I. EXECUTIVE SUMMARY

During the next several decades our nation will embark on human exploration in space. In the microgravity environment we will learn how human physiology responds to the absence of gravity and what procedures and systems are required to maintain health and performance. As the human experience is extended for longer periods in low Earth orbit, we will also be exploring space robotically. Robotic precursor missions, to learn more about the lunar and martian environments will be conducted so that we can send crews to these planetary surfaces to further explore and conduct scientific investigations that include examining the very processes of life itself.

Human exploration in space requires the ability to maintain crew health and performance in spacecraft, during extravehicular activities, on planetary surfaces, and upon return to Earth. This goal can only be achieved through focused research and technological developments. This report provides the basis for setting research priorities and making decisions to enable human exploration missions (Table I-1).

TABLE I-1
MISSION SCENARIO[1]

MOON	MARS
— Visit (IOC)*	— Visit (IOC)*
- Timeframe: 2003-2006 accelerated date 2000	- Timeframe: 2014-2018
- Surface: 14 days	- Duration: 600-1000 days
- Crew Size: 6	- Surface: 30-100 days
— Outpost**	- Crew Size: 6
- Timeframe: 2007-2010	— Outpost
- Surface: 40-180 days	- Timeframe: 2016-2020
- Crew Size: 6	- Duration: 1500 days
— Settlement**	- Surface: 600 days
- Timeframe: 2007-2011	- Crew Size: 6
- Duration: 360-600 days	— Settlement
- Crew Size: 6-18	- Evolving capability

* Initial Operational Capability
** Mars Simulation would include 120 to 460-day Moon orbit

The report expands the recommendations of several previous advisory committees (Table I-2). It is based on the results of comprehensive studies conducted by 12 Life Sciences Discipline Working Groups (DWGs). The appendices (Section VII) contain the methodology and membership for this report. In conjunction with NASA scientists, the DWGs defined the unresolved issues considered critical to advancement of knowledge in their discipline.

Footnote 1. This report is based on current life sciences knowledge bases, Vision 21, The NASA Strategic Plan (1992) and Offices of Aeronautics and Space Technology, and Exploration planning (Appendix G). Table 1 is not based on any single specific mission architecture.

Table I-2 Recommended Life Sciences Milestones

LIFE SCIENCES CAPABILITIES TO SUPPORT EXPLORATION MISSIONS	AMAC REPT (SEE APPENDIX G)	SEI DATA BOOK (OAST) (SEE APPENDIX G)	NRC REPT (SEE APPENDIX G)	AUGUSTINE REPT (SEE APPENDIX G)	SYNTHESIS REPT (SEE APPENDIX G)	NASA HEI 90-DAY REPT (SEE APPENDIX G)	ROBBINS REPT (SEE APPENDIX G)	LIFE SCI STRATEGIC PLAN (SEE APPENDIX G)
1. ENHANCED RESEARCH AND ANALYSIS PROGRAM	X	X	X	—	X	X	X	X
2 RADIATION HEALTH DATA COLLECTION USING FREE FLYERS	X	X	X	—	—	X	X	X
3. COUNTERMEASURES FOR EXTENDED HUMAN-TENDED SSF CAPABILITY	X	—	X	—	—	—	X	X
4. HUMAN FACTORS GROUND SIMULATORS	X	X	X	—	—	X	X	X
5. HUMAN-RATED CELSS GROUND TESTBED	X	X	X	X	X	—	X	X
6. LIFE SCIENCES SSF TESTBED	X	X	X	X	X	X	X	X
7 MOON DATA REQUIREMENTS	X	X	—	—	—	X	X	X
8 LIFE SCIENCES STANDARDS AND REQUIREMENTS FOR MOON MISSIONS	X	X	—	X	X	X	X	X
9 MOON SCIENCE OPERATIONS	X	X	—	X	X	X	X	X
10 MARS DATA REQUIREMENTS	X	X	—	X	X	X	X	X
11 LIFE SCIENCES STANDARDS AND REQUIREMENTS FOR MARS MISSIONS	X	X	—	X	X	X	X	X
12. MARS SCIENCE OPERATIONS	X	X	—	X	X	X	X	X

An Executive Steering Committee, composed of members from the Aerospace Medicine Advisory Committee (AMAC) and Chairpersons of the DWGs, and other distinguished advisors initially prioritized those issues into three major research thrusts (Figure I-1) that enable missions to Moon and Mars. Finally, the full AMAC reviewed and prioritized the critical issues for this report (Table I-3). The report describes constrained and robust programs. The constrained program was defined as essential and contained criticality 1 and 2 elements; and the robust program included 1, 2, 3, and 4 criticalities. The constrained program contains those elements necessary for all human missions, but it may not be sufficient for Mars mission execution.

