The Critical Path Roadmap Project:
Biomedical Risk Reduction for Extended Spaceflight

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Abstract. Human exploration of space requires an understanding of the risks to which crews will be exposed during such missions, and the mitigation of those risks to the fullest extent practical. This becomes a greater imperative as we prepare for interplanetary expeditions involving long periods in weightlessness in transit to and then from the destination (a planet, such as Mars, or perhaps a point in space, such as the Lagrangian point L2), and exposure to the unique environment of the destination itself. We need to know, more definitively, what the risks are to human health, safety, and performance, and how to prevent or counteract them throughout all phases of a long duration mission. The Johnson Space Center’s Space and Life Sciences Directorate and the National Space Biomedical Research Institute (NSBRI) have implemented an effort to identify the most critical risks confronting humans on such missions and the types of research and technology efforts required to mitigate and otherwise reduce the probability and severity of those risks. This paper describes the “Critical Path Roadmap Project” to define, assess and prioritize the risks and presents the results of the assessment with an emphasis on the research and technology priorities to meet the challenge of long duration human spaceflight missions.
Critical Path Roadmap
Approach to Risk Mitigation

- To the extent permitted by available resources, including funding, flight access, etc.:
  - Identify the risks
  - Understand the risks
  - Manage the risks
    ■ Prevent them, OR
    ■ Reduce their effects to acceptable levels
      - To endure safety, health and performance
      - During and after spaceflight
The CPR Process

- Iterative approach of review, analysis and deliberations among discipline experts

- Focused on "worst case" scenario: long duration, highly autonomous interplanetary missions such as a human expedition to Mars

Joint NASA and NSBRI Research Area Teams
January 1998

- Habitation Systems
  - Advanced Life Support
  - Environmental Health
  - Food & Nutrition
  - Human Behavior & Performance

- Human Adaptation and Countermeasures
  - Bone Loss
  - Cardiovascular Alterations
  - Human Behavior & Performance
  - Immunology, Infection & Hematology
  - Muscle Atrophy and Alterations
  - Neurovascular Adaptation
  - Radiation Effects

- Health Care Systems
  - Clinical Capabilities
Key Elements of The Critical Path Roadmap

- Requirements
- Critical Questions
- Deliverables (End Items)

Risk/Benefit Analysis

- Risk Mitigations
- Tasks

Ranking the Risks within each Risk Area

- Each research area team rank-ordered each of its risks using five criteria:
  - Probability of occurrence without countermeasures
  - Probability of occurrence with countermeasures
  - Severity of impact on accomplishing mission objectives
  - Severity of impact on crew health and safety

Results of Risk Ranking

- Identified 55 risks (across all risk areas)
- Rank order #1 (including all risk areas): 17
- Identified 361 critical questions
- Priority #1 (including all risk areas): 125
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Rating Across Risk Areas

- Subsequent to the risk ranking within risk areas, a panel of experts characterized risks across discipline areas, based on:
  - Rank-ordering within each risk area
  - Scores assigned for each risk
  - Extensive deliberations by the experts

- This risk characterization resulted in assignment of each risk to one of four “type” categories
  - “Type” is based on uncertainties in both the risk and its potential mitigation
### CPRP Risk Type Summary

<table>
<thead>
<tr>
<th>Countermeasure</th>
<th>Demonstrated Serious Problem</th>
<th>Suspected Serious Problem</th>
<th>Demonstrated Problem</th>
<th>Suspected Problem</th>
</tr>
</thead>
<tbody>
<tr>
<td>No Countermeasure Concept</td>
<td>I</td>
<td>II</td>
<td>II or III</td>
<td>III</td>
</tr>
<tr>
<td>Countermeasure Concept but No Ground Validation</td>
<td>II</td>
<td>II</td>
<td>II or III</td>
<td>III</td>
</tr>
<tr>
<td>Countermeasure Concept but No Space Flight Verification</td>
<td>III</td>
<td>III</td>
<td>III</td>
<td>III</td>
</tr>
<tr>
<td>Effective Operational Countermeasure</td>
<td>IV</td>
<td>Not Applicable</td>
<td>IV</td>
<td>Not Applicable</td>
</tr>
</tbody>
</table>

