

Table 10: Top ten Influential Conditions for LOCL for the Fully Treated timeline (**S-20200330-426**).

Scenario	Treated	Medical Condition	Category	Total LOCL	Percent Contribution
WORST CASE	TREATED	SEPSIS	MEDICAL	125	25.46%
WORST CASE	TREATED	STROKE (CEREBROVASCULAR ACCIDENT)	MEDICAL	101	20.57%
WORST CASE	TREATED	TRAUMATIC HYPOVOLEMIC SHOCK	INJURY/TRAUMA	62	12.63%
WORST CASE	TREATED	SMOKE INHALATION	ENVIRONMENTAL	45	9.16%
WORST CASE	TREATED	APPENDICITIS	MEDICAL	31	6.31%
WORST CASE	TREATED	HEAD INJURY	INJURY/TRAUMA	30	6.11%
WORST CASE	TREATED	MEDICATION OVERDOSE/ADVERSE REACTION	MEDICAL	25	5.09%
WORST CASE	TREATED	CHEST INJURY	INJURY/TRAUMA	22	4.48%
WORST CASE	TREATED	TOXIC EXPOSURE (AMMONIA)	ENVIRONMENTAL	20	4.07%
WORST CASE	TREATED	SUDDEN CARDIAC ARREST	MEDICAL	8	1.63%

Table 11: Top ten Influential Conditions for EVAC for the Fully Treated timeline (**S-20151123-341 RevA**).

Scenario	Treated	Medical Condition	Category	Total EVAC	Percent Contribution
WORST CASE	TREATED	VISUAL IMPAIRMENT AND/OR INCREASED INTRACRANIAL PRESSURE (VIIP)(SPACE ADAPTATION)	MEDICAL	1458	28.26%
WORST CASE	TREATED	DENTAL: ABSCESS	MEDICAL	744	14.42%
WORST CASE	TREATED	NEPHROLITHIASIS	MEDICAL	436	8.45%

WORST CASE	TREATED	SEPSIS	MEDICAL	234	4.54%
WORST CASE	TREATED	SMOKE INHALATION	ENVIRONMENTAL	233	4.52%
WORST CASE	TREATED	WRIST FRACTURE	INJURY/TRAUMA	167	3.24%
WORST CASE	TREATED	STROKE (CEREBROVASCULAR ACCIDENT)	MEDICAL	102	1.98%
BEST CASE	TREATED	ATRIAL FIBRILLATION/ ATRIAL FLUTTER	MEDICAL	99	1.92%
WORST CASE	TREATED	BACK SPRAIN/STRAIN	INJURY/TRAUMA	97	1.88%
WORST CASE	TREATED	HIP/PROXIMAL FEMUR FRACTURE	INJURY/TRAUMA	95	1.84%

Table 12: Top ten Influential Conditions for LOCL for the Fully Treated timeline (**S-20151123-341 RevA**).

Scenario	Treated	Medical Condition	Category	Total LOCL	Percent Contribution
WORST CASE	TREATED	SEPSIS	MEDICAL	117	25.11%
WORST CASE	TREATED	TRAUMATIC HYPOVOLEMIC SHOCK	INJURY/TRAUMA	78	16.74%
WORST CASE	TREATED	MEDICATION OVERDOSE/ADVERSE REACTION	MEDICAL	51	10.94%
WORST CASE	TREATED	STROKE (CEREBROVASCULAR ACCIDENT)	MEDICAL	50	10.73%
WORST CASE	TREATED	SMOKE INHALATION	ENVIRONMENTAL	44	9.44%
WORST CASE	TREATED	CHEST INJURY	INJURY/TRAUMA	25	5.36%
WORST CASE	TREATED	APPENDICITIS	MEDICAL	24	5.15%
WORST CASE	TREATED	HEAD INJURY	INJURY/TRAUMA	24	5.15%
WORST CASE	TREATED	TOXIC EXPOSURE: AMMONIA	ENVIRONMENTAL	18	3.86%
WORST CASE	TREATED	SUDDEN CARDIAC ARREST	MEDICAL	11	2.36%

Discussion

The results of this updated IMM simulation (S-20200330-426) reveal a significant decrease in the probability of total EVAC compared to the prior IMM simulation (S-20151123-341 Rev A). This decrease in the probability of total EVAC is due to a decreased probability of evacuation secondary to VIIP based on updated input values provided by subject matter experts for S-20200330-426. There is no significant change in the probability of emergent EVAC or the probability of LOCL.

