

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.



Human Space Life Sciences Critical Path Roadmap: Reducing the Risks for Human Exploration-class Missions

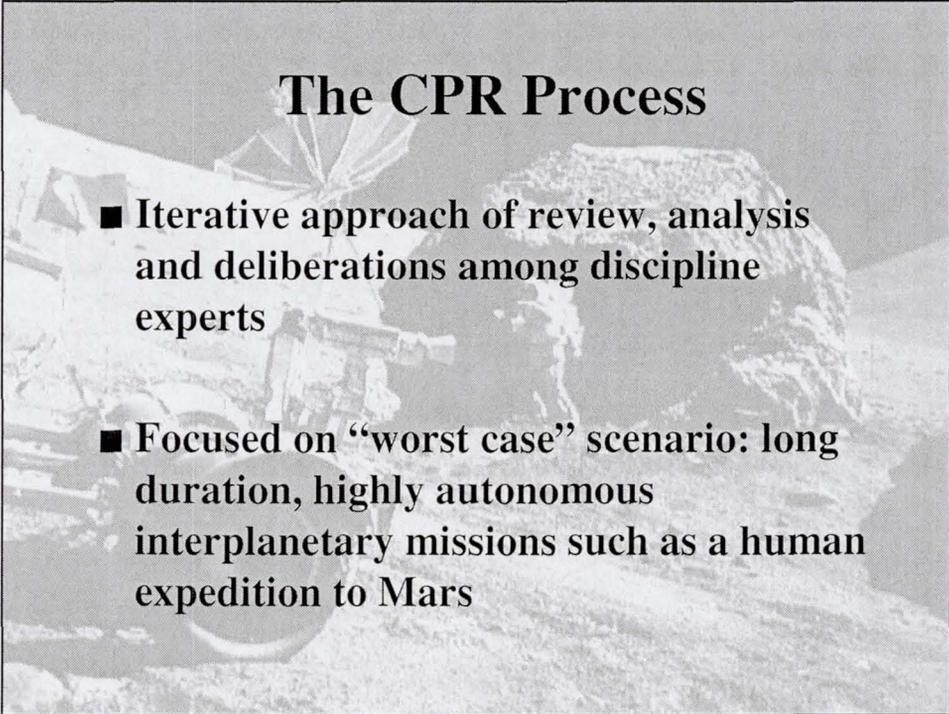


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Critical Path Roadmap* Approach to Risk Mitigation

*CPR

- 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

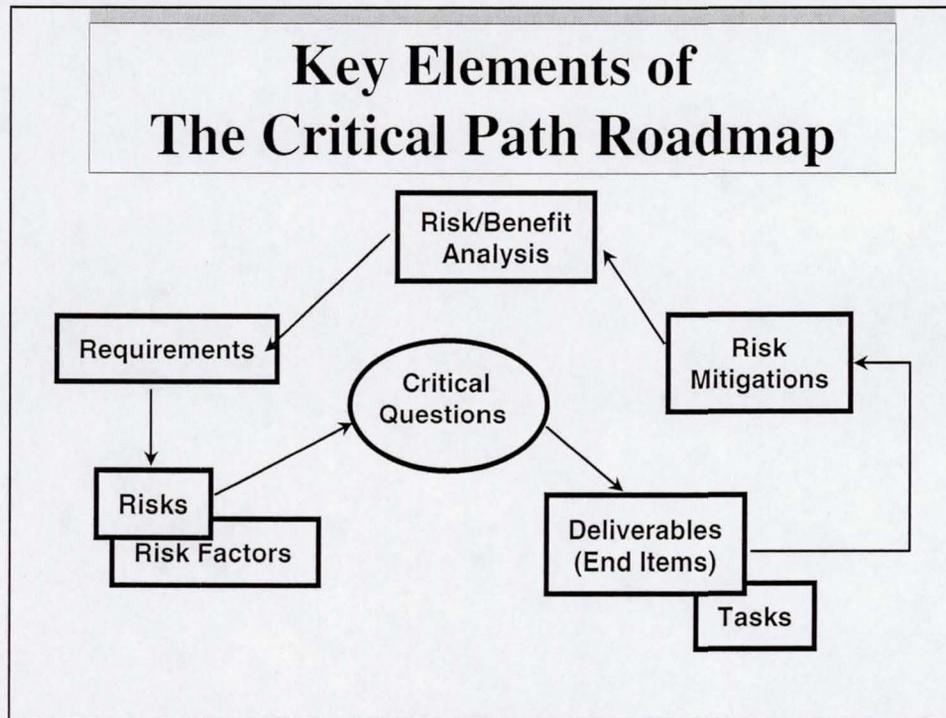
- Iterative approach of review, analysis and deliberations among discipline experts
- Focused on “worst case” scenario: long duration, highly autonomous interplanetary missions such as a human expedition to Mars



