The Integrated Medical Model

Presenters:
Douglas J. Butler, Project Manager
Dr. Eric Kerstman, Clinical Lead

Presentation to the Human Research Program Investigators’ Workshop
NASA Johnson Space Center/SD4
Wyle Integrated Science and Engineering Group
Houston, TX
4 February 2010
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
- $^{3}O_{h}G_{l}F_{o}D_{o}^{3}R_{S}H_{U}D_{W}L_{R}Q_{D}O^{3}R_{U}^{3}$
- 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**
  - What medical items do we fly for a given mass/volume allocation?

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

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

- **Requirement Managers**
  - How do I prioritize limited crew training hours?
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

Integrated Medical Model

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

**IMM Logic**

**INPUTS**

**OUTPUT of Distributions**

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

**IMM**

A simulation set may include 20,000+ trial missions

**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)

Integrated Medical Model

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**
- **Optimized Kit**
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**
- Medical (58%)
  1. Kidney Stone
  2. Exposed Dental Pulp
  3. Skin Infection
  4. UTI (female)
  5. Sepsis
  6. Atrial fibrillation
- Injury/Trauma (25%)
  1. Chest Injury
  2. Wrist Fracture
  3. Eye Abrasion
- Environmental (17%)
  1. Toxic Exposure
  2. Smoke Inhalation

**Actual Russian Flight Data**
- Three EVACs
  1. Urosepsis
  2. Cardiac Arrhythmia
  3. Toxic Exposure
- Three Close Call EVACs
  1. Kidney Stone
  2. Dental Abscess
  3. Toxic Exposure

**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\ DQG\ LQVWLQFW\ DUH\ SRRU\ VXEV

  careful analysis of uncertainty»

«7KLV\ UHTXLUHV\ WKDW\ DQDO\WLFDOS\ PRGHO

  appropriately to inform decisions»