References

1. Integrated Medical Model Project. Integrated Medical Model Operations Plan. JSC-66114. 2011. Houston, TX, NASA, Johnson Space Center. Ref Type: Report

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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

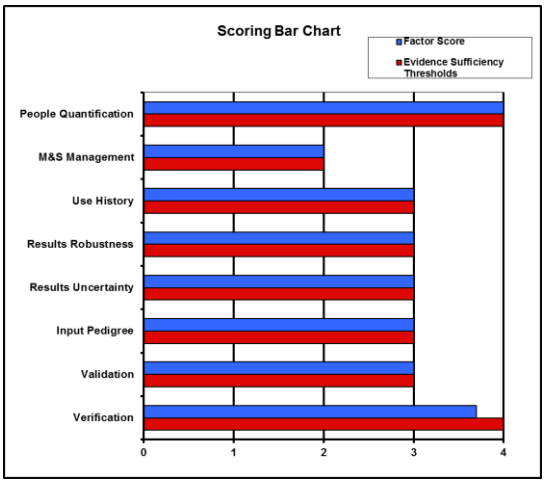
4. NASA-STD-7009: Standard for Models and Simulations (2008). NASA: Washington, DC.

5. ISS 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 A1: IMM Status at Time of Service Request Report S-20200330-426

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.



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 v4.1 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.

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	

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***

Additional verification and validation information applicable to this analysis

None

Integrated Medical Evidence Database (iMED) code version and date accessed

iMED Lockdown IDs: (68), created on (6/29/2020)

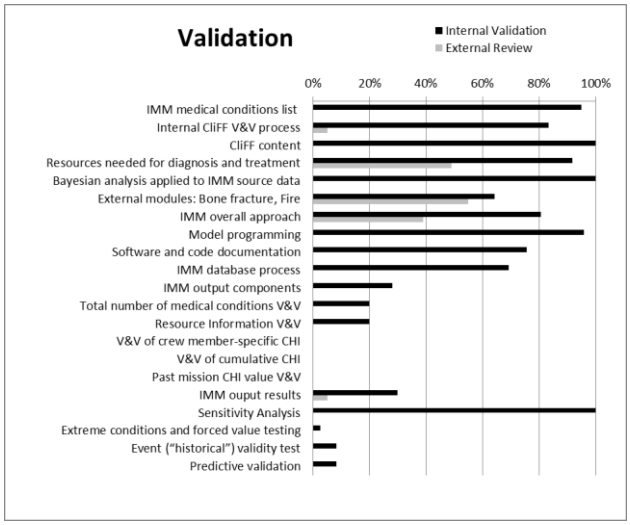
IMM version and code version

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 A2: IMM Status at Time of Service Request Report S-20151123-341 RevA

Validation status for IMM	**IMM V&V Matrix:** The following bar chart shows the IMM v3.0 MATLAB status of internal (black bars) and external (gray bars) IMM validation for each IMM element listed. 
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 (Integrated Medical Model Project); 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: 27 — Compliance Incomplete: 20 — Not applicable: 2
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. A review subfactor weight for bolded factors is 0.3.

