National Aeronautics and Space Administration


# THE INTEGRATED MEDICAL MODEL: OUTCOMES FROM INDEPENDENT REVIEW

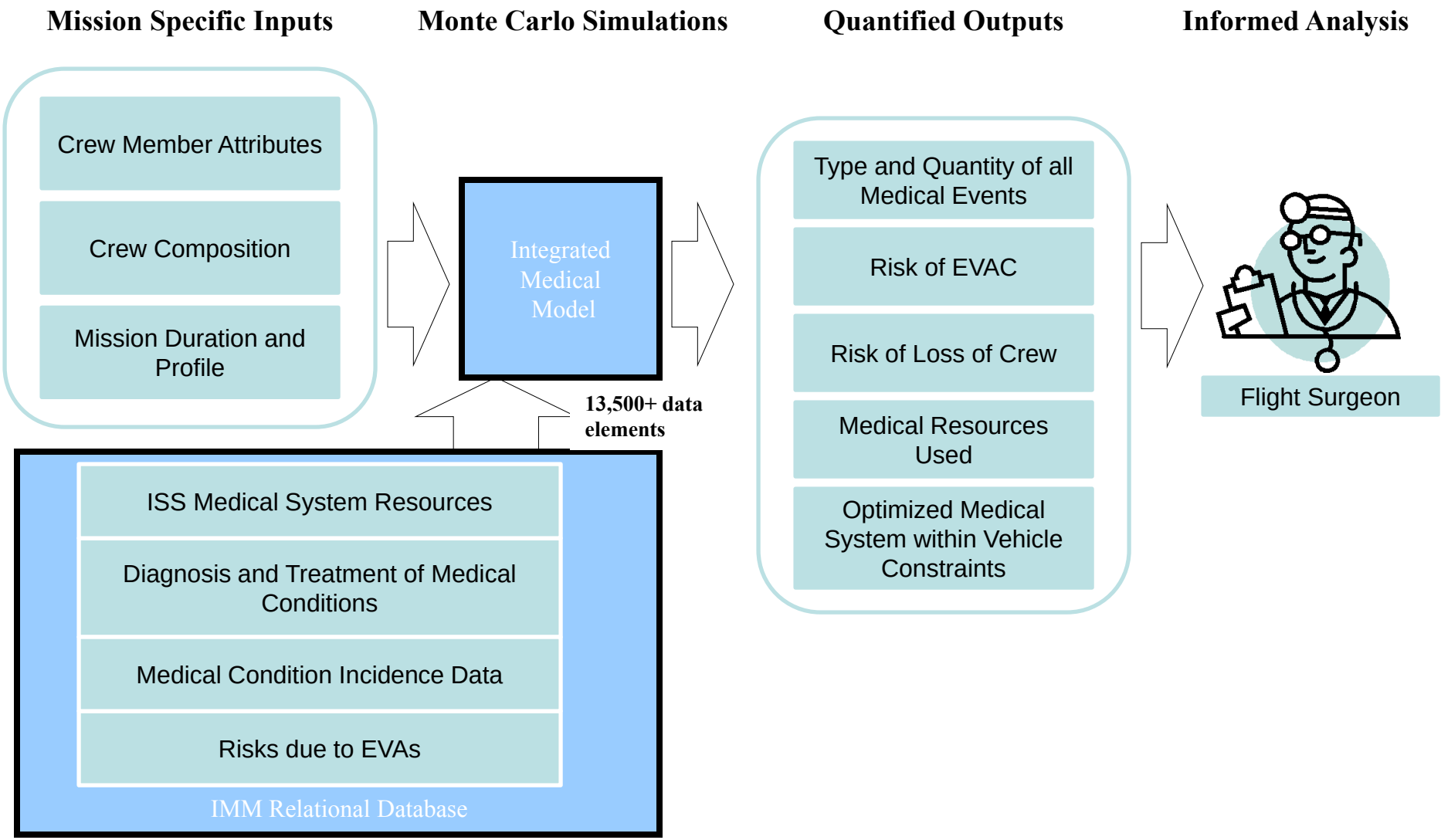
J. Myers[1], Y. Garcia[2], D. Griffin[1], J. Arellano[3], L. Boley[2], D. A. Goodenow[1], E. Kerstman[4], D. Reyes[4], L. Saile[2], M. Walton[2], and M. Young[5]

[1]NASA-Glenn Research Center, [2]KBRWyle, [3]MEIT, [4]UTMB, [5]NASA - Johnson Space Center

# Objectives

- Revisit IMM
  - What is the Integrated Medical Model?
  - How should it be used?
- External Review Design and Make-up
- External Review Findings and Responses

# Providing a tool to help informed decision making

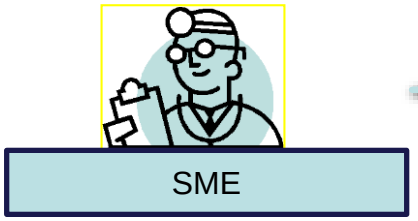


# IMM in a Nutshell

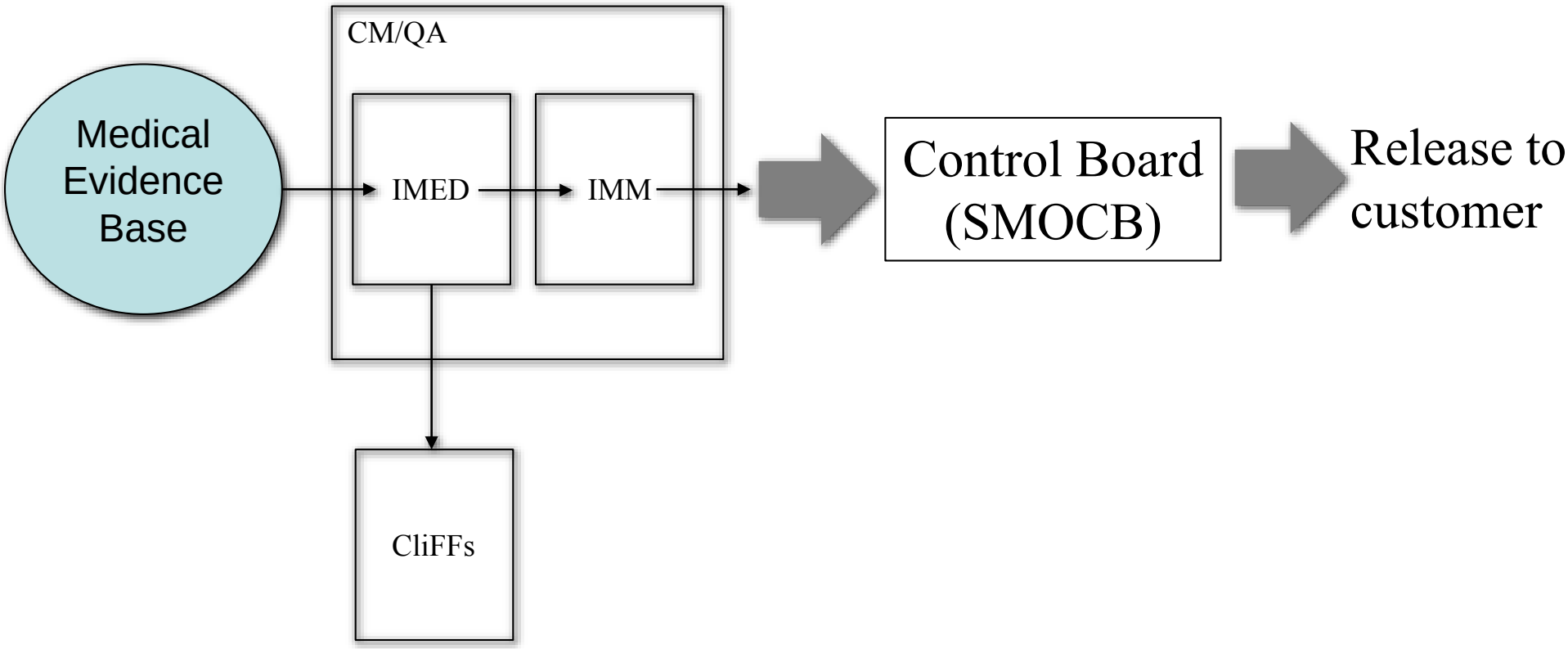
- **Platform to asses mission medical risk using proven risk assessment techniques.**
- **Platform for exploration of the medical kit trade space effects on risk.**
- **Gives decision-makers a means to balance medical risk with limited resources.**
- **Engineering teams with quantitative medical information to characterize risk.**

This is fundamentally about how the NASA Medical and Engineering communities communicate.

# A Verifiable and Validatable Process

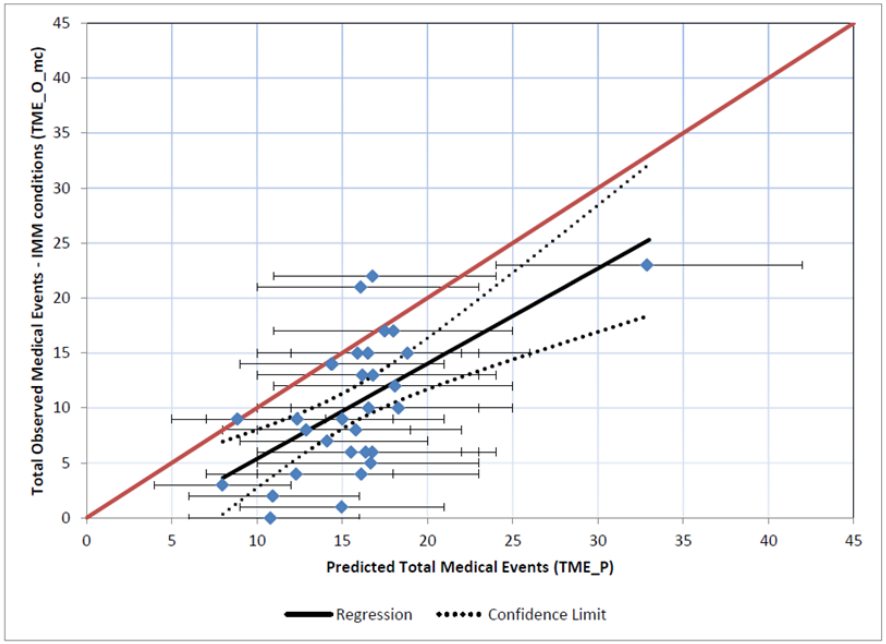



- Considerations for age, sex, and mission duration
- Optimum medical system to minimizing risk
- Estimate of functional impairment to the crew
- Mission risk affected by medical system trades