From its review, AMAC concludes that, within the current confines of our knowledge, no issue, a priori, precludes human exploration of the Moon or Mars if appropriately focused research is conducted and enabling technologies are developed. However, experimentation and/or long-term experience in space may disclose unexpected difficulties that will require reassessment of this conclusion.

The AMAC analysis identified 15 major issues (i.e., findings) and provides recommendations for corrective action. These findings and recommendations either were considered "overarching," in that they affected fundamental policies concerning research and technology needs, or were categorized into one of the three major research thrusts: (1) Environmental Health and Life Support Systems (EHLSS), (2) Countermeasures Systems (CS), or (3) Medical Care Systems (MCS).

Figure I-1 Life Sciences Research Thrusts

ENVIRONMENTAL HEALTH AND LIFE SUPPORT SYSTEMS (EHLSS)

Protect from the space environment

for example:
- Vacuum
- Radiation
- Absence of atmosphere, food, water

COUNTERMEASURE SYSTEMS (CS)

Compensate for effects caused by the space environment

for example:
- Hypogravity
- Confined space
- Limited crew size

MEDICAL CARE SYSTEMS (MCS)

Provide clinical intervention and or treatment

for example:
- Decompression sickness
- Transfusions
- Bone fracture

Table I-3 Definitions of Criticality

CATEGORY	PROGRAM	CRITICALITY 1	CRITICALITY 2	CRITICALITY 3	CRITICALITY 4
EHLSS	CONSTRAINED	■	■		
	ROBUST	■	■	■	■
CS	CONSTRAINED	■	■		
	ROBUST	■	■	■	■
MCS	CONSTRAINED	■	■		
	ROBUST	■	■	■	■
ENABLED SCIENCE		EXPLORATION CRITICALITY NOT APPLICABLE			
BASIC SCIENCE					

Criticality Criteria

Criticality 1: Consensus that answer is required for Mars mission (known effect and known problem for mission).*

Criticality 2: Answers might be required, but science basis to evaluate risk is not adequate.

Criticality 3: Required for practical optimization of resources (or countermeasure effectiveness) and minimization of risk.

Criticality 4: Important science that is relevant to exploration mission.

*Crewmembers must be able to effectively perform mission tasks in transit vehicles and on planetary surfaces; and must recover, in a reasonable time, upon return to earth.

Category Definitions

<u>Environmental Health and Life Support Systems (EHLSS)</u> are designed to protect the crew from inhospitable space and planetary environments.

<u>Countermeasure Systems (CS)</u> are designed to continuously compensate for detrimental physical, physiological and behavioral manifestations of the space environment (e.g., microgravity, confined volume). They must provide acceptable mission performance and postflight recovery when: (1) EHLSS designed to provide habitable environmental conditions for the crew are not totally feasible because of mission design, or inadequacy of scientific or technological basis, or where cost and schedule are prohibitive; or (2) partial EHLSS failures occur, until appropriate remedial action is taken.

<u>Medical Care Systems (MCS)</u> are designed to handle illness and injuries based on probability of occurrence, to restore crew health for continued mission performance, or stabilize an ill or injured crewmember for rescue. MCS are also designed to handle illness or injuries resulting from temporary failure, degradation, or maintenance of EHLSS or CS systems, until full function is restored.

OVERARCHING RECOMMENDATIONS

To accomplish this recommended work, a single focus of responsibility and accountability, within the NASA top management, for carrying out all agency life sciences/life support activities is required. The 15 findings and recommendations are as follows:

Finding 1: Health risks from exposure to ionizing radiation, long-duration exposure to microgravity, and reliable, self-sufficient life support systems are the three major unresolved issues for human exploration.

> **Recommendation 1:** Research and advanced technology development must focus intensely on characterizing and alleviating risks from radiation, long-duration exposure to microgravity, and development of life support technology. This effort must include continuing availability of a ground facility for proton and heavy charged particle (HZE) radiation research, variable gravity centrifuges on space-based platforms, and ground and space-based testbeds for life support systems.