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



Ranking the Risks within each Risk Area

- | | |
|--|--|
| <p>■ Each research area team rank-ordered each of its risks using five criteria:</p> <ul style="list-style-type: none"> - 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 | <p>■ Results of Risk Ranking</p> <ul style="list-style-type: none"> - 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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- Results of Risk Ranking
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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

	Demonstrated Serious Problem	Suspected Serious Problem	Demonstrated Problem	Suspected Problem
No Countermeasure Concept	I	II	II or III	III
Countermeasure Concept but No Ground Validation	II	II	II or III	III
Countermeasure Concept but No Space Flight Verification	III	III	III	III
Effective Operational Countermeasure	IV	Not Applicable	IV	Not Applicable

Critical Path Roadmap: Critical Risks

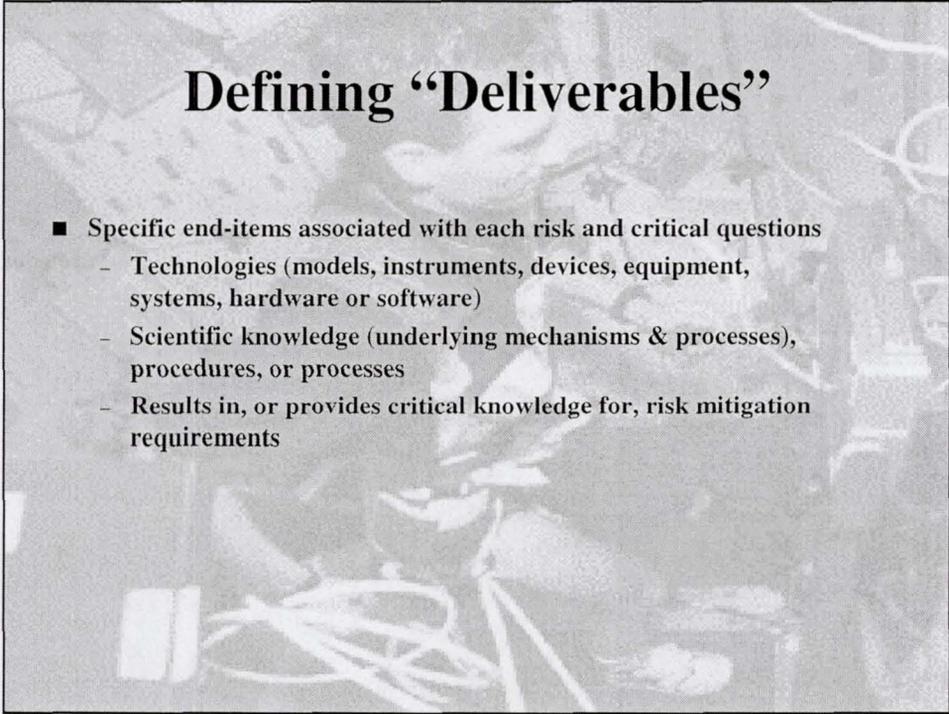
RDMF / OSR	CARDIOVASCULAR ALTERATIONS	HUMAN BEHAVIOR & PERFORMANCE	IMMUNOLOGY, INFECTION & HEMATOLOGY	MUSCLE ALTERATIONS & ATROPHY	NEUROVESTIBULAR ADAPTATION	RADIATION EFFECTS	CLINICAL CAPABILITY	OTHER	
Type I	Acceleration of Age-Related Osteoporosis (1) - 9		Human Performance Failure Because of Poor Psychosocial Adaptation (1) - 19			Carcinogenesis Caused by Radiation (1) - 38	Trauma & Acute Medical Problems (1) - 43		Severe Risks
	Fractures (Traumatic, Stress, Avulsion) & Impaired Fracture Healing (2) - 10	Occurrence of Serious Cardiac Dysrhythmias (1) - 13	Human Performance Failure Because of Sleep and Circadian Rhythm Problems (2) - 19	Loss of Skeletal Muscle Mass, Strength, and/or Endurance (1) - 28	Disorientation and inability to perform landing, egress, or other physical tasks, especially during after-g-level changes	Damage to Central Nervous System from Radiation Exposure (2) - 39	Toxic Exposure (2) - 44	Inadequate Nutrition (Maintenance) 7, 8, 53	
Type II		Impaired Cardiovascular Response to Ormestatic Stress (1) - 14		Inability to Adequately Perform Tasks Due to Motor Performance, Muscle Endurance, and Disruptions in Structural and Functional Properties of Soft and Hard Connective Tissues of the Axial Skeleton (3) - 32	(1) - 33 Impaired neuromuscular coordination and/or strength (2) - 54	Synergistic Effects from Exposure to Radiation, Microgravity and Other Spacecraft Environmental Factors (3) - 40	Altered Pharmacodynamics and Adverse Drug Reactions (3) - 45	Post-Landing Abnormalities in Various Systems Resulting in Severe Performance Decrements and Injuries 49	Very Serious Risks
				Inability to Sustain Multiple Performance Levels to Meet Demands of Performing Activities of Varying Intensity (2) - 30		Early or Acute Effects from Radiation Exposure (4) - 41		Habitation and Life Support 1, 2, 3, 4, 5, 6, 51, 52	
Type III	Injury to Soft Connective Tissue or Joint Cartilage and/or Intervertebral Disc Rupture With or Without Neurological Complications (3) - 11	Diminished Cardiac Function (2) - 15	Human Performance Failure Because of Human System Interface Problems and Ineffective Habits & Equipment Design, etc (3) - 20	Immunodeficiency/Infections (1) - 22	Propensity to Develop Muscle Injury, Connective Tissue Dysfunction, and Bone Fractures Due to Deficiencies in Motor Skill, Muscle Strength, and Muscular Fatigue (3) - 31	Impaired cognitive and/or physical performance due to motor sickness symptoms or treatments, especially during after-g-level changes (3) - 35	Radiation Effects on Fertility, Sterility and Heredity (5) - 42	Sickness and Ambulatory Health Problems (4) - 46	Serious Risks
	Renal Stone Formation (4) - 12	Manifestation of Previously Asymptomatic Cardiovascular Disease (3) - 16	Human Performance Failure Because of Neurobehavioral Dysfunction (4) - 21	Carcinogenesis Caused by Immune System Changes (1) - 22	Impact of Deficits in Skeletal Muscle Structure and Function on Other Systems (NR) - 32	Vestibular contribution to cardiorespiratory dysfunction (4) - 36	Development and Treatment of Decompression Sickness Complicated by Microgravity-Induced Ochronism (5) - 47		
		Impaired Cardiovascular Response to Exercise Stress (4) - 17		Altered Hemostasis and Altered Blood Components (1) - 24		Possible chronic impairment of orientation or balance function due to microgravity or radiation (4) - 37	Difficulty of Rehabilitation Following Landing (6) - 48, 54		
			Altered Wound Healing (2) - 25						
			Altered Host-Microbial Interactions (3) - 26						
			Allergies and Hypersensitivity Reactions (3) - 27						