### Critical Path Roadmap: Critical Risks

<table>
<thead>
<tr>
<th>Type</th>
<th>Cardiovrtscular Alterations</th>
<th>Human Behavior &amp; Interaction</th>
<th>Immunology, Infection &amp; Microbiology</th>
<th>Muscle &amp; Tendon Adaptation</th>
<th>Neurovestibular Adaptation</th>
<th>Radiation Effects</th>
<th>Clinical Capability</th>
<th>Other</th>
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</thead>
<tbody>
<tr>
<td>Type I</td>
<td>Age-related Cardiac Damage</td>
<td>Alcohol Use</td>
<td>Tobacco Use</td>
<td>IL-6</td>
<td>IL-10</td>
<td>20</td>
<td>20</td>
<td>HIV</td>
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<tr>
<td>Type II</td>
<td>Atherosclerosis</td>
<td>Diabetes</td>
<td>Hypertension</td>
<td>Infection</td>
<td>Immune Response</td>
<td>10</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>Type III</td>
<td>Heart Disease</td>
<td>Stroke</td>
<td>Coronary Artery Disease</td>
<td>Nerve Compression</td>
<td>Anoxia</td>
<td>5</td>
<td>5</td>
<td>5</td>
</tr>
</tbody>
</table>

**Severe Risks**

- Type I: Age-related Cardiac Damage
- Type II: Atherosclerosis
- Type III: Heart Disease

**Very Serious Risks**

- Type I: Alcohol Use
- Type II: Diabetes
- Type III: Stroke

**Serious Risks**

- Type I: Tobacco Use
- Type II: Hypertension
- Type III: Coronary Artery Disease

**Other**

- HIV
- Immune Response
- Anoxia
- Nerve Compression
- Heart Disease
- Alcohol Use
- Tobacco Use
- Diabetes
- Hypertension
- Coronary Artery Disease
- Nerve Compression
- Anoxia
- Heart Disease
Current Activities

- Independent extramural assessment of acceptable risk levels (Baylor College of Medicine/Marsh/Actuarial Research Group) on-going
- Configuration management of content through “CPR” Configuration Control Panel
  - Charter in revision
  - First CCP meeting in May-June 2000
- Website in development
  - http://criticalpath.jsce.nasa.gov
- Identification of deliverables and timelines for managing risks and addressing the critical questions by Risk Area Teams
- Assessment of current and potential tasks for CPR congruence and guidance as needed

### Science Readiness Levels of Currently Funded Code UL Tasks

<table>
<thead>
<tr>
<th>RISK AREA</th>
<th>SRL 1</th>
<th>SRL 2</th>
<th>SRL 3</th>
<th>SRL 4</th>
<th>SRL 5</th>
<th>SRL 6</th>
<th>Unknown</th>
<th>Total</th>
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<tbody>
<tr>
<td><strong>Pre-Phase A</strong></td>
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<td>26</td>
<td>5</td>
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<td>0</td>
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<tr>
<td><strong>Phase A</strong></td>
<td>11</td>
<td>25</td>
<td>2</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>3</td>
<td>30</td>
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<tr>
<td><strong>Phase B</strong></td>
<td>13</td>
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<td>6</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>2</td>
<td>30</td>
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<tr>
<td><strong>Phase C</strong></td>
<td>10</td>
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<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>21</td>
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<td><strong>Phase D</strong></td>
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<td>5</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>5</td>
<td>32</td>
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<tr>
<td><strong>Phase E</strong></td>
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<td>2</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>2</td>
<td>28</td>
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<tr>
<td><strong>Phase F</strong></td>
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<td>15</td>
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<td>0</td>
<td>0</td>
<td>0</td>
<td>3</td>
<td>27</td>
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<tr>
<td><strong>Phase G</strong></td>
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<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>3</td>
<td>46</td>
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<tr>
<td><strong>Phase H</strong></td>
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<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>2</td>
<td>28</td>
</tr>
<tr>
<td><strong>Unknown</strong></td>
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<td>1</td>
<td>3</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>5</td>
<td>10</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td>191</td>
<td>234</td>
<td>14</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>7</td>
<td>378</td>
</tr>
</tbody>
</table>

| Percentage | 57% | 61% | 5% | 0% | 0% | 0% | 2% | 100% |
Defining “Deliverables”

- Specific end-items associated with each risk and critical questions
  - Technologies (models, instruments, devices, equipment, systems, hardware or software)
  - Scientific knowledge (underlying mechanisms & processes), procedures, or processes
  - Results in, or provides critical knowledge for, risk mitigation requirements

Types of Deliverables

- (1) Risk Assessment and Acceptability
- (2) Scientific Knowledge
- (3) Development of Requirements
  - Pharmacological
  - Exercise regimes and fitness levels
  - Nutrition (including fluids, supplements, and stress reduction strategies)
- (4) Medical Intervention
  - Diagnosis and treatment
  - Post landing rehabilitation
- (5) Crew Screening and Selection Criteria
- (6) Crew Training (including expert systems)
- (7) Design
  - Artificial Gravity
  - Habitation
  - G suit design and mechanical devices
- (8) Mission Ops
  - Planning
  - Implementation
CPR

- For current 55 risks, identify and validate countermeasures and/or risk mitigations
  - for one-half by the year 2006
  - for all by the year 2010