Finding 2: In spite of numerous recommendations by previous committees, life sciences/life support efforts have not been funded or supported as a sustained and integrated program of research and technology development that will adequately support Moon/Mars missions.

> **Recommendation 2:** Starting with the FY 1994 budget, provide sustained support for a phased and integrated program that includes Spacelabs, international flight platforms, and utilization of Space Station Freedom (SSF) early in man-tended capability (MTC). Accelerate availability of permanently man-tended capability (PMC) to develop, test and validate concepts for Moon and Mars missions, including as a minimum limited bioregenerative life support. Employ Moon bases when available to enhance the scientific database and develop, test and validate concepts, hardware and operational protocols for Mars surface operations.

Finding 3: Robotic precursor missions are required to prevent contamination of Mars or potential back-contamination to Earth, as well as to collect essential information necessary for radiation protection and development of life support systems.

> **Recommendation 3:** Implement robotic precursor missions with life sciences participation to characterize radiation and resources available for life support, and for designing planetary protection protocols (i.e., contamination of Mars and back-contamination to Earth).

GROUND-BASED ACTIVITIES

Finding 4: Archiving and frequent updating of a comprehensive life sciences/life support database do not exist.

Recommendation 4: Based on the benchmark database generated during this study, develop a life sciences/life support database by FY 1993, and update it on a regular basis. Incorporate ground and flight-based mission results, relevant science and technology data from other NASA organizations, and evolving exploration scenarios and plans. Include appropriate information from other federal agencies, international partners, industry and universities. Mandate an annual AMAC review to assess progress toward answering critical questions defined in this plan.

Finding 5: Human exploration missions require fully coordinated and integrated participation among international, interagency, university and industrial institutions.

Recommendation 5: Achieve participation and full coordination of required international, interagency, university and industrial organizations by FY 1994.

Finding 6: Life sciences research in space has produced significant benefits to quality of life on Earth; additional contributions to human welfare on Earth can be expected from enhanced knowledge of the effects of gravity on biological systems, as well as from new medical and life support technologies developed during research to enable Moon and Mars missions.

Recommendation 6: Establish a regular AMAC evaluation of potential near- and long-term beneficial applications on Earth from life sciences research and technology development conducted for human exploration missions; promote further development and transfer of these applications to academia and industry.

Finding 7: National and international analog and testbed facilities (e.g., special facilities at NASA centers, DOD, DOE, NIH, National Science Foundation, and NOAA) for advanced space missions are unused or underutilized.

Recommendation 7: In concert with other agencies (e.g., DOE, NIH, NSF, NOAA, DOD), NASA must increase investment at NASA centers, universities and in industry to maintain and optimally utilize testbed facilities, particularly to promote research and advanced technology development.

Finding 8: Policies, equipment and procedures for preventing the back contamination of Earth and the biological contamination of Mars by humans are not yet developed.

Recommendation 8: Establish an interagency/international committee to focus development of planetary protection policy and appropriately fund the development of necessary equipment and procedures.

GROUND AND FLIGHT ACTIVITIES

Finding 9: Environmental Health and Life Support Systems, Countermeasure Systems, Medical Care Systems, and ultimately, mission design and hardware requirements, are driven by standards (e.g., air, water, and food purity) based on life sciences research and available technology. There is no comprehensive validated set of standards for Moon and Mars missions.

> **Recommendation 9:** Establish an interagency coordinating task force to develop a comprehensive set of standards required for human exploration missions; jointly conduct a detailed evaluation of the adequacy of each item; and expand the existing programs to collect relevant data and reach policy decisions.

FLIGHT ACTIVITIES

Finding 10: The absence of SSF funding for basic biological and biomedical research (like BMAC) in space, will result in underutilization of this facility for both science and space exploration.

> **Recommendation 10:** Enhance utilization of Shuttle middeck, Spacelab, and Russian assets for life sciences/life support, including BMAC, and provide early life sciences access for SSF. Immediately allocate resources for basic and applied life sciences research to facilitate utilization of SSF throughout the first 10 years of operations.

Finding 11: The current plan for a program in space life sciences and in the science needed for human exploration is well-balanced and must be supported. Partial funding of the program is likely to deprive NASA of a significant portion of the life sciences community.

> **Recommendation 11:** Maintain a balanced, synergistic core life sciences program which provides additional resources necessary to enable Moon and Mars missions, define and support exobiology research on those missions, transmit knowledge to life sciences students and make such knowledge and technology available to private commercial enterprises.