# Validation Against Real World Observations

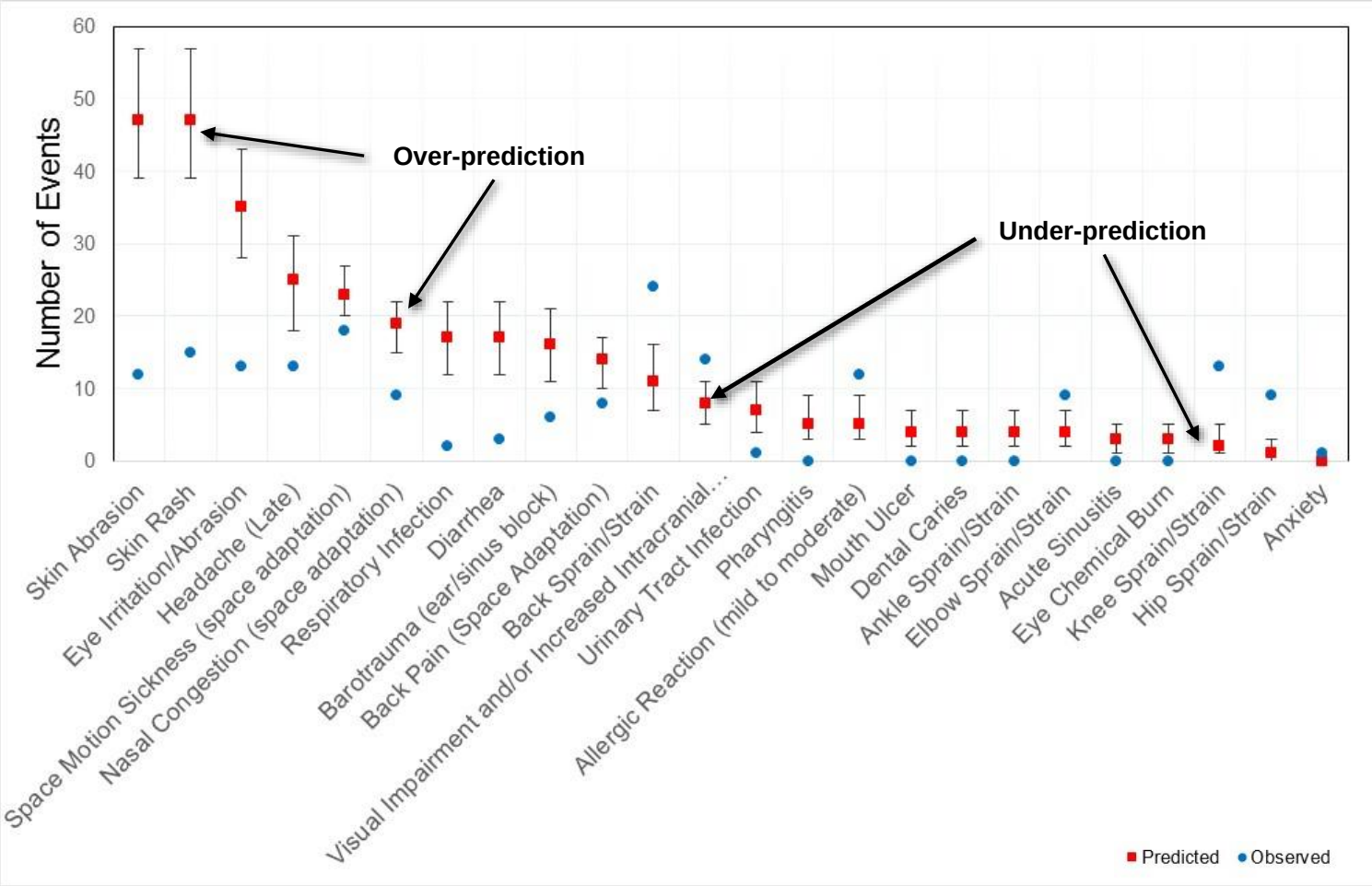
- **Model validation utilized real world system (RWS) observations from International Space Station (ISS) Expedition (Exp) 14 through 39/40**
- **IMM simulation for each expedition**
  - Assuming ISS med capabilities, crew specific parameters and duration
  - Using data obtained from ISS missions and STS missions prior to referent
- **Total number, type and outcomes compared to RWS**




Snapshot of results for RWS ISS missions: IMM generally over-predicts by 3-4 medical events as indicated by regression intercept estimates and slope generally less than 1 (Considering IMM Condition List events only).

# Individual Condition Counts

- **24 conditions failed to meet the performance characterization criteria**
- **17 over-predicted and 7 under-predicted the number of events**



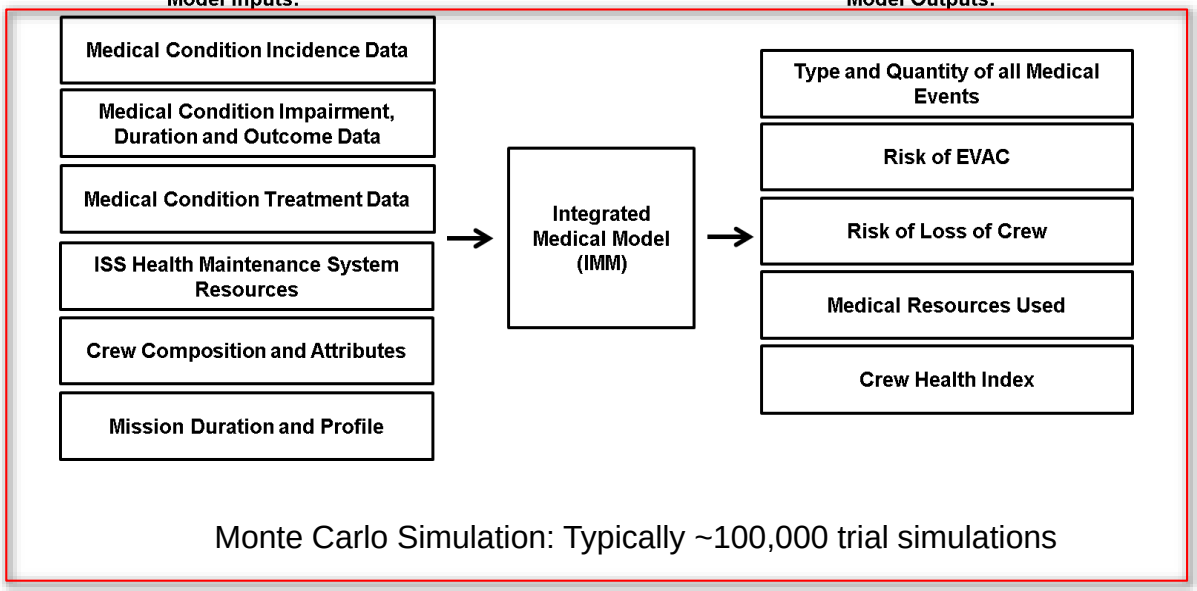
# External Review & Findings

# Model and External Review

Medicine
Epidemiology
Biostatistics
Software

Biostatistics
Modeling
Probability
Theory
Software

Aerospace
Medicine
Engineering
Software




Project
Management
Software

Review Expertise Needed in Red

# External Review Board

## ExMC convened an external review panel through the GSFC Systems Review Branch

- Chair: Dr. Bryant Cramer (GSFC – Retired)
- Review Manager: Mr. Neil Martin (GSFC)
- Aerospace Medical : Dr. Jan Stepanek (Mayo Clinic)
- Epidemiologist: Dr. Guohua LI (Columbia University)
- Chief Engineer /Software : Mr. Steve Scott (GSFC)
- Software: Mr. Robert Schweiss (GSFC)
- Biostatistics/Probability Theory : Dr. Nancy Lindsey (GSFC)
- Software/ Project Management : Mr. Dick Kauffman (Criterion systems)
- Computational Modeling : Dr. Gary Pradhan (Mayo Clinic)

# IMM External Review

## From Nov 2015 to May 2016

- 2 Pre-Meeting Summaries : “Introduction to IMM” and “IMM Validation Strategies”
- Board formally convened three times Dec 2015, Jan 2016, March/April 2016

## External Review Topics

- Model Concepts and Software and code standards (i.e. JPR- 7150.2B compliance)
- Input pedigree of incidence and outcomes information (NASA-STD-7009: Input Pedigree Credibility Factor)
- Model performance (NASA-STD-7009 Verification, Validation, Sensitivity, Operations, Use History)

# Input Pedigree

Ensure internal processes for identifying, ranking quality, and including medical data with evidence-based rationale is appropriate to capture medical risk likelihood, medical information, and outcome uncertainty for the model application.

