The Integrated Medical Model

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Presentation to the Human Research Program Investigators’ Workshop
NASA Johnson Space Center/SD4
Wyle Integrated Science and Engineering Group
Houston, TX
4 February 2010
IMM Project Goals

- To develop an integrated, quantified, evidence-based decision support tool useful to crew health and mission planners.

- To help align science, technology, and operational activities intended to optimize crew health, safety, and mission success.
Scope and Approach

IMM addresses in-flight risk only, and uses ISS data as stepping stone

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

- **Approach**
  - Use ISS data as stepping stone to Exploration Program
  - Employ best-evidence clinical research methods
  - Employ Probability Risk Assessment (PRA) techniques
  - Collaborate with other NASA Centers and Organizations
What is IMM?

- A software-based decision support tool
  - Forecasts the impact of medical events on space flight missions
  - Optimizes the medical system within the constraints of the space flight environment during simulations.
Several software technologies are used to operate and manage risk assessments, reports, and refinements to IMM.

- IMM - SAS (Statistical Analysis Software)
- Optimization ± SAS
- Database ± SQL
- Citation Management ± RefMan
- Report Generation ± Aspose
- Workflow and Configuration Management - SharePoint
Capability Status

- IMM 2.1/3.0
  - Locked down and undergoing clinical validation
  - Available for risk assessments, trade studies
- 83 medical conditions represented (47 of 83 medical conditions have been recorded to occur in flight)
- In-flight medical resources identified per medical condition
- $^{30}$HGLFDO´$^{13}$RSHUDWLRQDO´$^{8}$RU$^{3}$H classification of risk drivers
- Established database; build out continues
- Integrated citation management software
Who can benefit from IMM capabilities?

- **Flight Surgeons**
  - What in-flight medical threats are greatest for reference mission A?

- **Risk Managers**
  - What is the risk of evacuation - due to a medical event - for a 6-person, 180 day mission assuming the current in-flight medical capability?

- **Vehicle Designers**

- **Health Care System Designers**
  - What medical items do we fly for a given mass/volume allocation?

- **Trainers**
  - How do I prioritize limited crew training hours?

- **Requirement Managers**
Use History

- ISS medical system redesign rationale
- Storage Capacity Requirements of Vomitus/Diarrhea for Constellation
- ExMC List of Prioritized Medical Conditions
- ExMC Technology Watch
- Orion medical kit design support
- ISS Probabilistic Risk Assessment Updates
Comparison – 5x5 Risk Matrix vs. IMM

5x5 Matrix
- Qualitative
- Categorical
- Subjective
- Single Risk
- No Uncertainty
- No Confidence Interval
- Limited context

IMM
- Quantitative
- Probabilistic, Stochastic
- Evidence-based
- Integrated Risks
- Uncertainty
- Confidence Interval
- In context

- Medical Conditions & Incidence Data
- Crew Profile
- Mission Profile & Constraints
- Crew Functional Impairments
- In-flight Medical Resources

- Medical Condition Occurrences
- Crew Impairment & Clinical End States
- Resource Utilization
- Optimization of Vehicle Constraints and Medical System Capabilities
IMM Logic

INPUTS
- Medical Conditions & Incidence Data
- Crew Profile
- Mission Profile & Constraints
- Potential Crew Functional Impairments
- Potential Mission End States
- In-flight Medical Resources

OUTPUT of Distributions
- Medical Condition Occurrences
- Crew Impairment
- Clinical End States
- Mission End States
- Resource Utilization
- Optimized Medical System

A simulation set may include 20,000+ trial missions

Medical Conditions Occur?

Yes

Essential Resources Available?

Yes

Available Resources Decremented

No

Best-Case Scenario

Worst-case Scenario

Untreated Scenario- Best Case

Untreated Scenario- Worst-Case
Independent Risk Models & IMM

Risk Drivers

**Independent Model**
(Renal Stone)

**Independent Model**
(Bone Fracture)

**Independent Model**
(Insomnia)

For a specified mission scenario, the output from independent models can provide distributions of incidence data.
Innovations & Lessons Learned

- Essential vs. Nonessential medical items
- Untreated Best-Case/Worst-Case Scenario
- Level of Evidence Scale for Space Medicine
- Optimization Algorithms
- Space Adaptation Syndrome Incidence Proportions
Longitudinal Study of Astronaut Health
ISS Expeditions 1 thru 13 (2006)
STS-01 thru STS-114 (2005)
Analog, terrestrial data
Review of crew medical charts
Flight Surgeon Delphi Study

Russian medical data not used
Case Study - Orion Medical Kit Design

□ Goal
  □ Identify a medical kit that maximizes Crew Health Index while meeting mass and volume constraints
  □ Mass < 3.31 kg
  □ Volume < 4054.22 cm³
  □ Assume 30% packing factor

□ Mission Scenario
  □ Crew of four
  □ 3-day Orion transfer mission

□ Success Criterion
  □ The optimized medical kit approaches a risk profile of a medical kit with unlimited resources
### Orion Medical Kit Design - Results

<table>
<thead>
<tr>
<th>Attribute</th>
<th>“Bottomless” Kit</th>
<th>Optimized Kit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mass (kg)</td>
<td>43.60</td>
<td>3.25</td>
</tr>
<tr>
<td>Volume (cm³)</td>
<td>144684</td>
<td>4940</td>
</tr>
<tr>
<td>CHI (95% C.I.)</td>
<td>84.55 (67-93)</td>
<td>84.34 (66-93)</td>
</tr>
<tr>
<td>Risk of EVAC</td>
<td>0.07%</td>
<td>1.07%</td>
</tr>
<tr>
<td>Risk of LOCL</td>
<td>0.01%</td>
<td>0.02%</td>
</tr>
</tbody>
</table>

#### Crew Health Index (CHI)

![“Bottomless” Kit](chart.png)

![Optimized Kit](chart.png)
A shoebox size kit can be designed to treat the conditions that have a high probability of occurring during a 3-day mission without a reduction in CHI from the fully treated scenario.