ENVIRONMENTAL HEALTH AND LIFE SUPPORT SYSTEMS RECOMMENDATIONS

Finding 12: A high degree of self-sufficiency and reliability in the life support systems is required for exploration missions. Regenerative physico-chemical life support systems and hybrid bioregenerative life support systems are not adequately supported.

> **Recommendation 12:** Accelerate efforts to enable trade-off studies of the life support system capabilities for any given exploration mission scenario.

Develop bioregenerative life support systems and associated testbeds on the ground and for SSF on a schedule and with a level of effort sufficient to support early Moon and Mars missions until physico-chemical capabilities are verified. Develop Controlled Ecological Life Support Systems (CELSS) for Moon and Mars bases.

COUNTERMEASURE SYSTEMS RECOMMENDATIONS

Finding 13: Full characterization of the human adaptation process to long-duration space flight is incomplete. Differentiation between healthy adaptation and pathophysiological adaptation is required in order to devise appropriate countermeasures.

Recommendation 13: Develop a prospective standardized health and performance monitoring capability and research program to be implemented on all national and international missions, thus creating a consistent database to assess the efficacy of countermeasures. This database would also include information on environmental conditions and habitability factors (e.g., human-machine interfaces) associated with this research.

Finding 14: Ultimately crew selection, organization and training will be a critical countermeasure for dealing with psychological and physiological problems associated with space travel.

Recommendation 14: Using the databases created by the life sciences research program in analog and space flight environments, develop and test protocols for crew selection, organization and training.

MEDICAL CARE SYSTEMS RECOMMENDATIONS

Finding 15: Experience with medical care in space is limited to first generation systems appropriate for short-duration missions (i.e., essentially enhanced first-aid kits). Data and techniques to define equipment requirements and protocols appropriate for transit vehicles and planetary habitats are not available. Experience with decompression sickness in space is equally limited.

Recommendation 15: Develop clear protocols for medical triage and treatment of surgical and medical problems during transit and on planetary surfaces. Conduct multidimensional trade-off studies between risk for specific medical events, medical care system equipment and capabilities and crew medical skills, versus telemedicine and rescue capabilities. Develop and test health maintenance systems in ground-based simulators and at remote sites and deploy them to SSF for space flight validation. Evaluate effectiveness of the hyperbaric chamber on SSF.

In addition to the specific issues and recommendations, the AMAC analysis emphasized the benefits of providing access to space for life sciences basic research.

Space flight provides the only environment in which the force of gravity can be partially or completely removed to permit assessment of the undoubtedly profound influence of gravity on the structure and functional evolution of all living organisms.

AMAC realizes that a time table for space exploration has not been established and recognizes that development may occur in the future that will alter the emphasis, importance and timing of these findings and recommendations. Further, the ultimate time of transit to Mars is uncertain because of the undetermined nature of the propulsion scheme to be employed.

Despite these uncertainties, AMAC believes the findings and recommendations reflect the best assessment, that can be made at this time, of the most important issues in the life sciences facing human exploration, and would apply independent of mission scenario. Indeed, most of the issues identified and the paths proposed examine basic questions concerning the possibility of an extraterrestrial venture and are at the heart of any determination as to the potential of such missions.

AMAC did not presume to undertake the task of NASA program planning. However, it felt a responsibility to determine whether the recommendations could be implemented in a timely manner consistent with NASA's published plans. Figures I-2,3, and 4 identify life sciences milestones consistent with the plans available in NASA (e.g., Vision 21— The NASA Strategic Plan, January 1992, and Office of Aeronautics Space Technology Plan provided on September 23, 1991). Figure I-5 illustrates major opportunities for continuous support for external science group input to development of hardware and the definition of the science included in the Moon and Mars missions. External science community will be involved in defining the major life sciences research areas, lunar precursor missions, the research on the lunar base, Mars precursor missions, and the research in the Mars transit vehicle and for the Mars base. Detailed schedules and specific milestones and deliverables for human exploration missions are provided in Section II of the report. The science and technology necessary to provide the deliverables is discussed in Sections IV through VI. Section III addresses the Mission From Planet Earth goal: "to maximize scientific return from exploration that will benefit the people on Earth." This section discusses three categories of research:

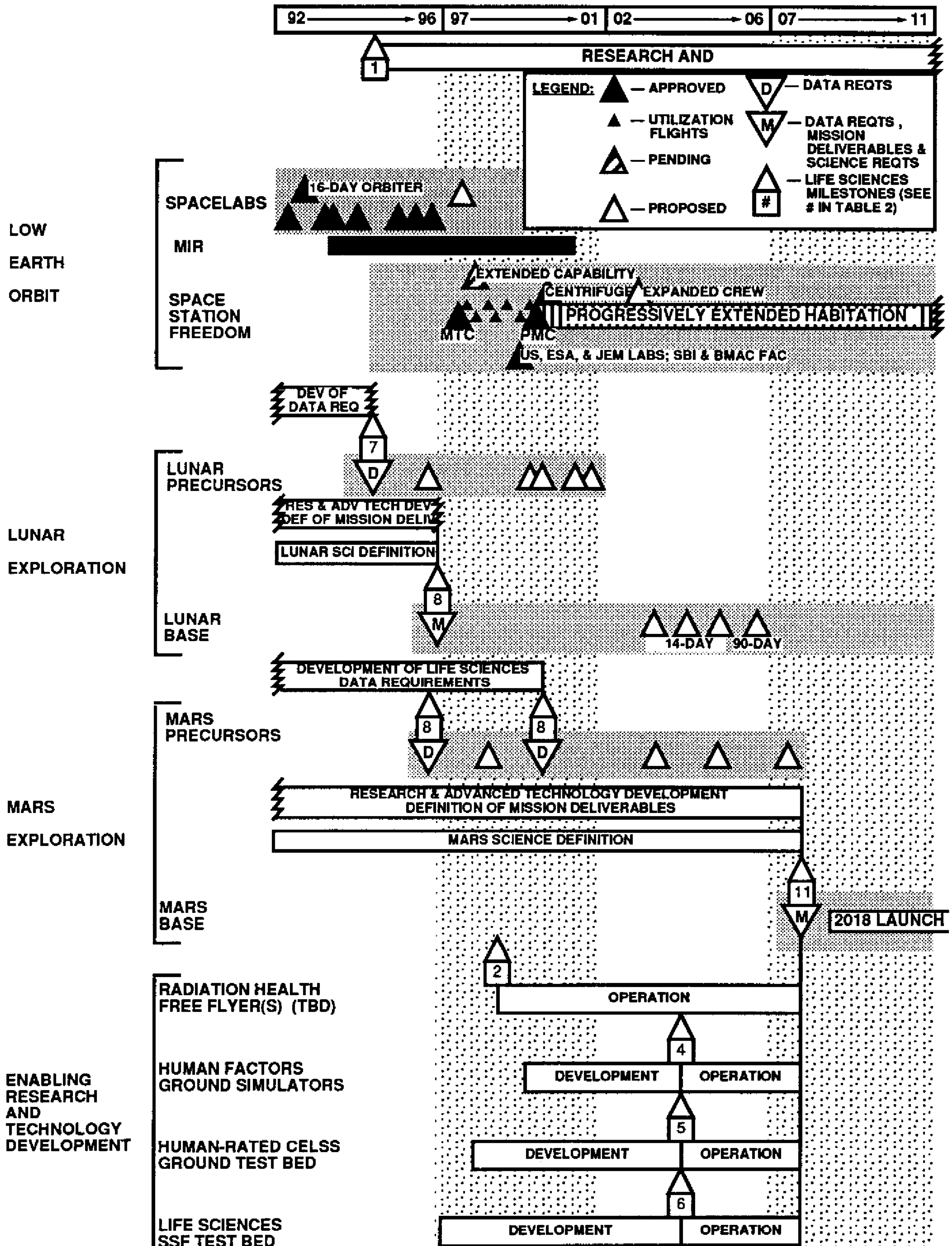
- Science identified as supporting MFPE that is justifiable based on its inherent scientific or technical merit.
- Science that is enabled by Moon and/or Mars exploration missions.[2] Enabled science is a unique component of basic science.
- Basic science not directly applicable to Moon or Mars missions.[3]

Footnote 2. 12% of the critical questions in Life Sciences Discpline Plans will be specifically enabled by Moon and/or Mars missions. See Volume II, Table 7

Footnote 3. 22% of the critical questions in Life Sciences Discipline Plans are basic science not immediately applicable to Moon and/or Mars missions. See Volume II, Table 3