- Presented evidence related to data process and ~~data~~ capture
  - A selection of 10 Clinical Findings Forms (CliFFs) summarizing the types of data and conditions used to inform IMM simulations

    - Atrial Fibrillation
    - Burns Secondary to Fire
    - Decompression Sickness Secondary to EVA
    - Dental Abscess
    - Headache (Space Adaptation)
    - Hip-Proximal Femur Fracture
    - Eye Chemical Burn
    - Stroke
    - Sepsis
    - Urinary Retention (Space Adaptation)

# Summary Review Comments

**Board identified strengths:**

- **The concept of the IMM is scientifically sound and it works.**
- **The IMM represents a necessary, comprehensive approach to identifying medical and environmental risks facing astronauts in long duration missions.**
- **Because it integrates with the Exploration Probabilistic Risk Assessment (ExPRAT), the IMM has become an excellent tool through which engineers and physicians can better communicate with each other by speaking a common risk assessment language.**
- **The validation approach is sound and the use of actual space medical data is logical and compelling.**
- **IMM statistical methods for processing and analyzing the input data, performing simulations, and generating and presenting quantitative outputs are scientifically sound.**
- **The IMM validation approach is sound and the match between the IMM and the real world system is good.**

# Summary Review Comments cont.

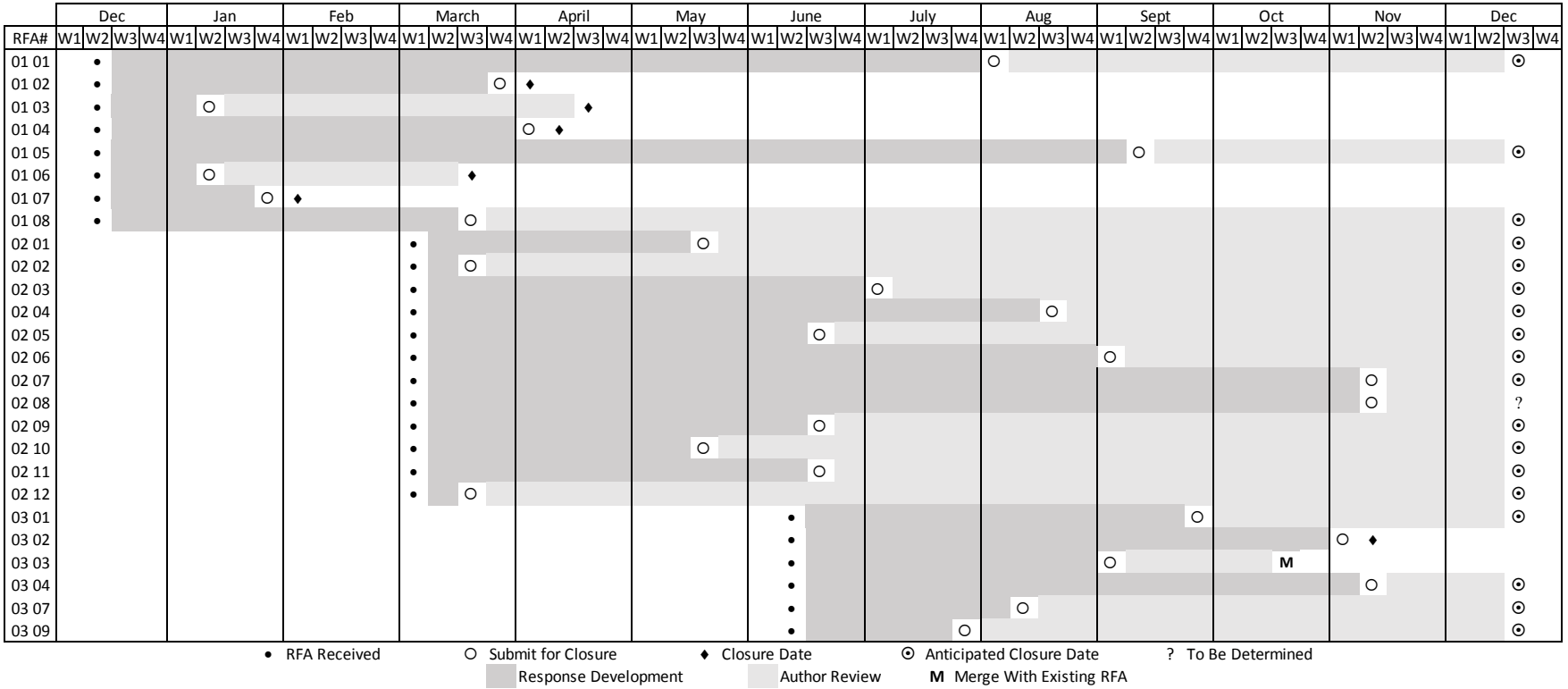
**Board identified issues:**

- **Need for stronger software engineering involvement particularly in terms of quality assurance.**
- **Accuracy concerns regarding the CliFFs; the Board found a numbers of errors necessitating a robust reviews of all remaining CliFFs.**
- **Need for a sustainable approach to augment, peer review, and maintain the CliFFs.**
- **Organizational issues:**
  - Physical separation of Project Management from Development Team presents a challenge.
  - Evolutionary path for IMM insufficiently defined.
  - Need for a well-developed Operations Concept.

# RFA Summary

- **Total of 28 RFAs and 6 advisories submitted**
- **Project combined 8 of the RFAs for consolidated responses**
  - New total : ***24 RFAs***
- **RFA closure summary**
  - All Submitted for closure as of 11/15/2016
    - 23 – Evidence or plan to secure evidence supplied as a response
    - 1 – Element and project decision not to pursue a response at this time
  - Closure acceptance received 12/2016

# RFA Closure Schedule




- A summary of each IMM Project response is provided in the backup slides

# Summary of Significant RFA Closure Activities

- **Code modifications were performed to reduce run times by 70%.**

- **Adjustments to reviewed condition information**
  - Minor typographical updates to DCS and Stroke CLIFF.
  - Updated data after addressing board suggestions and source data from the primary references.
    - Dental Abscess CLIFF – reevaluation of source data categorization of medical condition.
    - Space Adaption headache leading to evacuation reduced from 1.5% max to 0% max.
    - Eye Chemical Burn updated rationale.
    - Sepsis Updated rationale.

- **Developed survey document guidelines for improved configuration management of clinical data identification.**

- **Performed a calibration of CHI using the RWS and iMED data information (Accepted for Closure RFA 3.02).**

# IMM Project Planned Pre- Delivery Activities

- **Updated NASA-7009 Credibility Thresholds Per accepted RFA plan (12/1/2016 – 3/7/2017)**
- **Complete STS RWS validation activity (12/1/2016 – 6/1/2017)**
- **Complete iMED 6.5 (12/5/2016 – 2/10/2017)**
- **Add RWS data to iMED 6.5 (3/31/2107 – 4/21/2017)**

# Conclusions

- **IMM is a tool intended to help mission planners make decisions regarding medical risk and supplies.**

- **It is intended to pull in data and experience to provide the best current information to inform medical resource planning.**

- **Outcomes of the IMM 4.0 review**
  - Definite need for the model of this type - validation testing illustrates its utility
  - Concerns expressed that the medical condition information requires further review
- **Forward work plan toward transition to customer baselined**
  - Final negotiation of ConOps plan with CHS
  - RWS validation for STS and RWS data integrated into iMED
  - Completion planned NLT 5/30/2017

# Backup Slides

# Forward Work

- **Obtain Feedback from Medical Operations that the validation activity of IMM has appropriate clinical context**
  - (Provided guidance) Requires a formal flight surgeon participant review of IMM validation activities

- **Develop a Process and Review Remaining CliFFs**
  - (Completed as part of another RFA) Develop formal process for surveying, identifying, implementing and routine maintenance of IMM source data
  - (Completed) All CLIFF references double checked and improved CLIFF report generation implemented within iMED
  - (Deferred) Develop/Negotiate requirements, review criteria and formulate review plan guidance
  - (Deferred) Implementation to follow plan development

# Board Findings: Recommendations

| Recommendation Number | Recommendation | ExMC Response | Subject |
|---|---|---|---|
| 1 | To achieve operational status, the IMM Team should add a Software Engineer and a software architect with experience in developing software as outlined in JSC 7150.2 and Capability Maturity Model Integration (CMMI) with a one year goal of achieving a CMMI Level 2. CMMI Level 3 as a three-year goal. | Recommendation noted and will be forwarded to the operator; further development beyond delivered S/W is at the discretion of Operator. SQA processes adhere to 7150.2 requirements | S/W Maturity |
| 2 | Implement the credible solutions developed in response to RFA 2.07 to improve document management, configuration management, and verification (of medical conditons data). | Recommendation noted. CM processes of the iMED database implemented by 2/2017. Guidance on maintenance and survey document content to be provided to Operator at delivery. | CM |
| 3 | The remaining CliFFs should be meticulously reviewed. The Project does not plan to undertake a comprehensive review. The Board recommends that JSC reconsider this decision at the earliest opportunity. | Recommendation noted will be passed on to Operator; decision on further CLiFFs review is discretion of the Operator | CliFFs |

Recommendations and Conclusions paraphrased from original Text. Original Text presented in backup slides

# Board Findings: Recommendations cont.

| Recommendation Number | Recommendation | ExMC Response | Subject |
|---|---|---|---|
| 4 | Recommend the development of a rigorous, scientifically sound, plan for long term sustainment of the CliFFs through systematic, periodic reviews of the terrestrial medical literature and space-based medical data while utilizing the professional services of a medical librarian. | Recommendation noted will be passed on to Operator. Operator to be provided guidance on prioritization, process and frequency of medical data review within the CONOPS. Decision on iMED data sustainment is discretion of the Operator. | CliFFs |
| 5 | Complete the current CONOPS and a compatible plan for an ORR so that a reviewer can readily see that in passing the ORR, the IMM Project and IMM Version 4.0 can successfully execute the CONOPS. | Agree with recommendation. A Draft CONOPS will be delivered to operator, however some decisions and finalization of the CONOPS is discretion of the Operator as is the decision to proceed to ORR | ConOps |
| 6 | Address the Use History in the CONOPS, review the managerial processes in the CONOPS to address the Model & Simulation Management, and consider reducing the threshold of Input Pedigree from 3 to 2. | CONOPS contains detail examples of IMM 3.0 use history. Management process of the operation of the IMM is at the Operator discretion. Reassessment of pedigree score planned by 1/2017. | ConOps |

Recommendations and Conclusions paraphrased from original Text. Original Text presented in backup slides

# Board Findings: Conclusions

| Conclusion Number | Title | Conclusion | ExMC Response | Subject |
|---|---|---|---|---|
| C1 | *Assess the development of IMM Version 4.0.* | IMM Version 4.0 needs more robust managerial processes in requirements development, requirements management, documentation management, configuration control, and software verification. This is particularly evident in software development. | Conclusion noted and will be forwarded to the operator; project staffing and future development is at the discretion of Operator (See R1). Current project team will implement board recommended code changes with SQE oversight prior to delivery to the Operator. | S/W Maturity |
| C2 | *Assess the accuracy and adequacy of medical baseline data incorporated in the Clinical Findings Forms (CliFFs)* | Due to the shortcomings found in the ten CliFFs that were reviewed, the Board recommends that the remaining CliFFs be meticulously reviewed and a long-term process must be established to sustain and evolve the CliFFs. The CliFFs are the foundation of IMM and the use of the IMM will never be widely accepted until the CliFFs are fully trusted. | Conclusion noted will be passed on to Operator; decision on further CLiFF review is discretion of the Operator (See R 3, 4) | CliFFs |
| C3 | *Assess the readiness of IMM Version 4.0 for operations* | IMM Version 4.0 is not yet ready for operations. Readiness requires the completion of the CONOPS, passing an Operational Readiness Review and completing a comprehensive review of the CliFFs. | A Draft ConOps will be delivered to operator, however some decisions and finalization of the ConOps is discretion of the Operator as is the decision to proceed to ORR (See R5, 6). The board's reservation to deploying the current iMED without complete CliFF review will be communicated to the Operator as well as RWS data to support a decision about deployment (and at what level) | ConOps |

Recommendations and Conclusions paraphrased from original Text. Original Text presented in backup slides

# IMM Core Application Questions

- **What medical conditions will occur most?**
- **What medical resources will be used?**
- **What is the probability of evacuation?**
- **What is the probability of loss of crew life?**
- **What is the range of crew impairment?**
- **What are the optimal medical resources?**

These are the types of questions that helped create the model

# Integrated Medical Model (IMM) Project History

**Conceived in 2005, as a means to inform medical resource planning and quantify aspects of mission medical risk for CHS and ExMC**

- Developed by ExMC and operated by CHS

We wanted to know what was likely to happen in a mission.
We wanted to know how to best design a medical kit.