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.jsc.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

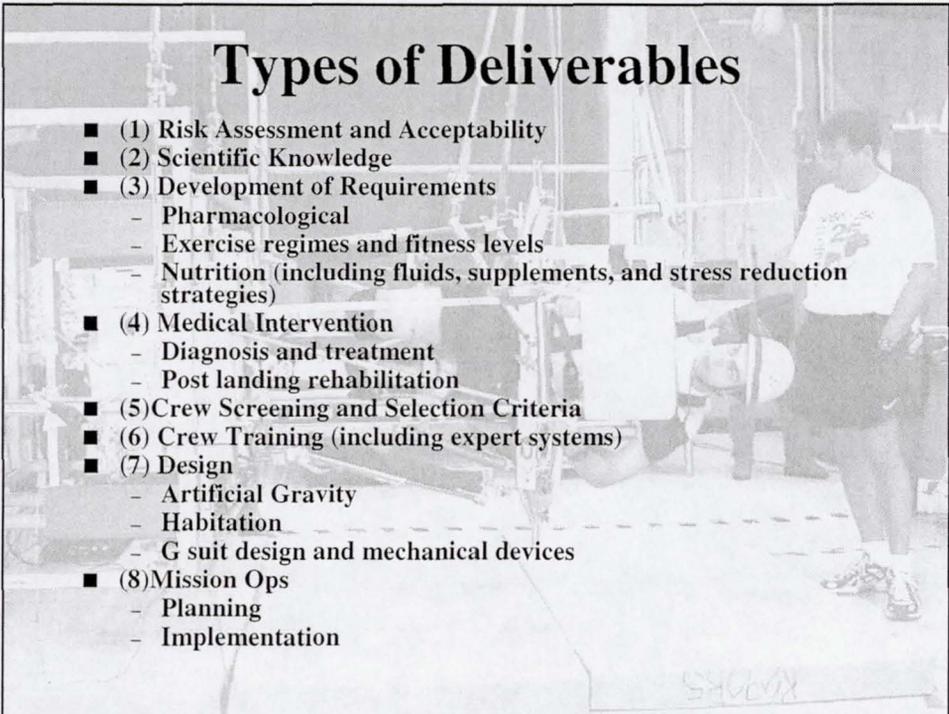
Science Readiness Levels of Currently Funded Code UL Tasks