The trade-off is that the kit does not include resources to treat low probability, worst-case scenario conditions, leading to an increase in the probability of evacuation from the fully treated scenario.
# Validation – ISS Risk of EVAC Rates

IMM forecasted EVAC rates compare favorably with literature review EVAC rates (0.010 to 0.072)

<table>
<thead>
<tr>
<th>Source</th>
<th>Low (events/person-yr)</th>
<th>Max (events/person-yr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>IMM</td>
<td>0.021</td>
<td>0.030*</td>
</tr>
<tr>
<td>Terrestrial General Population</td>
<td>0.060</td>
<td>-</td>
</tr>
<tr>
<td>Antarctic Population</td>
<td>0.036</td>
<td>-</td>
</tr>
<tr>
<td>U.S. Submarine Population</td>
<td>0.023</td>
<td>0.028</td>
</tr>
<tr>
<td>Russian Historical Space Flight Data</td>
<td>0.032</td>
<td>0.072</td>
</tr>
<tr>
<td>LSAH Data</td>
<td>0.010</td>
<td>0.020</td>
</tr>
<tr>
<td>Space Station Freedom Clinical Experts Seminar Proceedings (1990)</td>
<td>0.010</td>
<td>0.030</td>
</tr>
</tbody>
</table>

* Reference Mission 2: 6 crew, 6 month mission
 Validation – ISS Risk of LOCL

IMM forecasted LOCL rates compare favorably with literature review results for LOCL rates (0.0029 to 0.0081)

<table>
<thead>
<tr>
<th>Source</th>
<th>LOCL (events/person-yr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>IMM (3 crew/6-month mission)</td>
<td>0.0053</td>
</tr>
<tr>
<td>IMM (6 crew/6-month mission)</td>
<td>0.0046</td>
</tr>
<tr>
<td>Terrestrial Mortality Rate</td>
<td>0.0081 (2006)</td>
</tr>
<tr>
<td>48-year old male</td>
<td>0.0048 (2005)</td>
</tr>
<tr>
<td>48-year old female</td>
<td>0.0029 (2005)</td>
</tr>
<tr>
<td>Antarctic</td>
<td>0.0054 (1904-1964)</td>
</tr>
<tr>
<td>LSAH Data</td>
<td>0.0054 (1959-1991)</td>
</tr>
</tbody>
</table>
# Validation - Sensitivity Analysis

## IMM Simulation Data

<table>
<thead>
<tr>
<th>Category</th>
<th>Percentage</th>
<th>Conditions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Medical</td>
<td>58%</td>
<td>1. Kidney Stone</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2. Exposed Dental Pulp</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3. Skin Infection</td>
</tr>
<tr>
<td></td>
<td></td>
<td>4. UTI (female)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>5. Sepsis</td>
</tr>
<tr>
<td></td>
<td></td>
<td>6. Atrial Fibrillation</td>
</tr>
<tr>
<td>Injury/Trauma</td>
<td>25%</td>
<td>1. Chest Injury</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2. Wrist Fracture</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3. Eye Abrasion</td>
</tr>
<tr>
<td>Environmental</td>
<td>17%</td>
<td>1. Toxic Exposure</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2. Smoke Inhalation</td>
</tr>
</tbody>
</table>

## Actual Russian Flight Data

<table>
<thead>
<tr>
<th>Conditions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Three EVACs</td>
</tr>
<tr>
<td>1. Urosepsis</td>
</tr>
<tr>
<td>2. Cardiac Arrhythmia</td>
</tr>
<tr>
<td>3. Toxic Exposure</td>
</tr>
<tr>
<td>Three Close Call EVACs</td>
</tr>
<tr>
<td>1. Kidney Stone</td>
</tr>
<tr>
<td>2. Dental Abscess</td>
</tr>
<tr>
<td>3. Toxic Exposure</td>
</tr>
</tbody>
</table>

*NOTE: No Russian input data is in IMM*
Next Steps through Sept 2010

- Validation of IMM 3.0 per plan (Jan-July)
- IMM Database 3.0 Development (Jan-July)
- Complete Ops Documentation (July)
- Operational Acceptance Review (Aug)
- Delivery of IMM 3.0 (Sept)
- Delivery of Database 3.0 (Sept)
- IMM 4.0 Development (Feb-Sept)
- Transition to Operations (1 October 2010)
Closing

IMM addresses the observations documented by the RTF Task Group

«H[SHULHQFH DQGLQVWLQFW DUH SRRUVXE careful analysis of uncertainty»

«7KLV UHTXLUHV WKDW DQDO\WLFDOPRGH appropriately to inform decisions»


Questions?