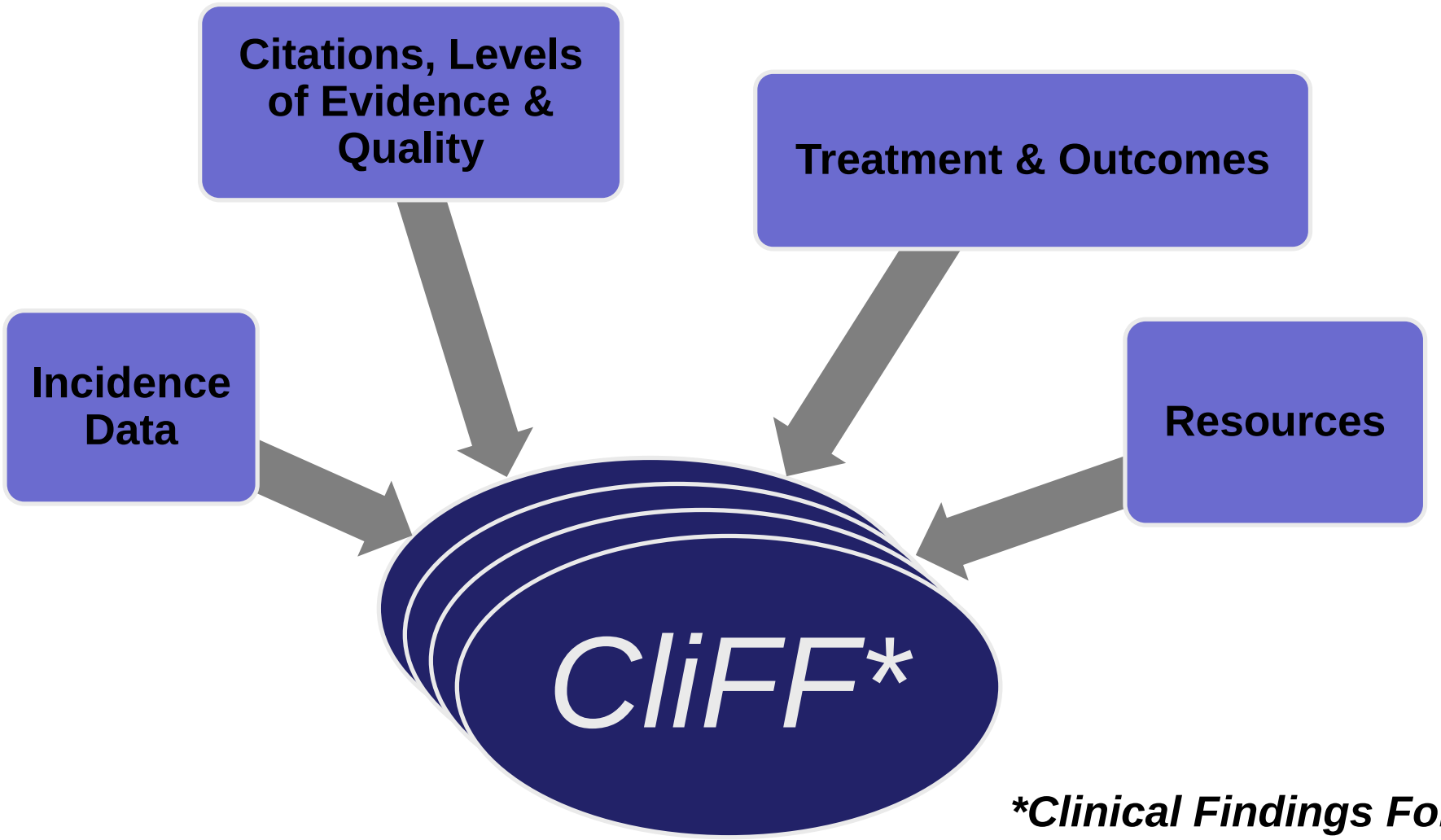
**The intent was to utilize available space flight community knowledge base as an integral part of the simulation environment**

- Sources: U.S. astronaut data
- analog and general population information with appropriate quality and applicability to space flight concepts

**Not envisioned to be**

- A diagnosis tool or definitive assessment of medical treatment
- A means of assessing countermeasure efficacy or performance decrement

# iMed Database




*Clinical Findings Form

# IMM Evidence Database

- **Lifetime Surveillance of Astronaut Health (LSAH)**
- **ISS Expeditions 1 thru 13 (2006)***
- **STS-01 thru STS-114 (2005)**
- **Apollo, Skylab, Mir (U.S. crew only)**
- **Analog, terrestrial data**
- **Bayesian Analyses**
- **Independent predictive models**
- **Flight Surgeon Delphi Study**

- ***Russian medical data not used***
- ***Sizeable U.S. crew data update received from LSAH in the past few weeks. This will be added to the model.***

* More current data used for Visual Impairment Intracranial Pressure (VIIP)

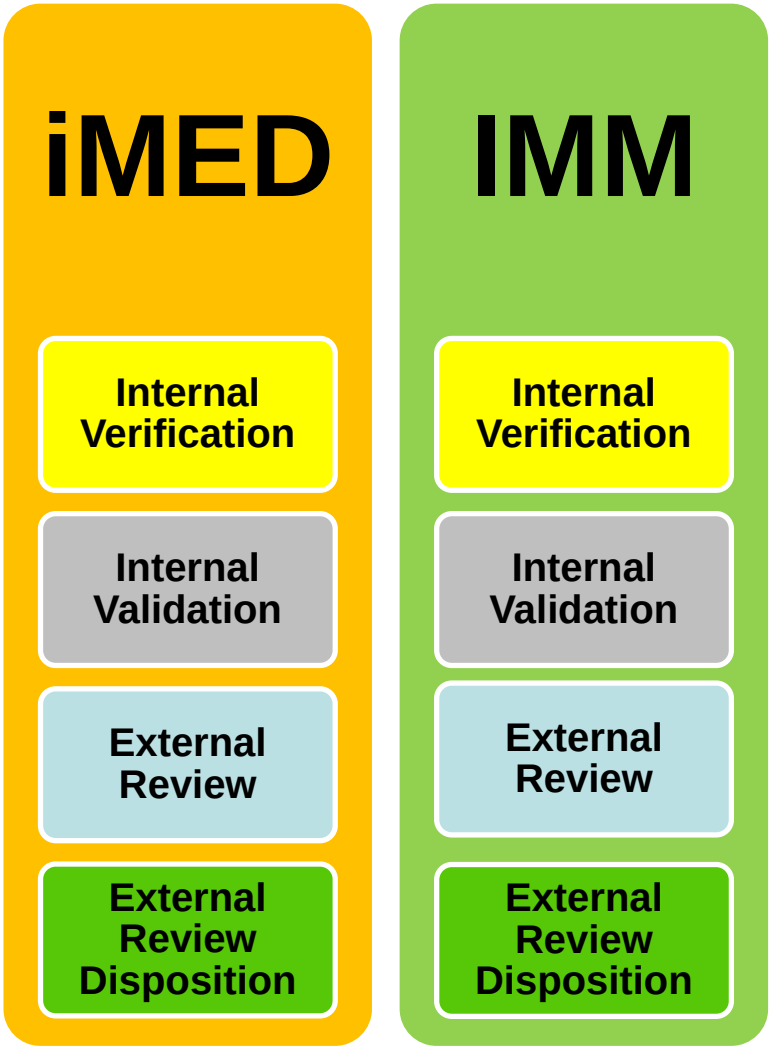
# What does EVAC mean?

- **EVAC in the context of the ISS**

- **EVAC if any criteria are met:**
  - potential LOCL
  - potential significant permanent impairment
  - potential intractable pain