RISK AREA	Science Readiness Levels (SRL)							Total No. Projects
	Pre-Phase A SRL 1 Advanced Studies/ Feasibility	Phase A SRL 2 Preliminary Analysis	Phase B SRL 3 Definition	Phase C SRL 4 Design	Phase D SRL 5 Development	Phase E SRL 6 Operations	Unknown (?)	
Advanced Life Support	4	26	6	0	0	0	2	38
Bone Loss	14	35	2	0	0	0	0	51
Cardiovascular Alterations	11	25	0	0	0	0	2	38
Environmental Health	2	19	1	0	0	0	1	23
Food and Nutrition	4	6	0	0	0	0	0	10
Human Behavior and Performance	24	25	3	0	0	0	0	52
Immunology, Infection and Hematology	8	35	0	0	0	0	0	43
Muscle Alterations and Atrophy	8	19	0	0	0	0	0	27
Neurovestibular Adaptation	21	28	0	0	0	0	0	49
Radiation Effects	3	29	1	0	0	0	2	35
Clinical Capabilities	2	7	1	0	0	0	0	11
TOTAL	101	254	14	0	0	0	7	377
Percent	27	67	4	0	0	0	2	100



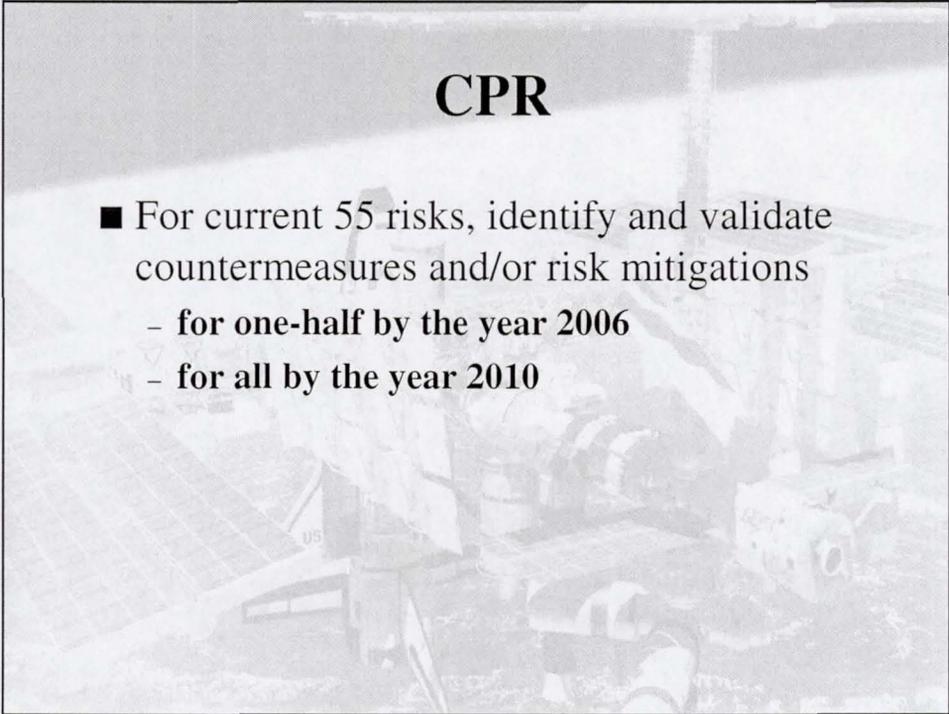
Defining “Deliverables”

- 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