Legend

CAS Score > Threshold	
Threshold > CAS Score > Threshold-0.5	
Threshold-0.5 > CAS Score > Threshold-1.0	
CAS Score < Threshold - 1.0	
Overall score indicating sufficiency thresholds met	**3.075**

Factor	Sufficiency Thresholds	Factor Score	Weighted Scores	Overall Score
Verification	**4**	**3**	0.225	
Validation	**3**	**2.3**	0.345	
Input Pedigree	**3**	**1.6**	0.28	
Results Uncertainty	**3**	**3**	0.6	**2.50**
Results Robustness	**3**	**3**	0.45	
Use History	**3**	**2**	0.3	
M&S Management	**2**	**2**	0.1	
People Qualification	**4**	**4**	0.2	

Additional verification and validation information applicable to this analysis	none
Integrated Medical Evidence Database (iMED) code version and date accessed	iMED_20151118
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: Medical Conditions in iMED by Category (iMED_20170221)

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 (CO_2 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 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/Increased Intracranial Pressure (VIIP) (space adaption

Appendix C: iMED Updates 03/2018 – 05/2020

Title	Comments
Added Real World System (RWS) incidence data	Update summary: added data from LSAH including medical events from ISS Exp 15-39/40, ISS exp 9, STS 114-135, and STS 107
Added CHS updates to incidence and best case/worst case numbers (C2-20190219-481)	Update summary: reconciliation of data entry errors (translational/typographic errors & incorrect denominator for BC/WC numbers).
Updated RWS BC and WC probabilities from single point values to a range (IMM CR C2-20190226-482)	Update summary: applied use of established method for rare event estimation consistently across all BC/WC inputs values to produce a range of BC/WC values from a single point estimate.
Updated worst case probability for Eye Corneal Ulcer (C2-20190404-483)	Update summary: Corrected incidence type to "processed in-flight" to accommodate using terrestrial data for BC/WC due to limited in-flight data. Condition incidence is still based on in-flight data.
Updated data for Visual Impairment and/or Increased Intracranial Pressure (VIIP) (space adaptation) (C2-20200312-390)	Update summary: 1) Corrected calculation error for WC probability of SANS. 2) Removed Diamox from VIIP resources. 3) updated EVAC probability based on SME input. (Probability of worst case EVAC was reduced from 0-21% to 0-1%.) 4) Removed fluorescein strips from VIIP resources, as it is the back of the eye that is being examined. (SANS SMEs agree.)
Updated incidence for Eye Chemical Burn (C2-20200214-389)	Update summary: Updated incidence by removing cases of EVA anti-fog surfactant-related eye irritation as this surfactant is no longer in use.
Updating resources from what was flown on ISS in 2012 to what is now flown on ISS as of February 2020 (C2-20200224-391)	Update summary: 1) Updated iMED resources to match 2018 ISS Medkit. Also updated some quantity data and mass/volume data based on 2020 ISS content list. 2) separated ECG and BP monitor into distinct resources as the combined unit is no longer flown 3) Combined items with equal treatment value among different sizes of items (e.g. 18g vs 20g catheter)

Appendix D: Conceptual Updates from IMM 3.0 to IMM 4

Updates in IMM 4	Description	What this means
Timeline	In addition to generating if conditions occur, IMM 4 generates when conditions occur.	Previously in IMM 3, all events occurred on day 1, and metrics, e.g. CHI, were calculated accordingly. In IMM 4, CHI can be better estimated based on this change.
Partial Treatment	IMM 4 gives partial credit for partial treatment in generating the outcomes of a condition	Previously, if a resource was unavailable for treatment, the event was considered fully untreated, CHI, probability of EVAC and probability of LOCL were calculated based on the event being fully untreated. With partial treatment, CHI, EVAC, and LOCL are weighted between fully treated and fully untreated, i.e. can mean higher CHI, higher likelihood of NOT going to EVAC or LOCL.
Alternative Drug	If primary drug required for treatment is not available, IMM 4 searches for medically appropriate substitutes	IMM 4 looks at available resources for equivalences between the primary drug and other pharmaceuticals. This can translate to less fully untreated events, and/or better partial treatment.