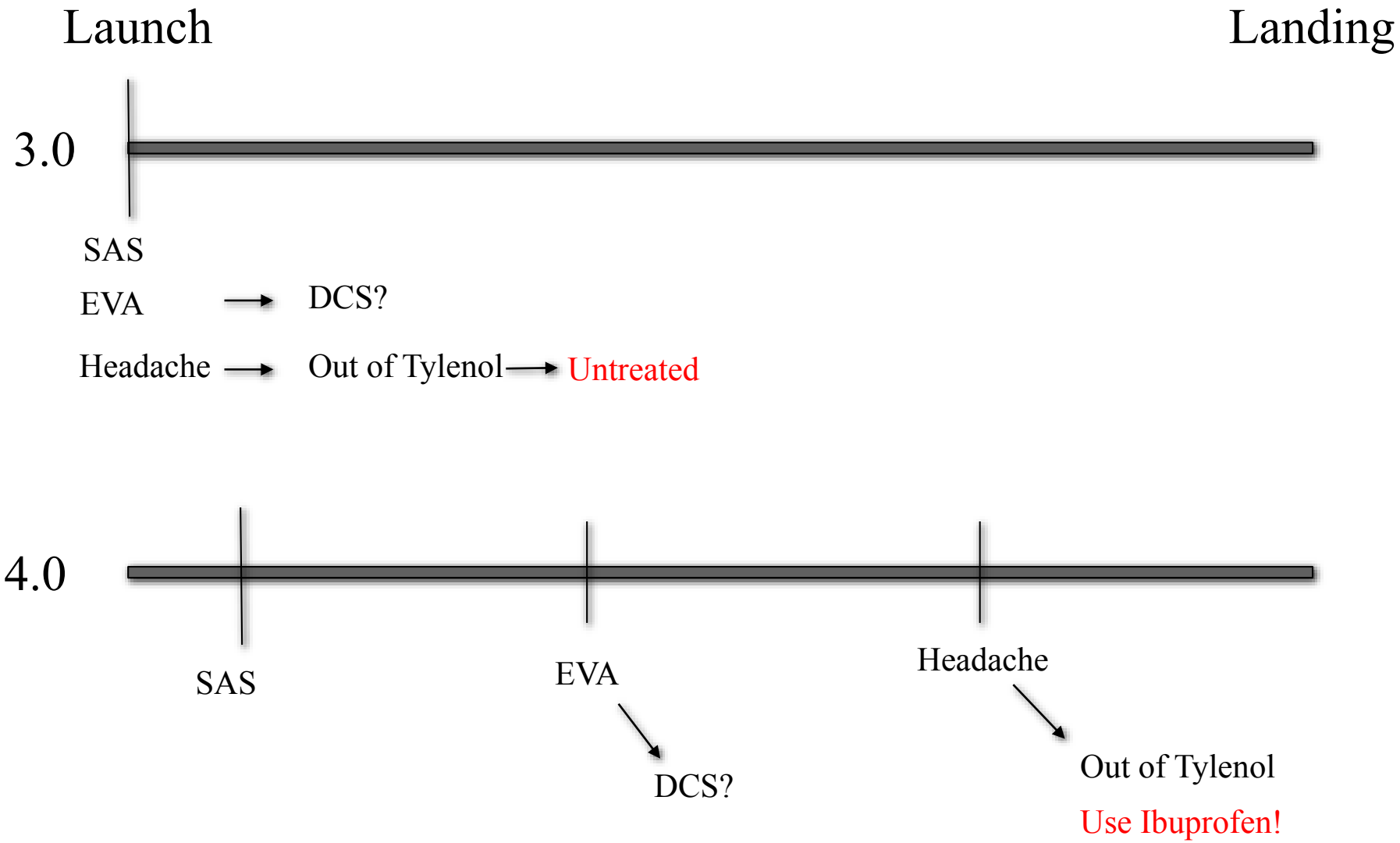
  - No other assumptions are made

# Verification, Validation & Credibility (VV&C)




- Version 3.0 in use since 2011
- Following NASA-Standard-7009
- Internal VV&C v4.0:
  - 7150.2 compliance review
  - Testing with specific DRM challenges
  - Assess face validation of performance capabilities
  - Quantitative comparison to real world system and LSAH data pool (shuttle and ISS)
- External VV&C v4.0:
  - SME review external to lead center (JSC)

# Inclusion of Timeline in 4.0



# How can it be used for operations?

***IMM addresses in-flight risk using ISS information as a stepping stone***

- **Scope**
  - Forecasts medical outcomes for in-flight operations only
  - Forecasts medical impacts to mission
  - Does not assess long-term or chronic post-mission medical consequences

Algorithm: Maximize or minimize CHI, Evac, LOCL by changing your resources (what kit has the best CHI?)

# How can CHS, HRP and ExMC use IMM?

- Which science and technology investments decrease crew and/or mission risk within vehicle resource constraints?

- Which countermeasures have the greatest influence on in-flight crew and/or mission risk?

Ref: IMM Conceptual Model Document

# What is the current state of IMM?

- **Version 3.0 has been used for operational questions to this point.**

- **Version 4.0**
  - Internal Validation, Verification and Certification finished October 2015.
  - Delivery is targeting March 2016 (flexible).
  - External Review (external to JSC and GRC) has been assembled and is proceeding.

# External Review of IMM v4.0

| Review Type | Conent |
|---|---|
| **IMM software and code verification review (JPR 7150.2)**<br>**Dec 15-17, 2015** | Ensure IMM satisfies requirements set out in JPR 7150.2. These include compliance review, including black and white box testing, code verification. Review products include a report with request for actions (RFAs) |
| **Model Input Pedigree (iMED data): Process Review (required by 7009)**<br>**Jan 28-29, 2016** | Ensure internal processes for identifying, ranking quality, and including medical data with evidence-based rationale in iMED is appropriate to capture medical risk likelihood, medical information, and outcome uncertainty for the model application. Insure current data in model is of sufficient pedigree for the model's intended use.<br>Review products: Summary report on the review outcomes including a prioritized list of RFA's |
| **End-to-end review (required by 7009 and 8900)**<br>**Feb 24-25, 2016** | Perform thorough review of the model application and VV&C efforts to assess model performance meet functional requirements in the in area of application. This review addresses documented performance and VV&C efforts and could include independent testing of the model<br>Review Products: Summary report of the panel findings and a prioritized list of RFAs |

→ ExMC Project Scientist convenes these reviews

# Status of Review

- **Panel has been set**
  - Bryant Cramer  - Chair
  - Neil Martin  - Review Manager  GSFC
  - Jan Stepanek - Aerospace Medicine  Mayo Clinic
  - Guohua LI - Epidemiologist  Columbia University
  - Steve Scott - Chief Engineer/Software - GSFC
  - Robert Schweiss - Software – GSFC
  - Nancy Lindsey - Biostatistics/Probability Theory - NASA
  - Dick Kauffman – Software – Criterion Systems
  - Gary Pradhan – Modeling Mayo Clinic

# IMM 7009 Review materials highlights

- **Verification**
  - Unit testing for numerical accuracy, in combination with the 7150.2 req.
- **Validation and Results Uncertainty**
  - Evaluation of model performance with respect to Clinical SME experience
    - Face Validation
  - Comparison to a Real World System : ISS (and STS if requested by panel)
    - Qualitative – RWS conditions rates and ranked resource types
    - Quantitative – Conditions and outcomes
- **Input Pedigree**
  - All Clinical Findings Reports for all 100 conditions in IMM – Details incidence, outcomes and resources
- **Results Robustness**
  - Formal Sensitivity Analysis on conditions vs. outcomes using two techniques
- **Use History**
  - Utilization of IMM v.3.0 (v4.0 technically has zero use history unless it can be deemed to encompass IMM v3.0)
- **M&S Management**
  - Project and operation plans and schedules
- **People Qualifications**
  - Training requirements, education and experience information (similar to a NIH proposal would require)

# Review of software and code verification

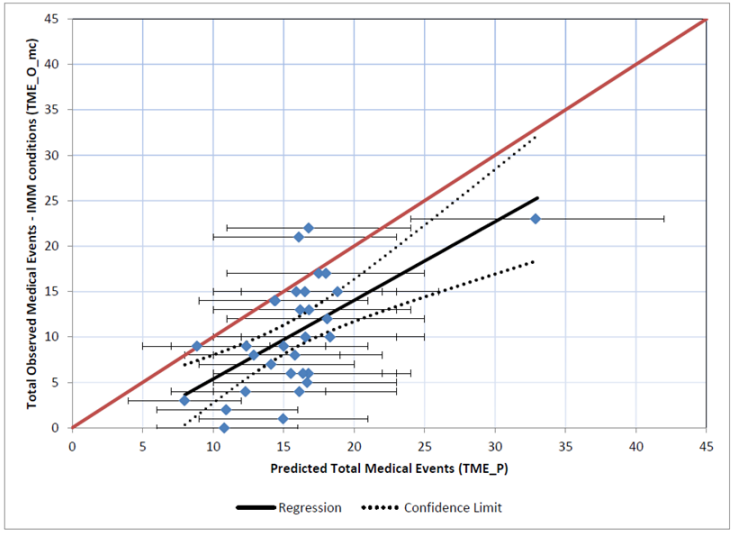
Ensure the elements of IMM satisfy requirements set out in JPR 7150.2B. These include compliance review, black and white box testing, and code verification

- **Presented evidence**
  - IMM development concept and early concept of operations
  - Functional requirements compliance
  - Derived software requirements compliance
    - IMM, iMED database and tool for optimization of medical capabilities
  - Compliance with standards JPR 7150.2B
    - Software assurance plan and Software classification review
  - Introduction to model and simulation VV&C plan and NASA-STD-7009 compliance
    - Use History (v3.0), Project Management and Personnel

# Review of Model Performance : Verification, Validation, Sensitivity and Operations

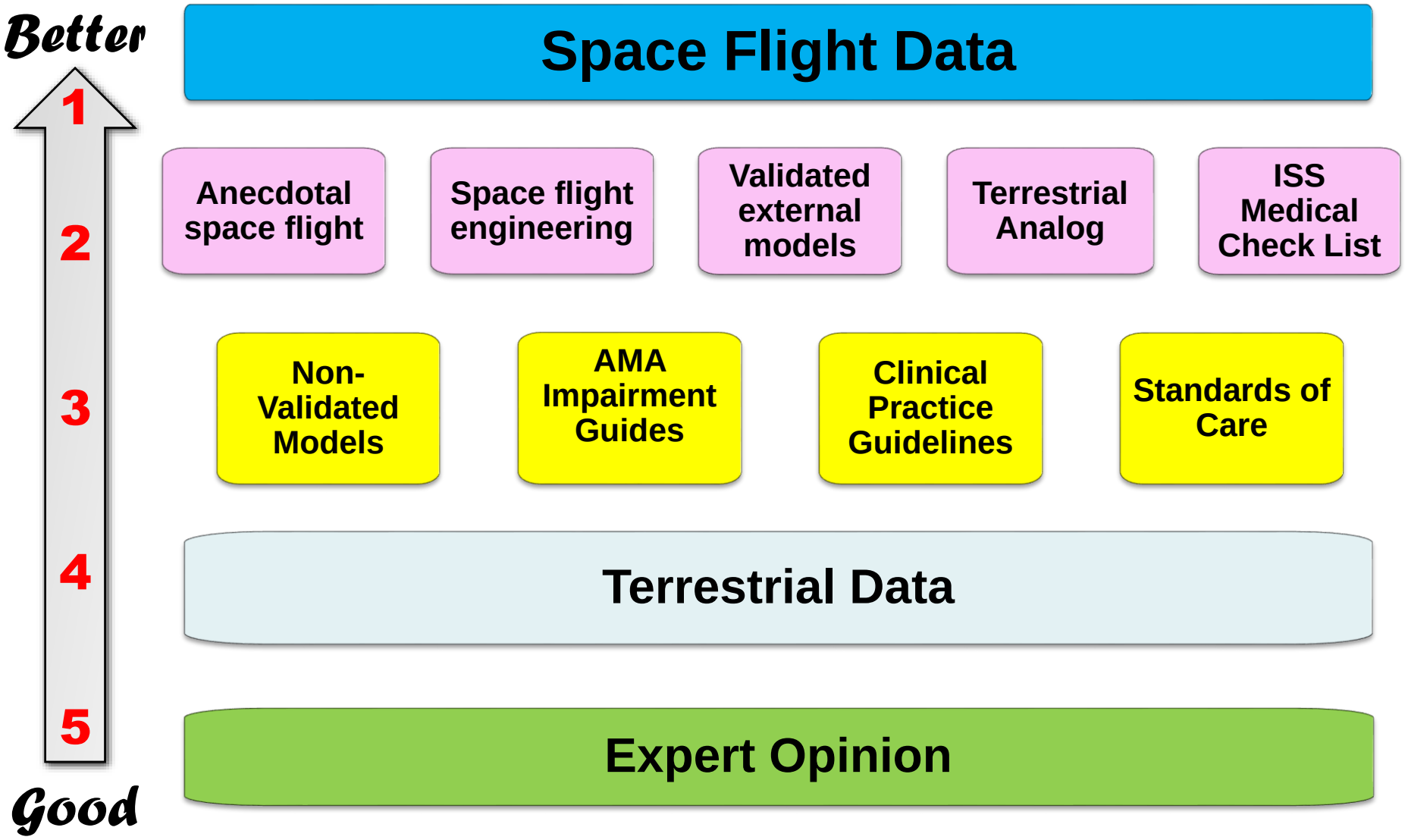
Review of the model application and VV&C efforts to assess model performance in meeting functional requirements and adherence to NASA-STD-7009

- **Presented evidence**
  - Acquisition and processing of real world system (RWS) observed data
  - Qualitative and Quantitative comparison of IMM performance versus RWS
  - Uncertainty and sensitivity analysis for ISS class missions
  - Briefing from customer on use history and future ops concepts




Snapshot of results for RWS ISS missions: IMM generally over-predicts by 3-4 medical events as indicated by regression intercept estimates and slope generally less than 1 (Considering IMM Condition List  events only)

# Levels of Evidence



# IMM Contacts

**ExMC - IMM Project / Technical Management**

**Project Manager (GRC)**
**DeVon Griffin**
Devon.w.griffin@nasa.gov

**Technical Director (GRC)**
**Jerry Myers**
jerry.g.myers@nasa.gov

**Integration Lead (JSC)**
**Kerry McGuire**
kerry.m.mcguire@nasa.gov

**SSC Project Manager (WYLE)**
**Yamil Garcia**
Yamil.garcia@nasa.gov

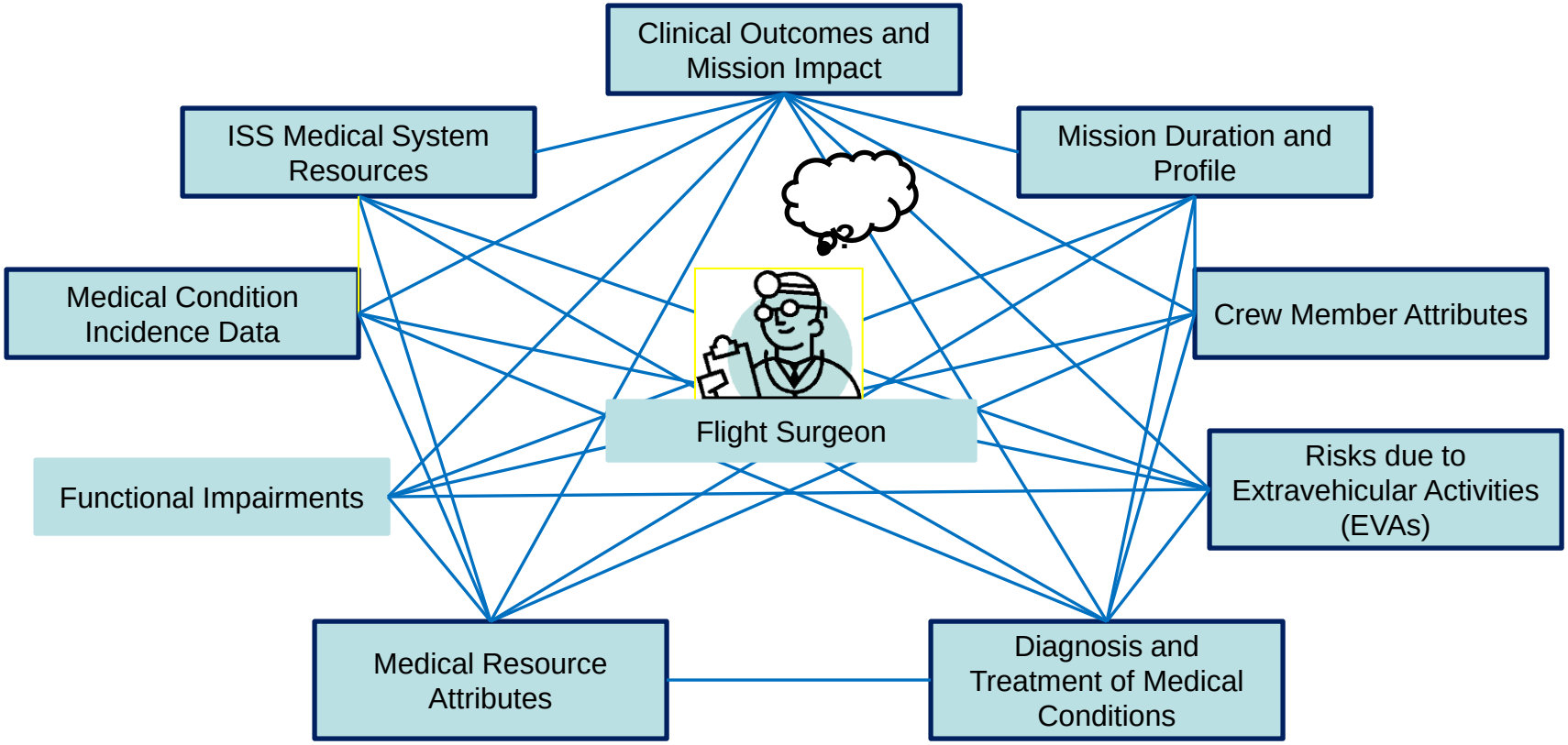
**IMM Development Team**

**Lead Team (SSC, Wyle)**
**Lynn Boley**
**Alexandra Keenan**
**Eric Kerstman**
**David Reyes**
**Lynn Saile**
**Marlei Walton**
**Millennia Young**

**Support Team (GRC)**
**Debra Goodenow**
**Donald Jaworske**

# Without IMM

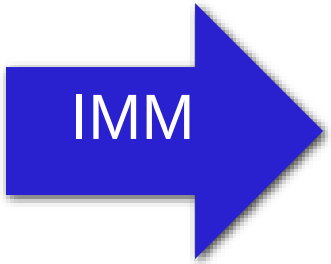
| What is the likelihood of a medical evacuation? | What is the risk of Loss of Crew Life due to illness on ISS? | What medical devices should we have on ISS? | What should be in the Exploration Medical Kit? |
|---|---|---|---|



# How does it work?

## Inputs

- **Crew composition**
- **Crew size**
- **Gender**
- **# crowns**
- **Mission duration**
- **CAC score**
- **Prior abdominal surgery**

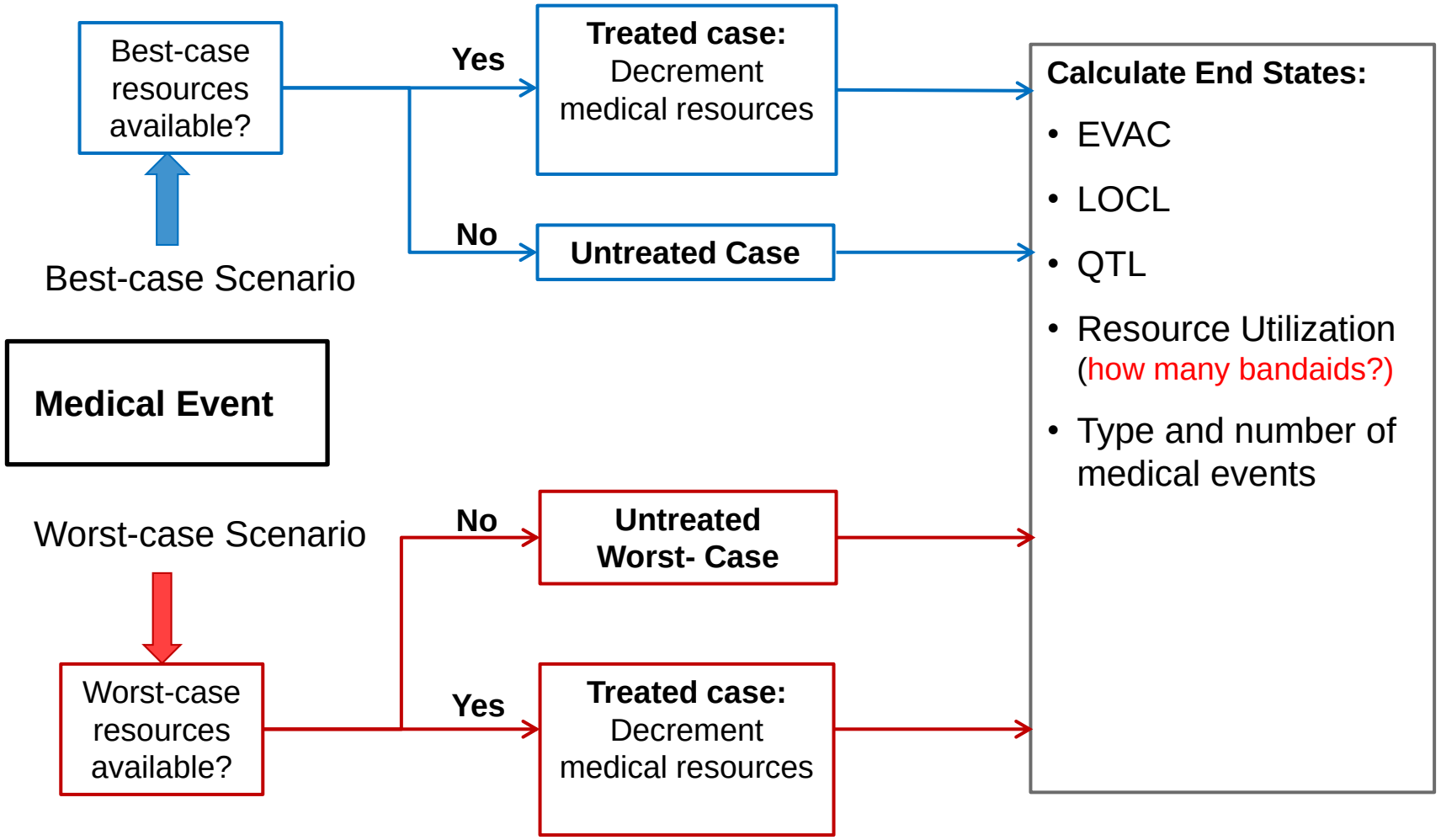



## Outputs

- **Crew Health Index (CHI)**
- **LOCL (Loss of Crew Life)**
- **EVAC (Evacuation)**
- **Probability of occurrence for a condition(s)**
- **Best or worst case**
- **Optimized resources associated with above**

Typically runs 10,000 or 100,000 simulations using Monte Carlo techniques to Explore the parameter range

# IMM Methodology



# The IMM Medical Conditions**

1. Abdominal Injury
2. Abdominal Wall Hernia
3. Abnormal Uterine Bleeding
4. Acute Arthritis
5. Acute Cholecystitis / Biliary Colic
6. Acute Compartment Syndrome
7. Acute Diverticulitis
8. Acute Closed-Angle Glaucoma
9. Acute Pancreatitis
10. Acute Prostatitis
11. Acute Radiation Syndrome
12. Acute Sinusitis
13. Allergic Reaction (mild to moderate)
14. Altitude Sickness
15. Angina/ Myocardial Infarction
16. Anaphylaxis
17. Ankle Sprain/Strain
18. Anxiety
19. Appendicitis
20. Atrial Fibrillation/ Flutter
21. Back Sprain/Strain
22. Back Pain (SA)
23. Barotrauma (sinus block)
24. Behavioral Emergency
25. Burns secondary to Fire
26. Cardiogenic Shock secondary to Infarction
27. Chest Injury
28. Choking/Obstructed Airway
29. Constipation (SA)
30. Decompression Sickness Secondary to EVA
31. Dental : Exposed Pulp
32. Dental Caries
33. Dental: Abscess
34. Dental: Avulsion (Tooth Loss)
35. Dental: Crown Loss
36. Dental: Filling Loss
37. Dental: Toothache
38. Depression
39. Diarrhea
40. Elbow Dislocation
41. Elbow Sprain/Strain
42. Eye Irritation/Abrasion
43. Eye Chemical Burn
44. Eye Corneal Ulcer
45. Eye Infection
46. Eye Penetration (foreign body)
47. Finger Dislocation
48. Fingernail Delamination (2° EVA)
49. Gastroenteritis
50. Head Injury
51. Headache ($CO_2$ induced)
52. Headache (Late)
53. Headache (SA)
54. Hearing Loss
55. Hemorrhoids
56. Herpes Zoster
57. Hip Sprain/Strain
58. Hip/Proximal Femur Fracture
59. Hypertension
60. Indigestion
61. Influenza
62. Insomnia (SA)
63. Knee Sprain/Strain
64. Late Insomnia
65. Lower Extremity Stress Fracture
66. Lumbar Spine Fracture
67. Medication Overdose / Reaction
68. Mouth Ulcer
69. Nasal Congestion (SA)
70. Nephrolithiasis
71. Neurogenic Shock
72. Nose bleed (SA)
73. Otitis Externa
74. Otitis Media
75. Paresthesias (2° EVA)
76. Pharyngitis
77. Respiratory Infection
78. Retinal Detachment
79. Seizures
80. Sepsis
81. Shoulder Dislocation
82. Shoulder Sprain/Strain
83. Skin Abrasion
84. Skin Infection
85. Skin Laceration
86. Skin Rash
87. Small Bowel Obstruction
88. Smoke Inhalation
89. Space Motion Sickness (SA)
90. Stroke (CVA)
91. Sudden Cardiac Arrest
92. Toxic Exposure: Ammonia
93. Traumatic Hypovolemic Shock
94. Urinary Incontinence (SA)
95. Urinary Retention (SA)
96. Urinary Tract Infection
97. Vaginal Yeast Infection
98. VIIIP – Visual Impairment/ Increased Intracranial Pressure (SA)
99. Wrist Fracture
100. Wrist Sprain/Strain

**SA = Space Adaptation** ****47 conditions have occurred inflight, 53 others considered possible**

# The IMM Medical Conditions

**SKIN**
- Burns secondary to Fire
- Skin Abrasion
- Skin Laceration

**EYES**
- Acute Angle-Closure Glaucoma
- Eye Corneal Ulcer
- Eye Infection
- Retinal Detachment
- Eye Abrasion
- Eye Chemical Burn
- Eye Penetration

**EARS, NOSE, THROAT**
- Barotrauma (Ear/Sinus Block)
- Nasal Congestion (SA)
- Nose Bleed (space adaptation)
- Acute Sinusitis
- Hearing Loss
- Otitis Externa
- Otitis Media
- Pharyngitis

**DENTAL**
- Abscess
- Caries
- Exposed Pulp
- Tooth Loss
- Crown Loss
- Filling Loss

**CARDIOVASCULAR**
- Angina/Myocardial Infarction
- Atrial Fibrillation / Atrial Flutter
- Cardiogenic Shock secondary to Myocardial Infarction
- Hypertension
- Sudden Cardiac Arrest
- Traumatic Hypovolemic Shock

**GASTROINTESTINAL**
- Constipation (space adaptation)
- Abdominal Injury
- Acute Cholecystitis/Biliary Colic Acute Diverticulitis
- Acute Pancreatitis
- Appendicitis
- Diarrhea
- Gastroenteritis
- Hemorrhoids
- Indigestion
- Small Bowel Obstruction

**LUNG**
- Choking/Obstructed Airway
- Respiratory Infection
- Toxic Exposure: Ammonia
- Smoke Inhalation
- Chest Injury

**IMMUNE**
- Allergic Reaction (mild to moderate)
- Anaphylaxis
- Skin Rash
- Medication Overdose/Adverse Reaction

**NEUROLOGIC**
- Space Motion Sickness (Space Adaptation)
- Head Injury
- Seizures
- Headache (Late)
- Stroke (cerebrovascular accident)
- Paresthesia Secondary to Extravehicular Activity
- Headache (Space Adaptation) Neurogenic Shock
- VIIP (Space Adaptation)

**MUSKULOSKELETAL**
- Back Pain (Space Adaptation)
- Abdominal Wall Hernia
- Acute Arthritis
- Back Sprain/Strain
- Ankle Sprain/Strain
- Elbow Dislocation
- Elbow Sprain/Strain
- Finger Dislocation
- Fingernail Delamination Secondary to Extravehicular Activity
- Hip Sprain/Strain
- Hip/Proximal Femur Fracture
- Knee Sprain/Strain
- Lower Extremity (LE) Stress fracture
- Lumbar Spine Fracture
- Shoulder Dislocation
- Shoulder Sprain/Strain
- Acute Compartment Syndrome
- Neck Sprain/Strain
- Wrist Sprain/Strain
- Wrist Fracture

**PSYCHIATRIC**
- Insomnia (Space Adaptation)
- Sleep Disorder
- Anxiety
- Behavioral Emergency
- Depression

**GENITOURINARY**
- Abnormal Uterine Bleeding
- Acute Prostatitis
- Nephrolithiasis
- Urinary Incontinence (space adaptation)
- Urinary Retention (space adaptation)
- Vaginal Yeast Infection

**INFECTION**
- Herpes Zoster Reactivation (shingles)
- Influenza
- Mouth Ulcer
- Sepsis
- Skin Infection
- Urinary Tract Infection

**ENVIRONMENT**
- Acute Radiation Syndrome
- Altitude Sickness
- Decompression Sickness Secondary to Extravehicular Activity
- Headache ($CO_2$)

**47 conditions have occurred inflight, 53 others considered possible**

# Definitions of Calculated End States

Mission-level Outputs:

- Probability of (Consideration of) evacuation (EVAC)
  - Proportion of simulated missions with one or more cases where evacuations considered for medical events
  - Confidence limits are estimated
- Probability of loss of crew life (LOCL)
  - Proportion of simulated missions with one or more loss of crew life
  - Confidence limits are estimated
- Quality Time Lost (QTL)
  - Sum (Functional Impairment x Duration) for all conditions that occur during a mission
- Resources used to treat these conditions

# Assumptions and Limitations

| | Assumption or Limitation | Addressed in IMM v# |
|---|---|---|
| 1 | Baselined to ISS environment and ISS NASA medical system | |
| 2 | No timeline | 4.0 |
| 3 | Medical conditions occur in pre-specified order | 4.0 |
| 4 | Full treatment at time of medical event occurrence | 4.0 |
| 5 | No correlation of medical conditions to crew activities | |
| 6 | No correlation of medical conditions between crew members | |
| 7 | All crew members have essentially equal incidence for all medical conditions | 4.0 |
| 8 | No partial or alternative treatment | 4.0 |
| 9 | CMO time not accounted for | |
| 10 | Diagnosis and treatment of medical conditions is 100 percent accurate | |
| 11 | All pharmaceuticals are 100 percent effective | |
| 12 | All medical equipment is 100 percent reliable | |
| 13 | All exercise equipment is 100 percent reliable | |
| 14 | Unlimited vehicle resources | |
| 15 | No restocking of medical kit | |
| 16 | No IMAK | |

* Currently operating v3.0. In 2017 v4.1 will be operational.

# IMM Operational

## IMM Operational Version

- **V3.0 Operational since 2011**
- **V4.1 Expected to be operational in May 2017.**

## Upgrades in V4.1

- **Timeline** – In addition to generating **if** conditions occur, IMM v4.0 generates **when** conditions occur.
- **Partial Treatment** – IMM v4.0 gives partial credit for partial treatment in generating the outcomes of a condition.
- **Alternative Drug** – If a primary drug required for treatment is not available, IMM v4.1 searches for medically appropriate substitutes.

## Usage of IMM

- Made via requests for information through CHS
- Operational Team works to insure the model scenario is tailored to your needs
- Due to review process the turn around time is ~8-12 weeks.

# Service Requests

| Requestor | Question | IMM Analysis |
|---|---|---|
| SD2 | Requirement for Oxygen / Ventilator for Commercial Crew Vehicles? | Probability of Oxygen / Ventilator use for ISS DRM (S-20130607-100) |
| SD2 | Is 4-orbit Soyuz docking to ISS safe? | Probability of SMS during docking to ISS (D-20130425-91) |
| SK | Which medications should be tested for stability? | Most frequently used medications for Mars DRM (S-20140306-145) |
| HMTA | Loss of Crew Life (LOCL) Analysis | Probability of medical LOCL for EM-2 DRM (S-20130509-94) |
| ISS Program | Medical Inputs to ISS PRA | Probability of medical EVAC and LOCL for ISS DRM (D-20101201-39) |

# Final Thought

***Essentially, all models are wrong, but some are useful***

**George Box (1987); Professor Emeritus of Statistics at the University of Wisconsin**

# After Delivery - Communications Planning

- **Coordinated with CHS on ~6 publications for IMM, its components, or its application in the decision making process**
  - Real World System Validation (scheduled out to 8/2017)
  - One and Two Factor Optimization of Space Flight Medical Resources
  - Development and Application of Utility Metrics for Space Flight Risk Assessment
  - 3 Application Case Studies

- **Optional Tech Memos**
  - Medical Data Survey and Review
  - Medical Data Processing and Maintenance

- **Budget for contributing to the publications**
  - Current understanding is CHS will cover contractor efforts
  - CS estimate is 0.1 - 0.2 FTE, contributing to 3 of the publications

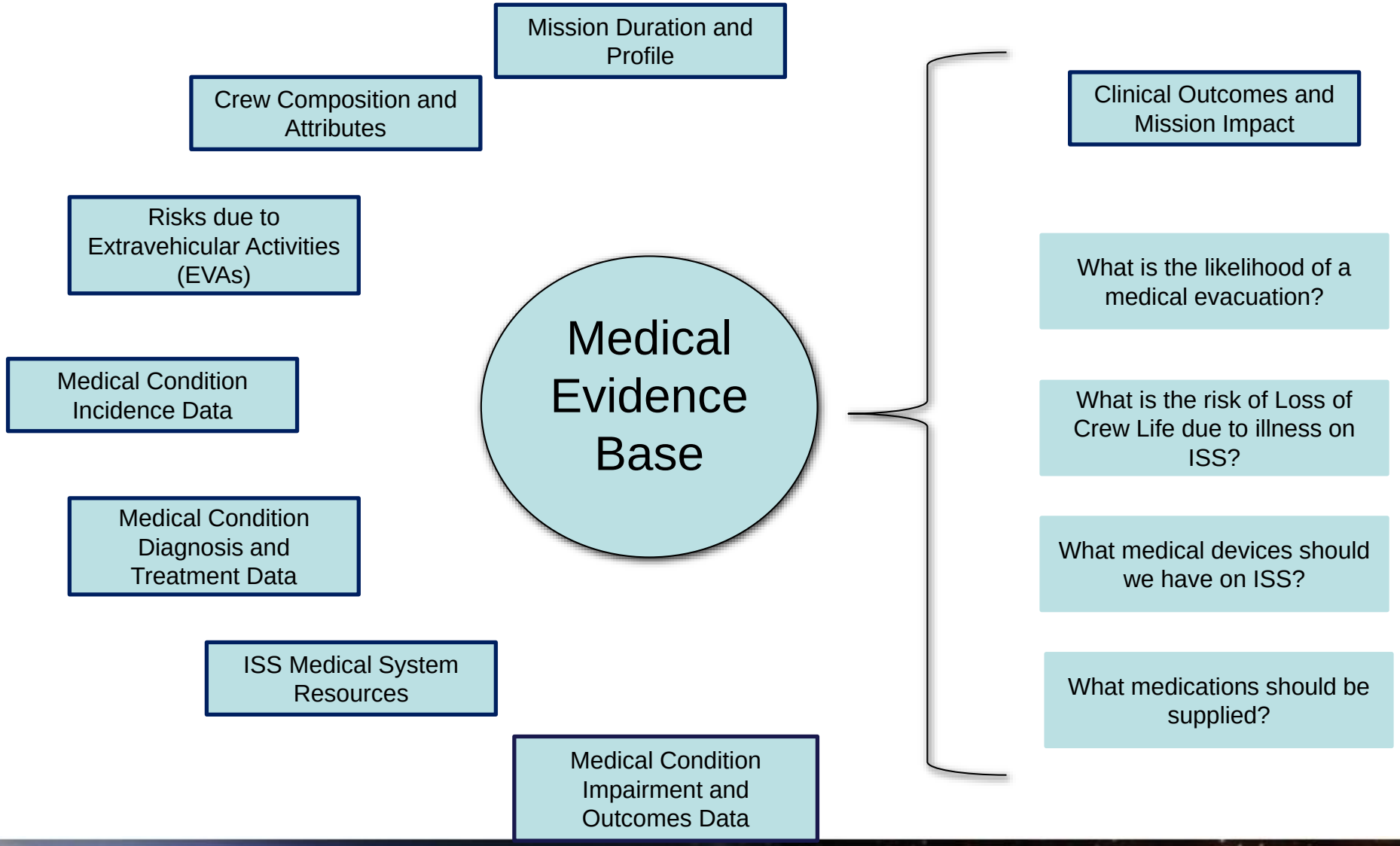
# Validation Of Model

# Why did we start building this model?

- **Originally an Engineering attempt to use a Probabilistic Risk Analysis model that did not rely on a strong medical evidence base drove the development.**
- **Engineering teams need quantitative medical information to characterize risk.**
- **Medical SMEs did not have the capability to provide this.**

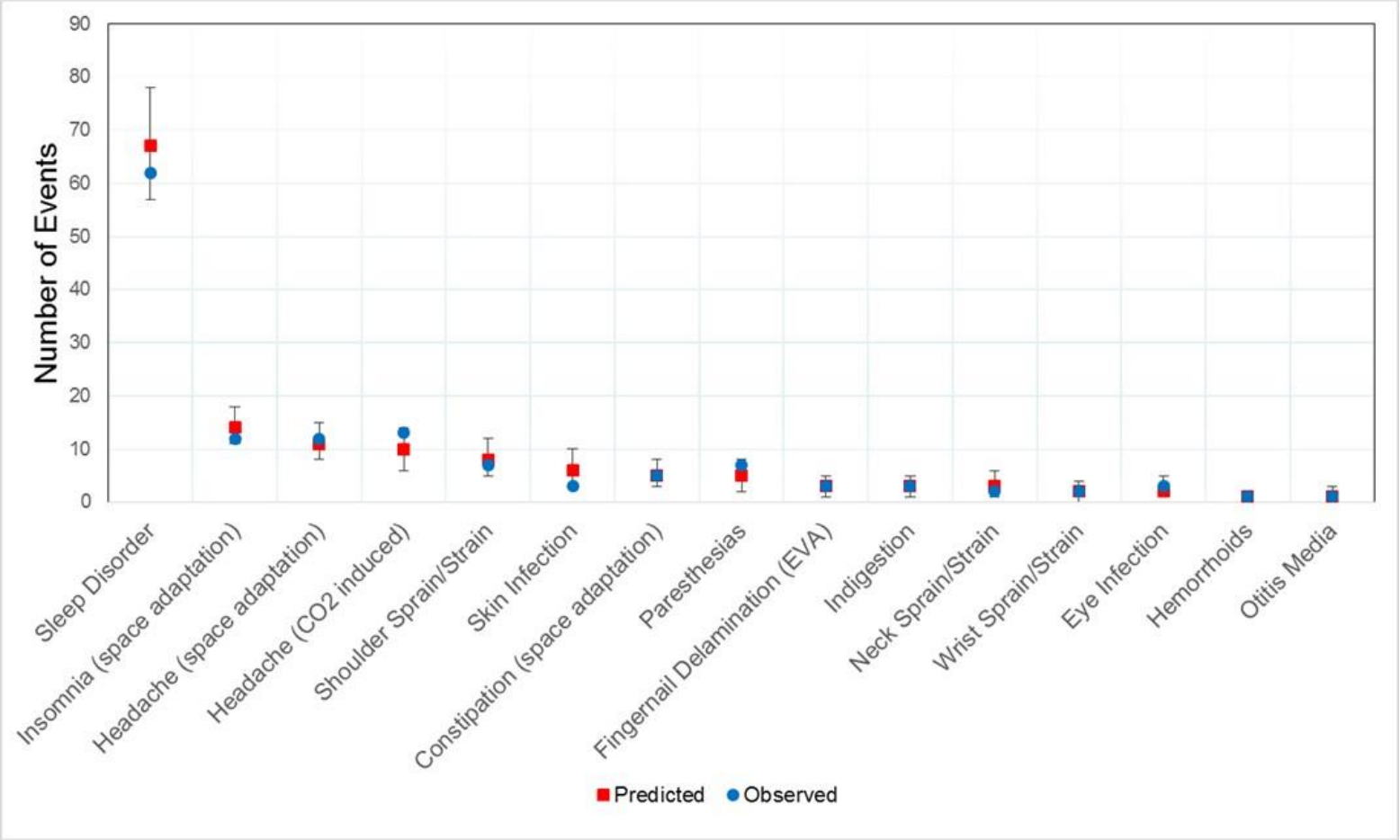
This is fundamentally about how the NASA Medical and Engineering communities communicate.

# What need does it fill?



# Individual Condition Counts

**15 conditions met the performance characterization criteria**



# IMM Medical Risk Application Questions

- How do age, sex, and mission duration affect the composition of medical system contents?
- What are the optimum medical system components that minimize risk (LOCL, EVAC) for a crew of six and mission duration of twelve months?
- How does the composition of medical system contents change for a crew of six (four male, two female) for mission durations of four weeks, six months, twelve months, or three years to maintain a minimal risk posture?
- What is the estimate of the in-flight functional impairment to the crew for a given level of care?
- How is crew and mission risk affected by replacing one piece of hardware with the equivalent mass and volume of medications A, B, and C, and consumable items X, Y, and Z