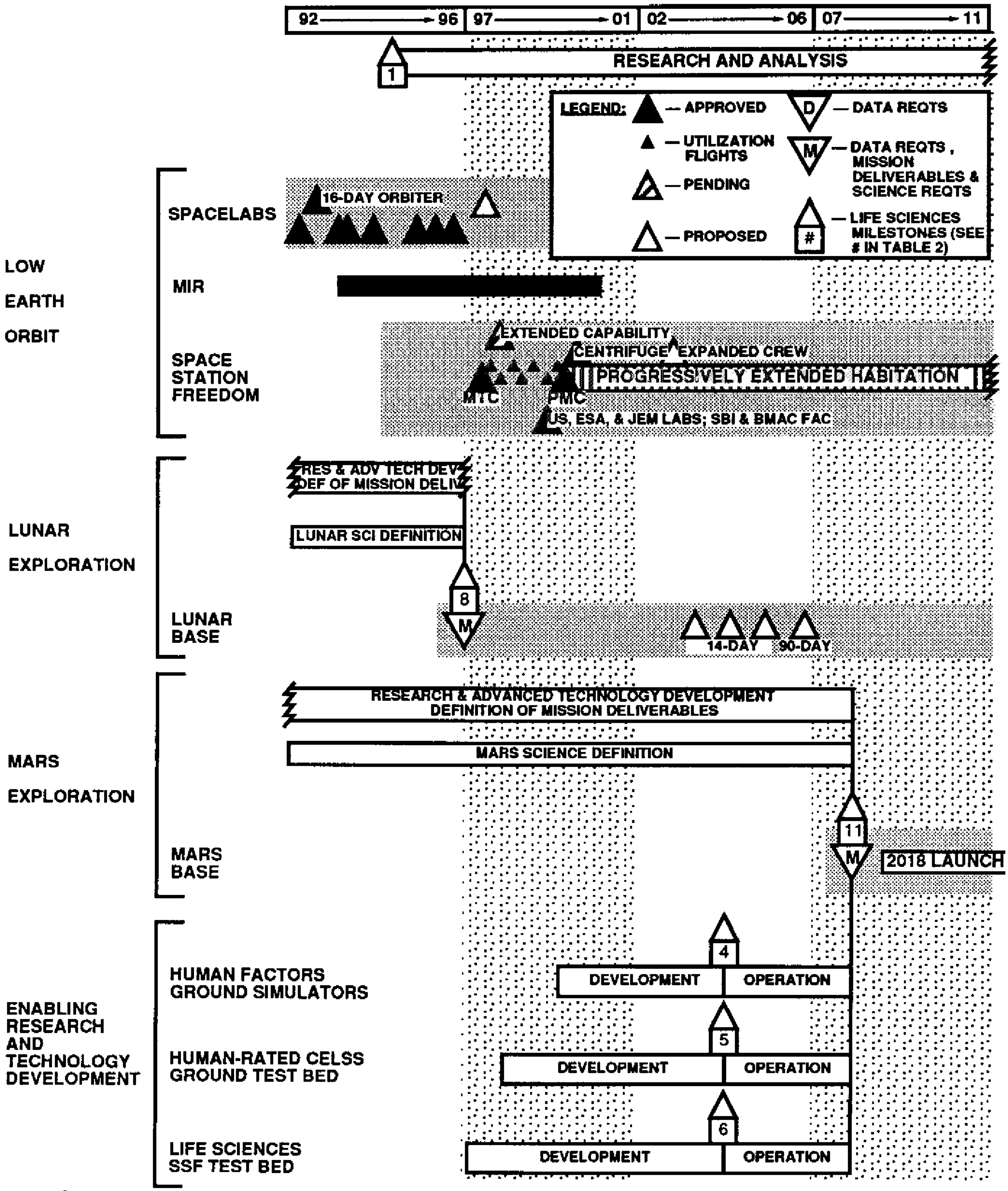
Changing budgets and technical complexities are realities that will affect mission scenarios and milestones, and thus, the execution of this strategy. AMAC assumed that scheduling adjustments, flexible engineering and development planning (e.g., retaining parallel paths of development for contingencies until data is available), and acceleration of appropriate programs could compensate to some degree for any shortfalls and schedule compression. If timely development of the deliverables described in Section II is not possible, the consequence will be increased risk. Frequent updates and refinements of mission scenarios, planned crew activities, and schedule and design decisions as NASA plans for Mars and Moon missions mature, will allow focused life sciences research, thereby decreasing costs and ensuring timeliness.

FIGURE I-2 ENVIRONMENTAL HEALTH AND LIFE SUPPORT SYSTEMS MILESTONES*



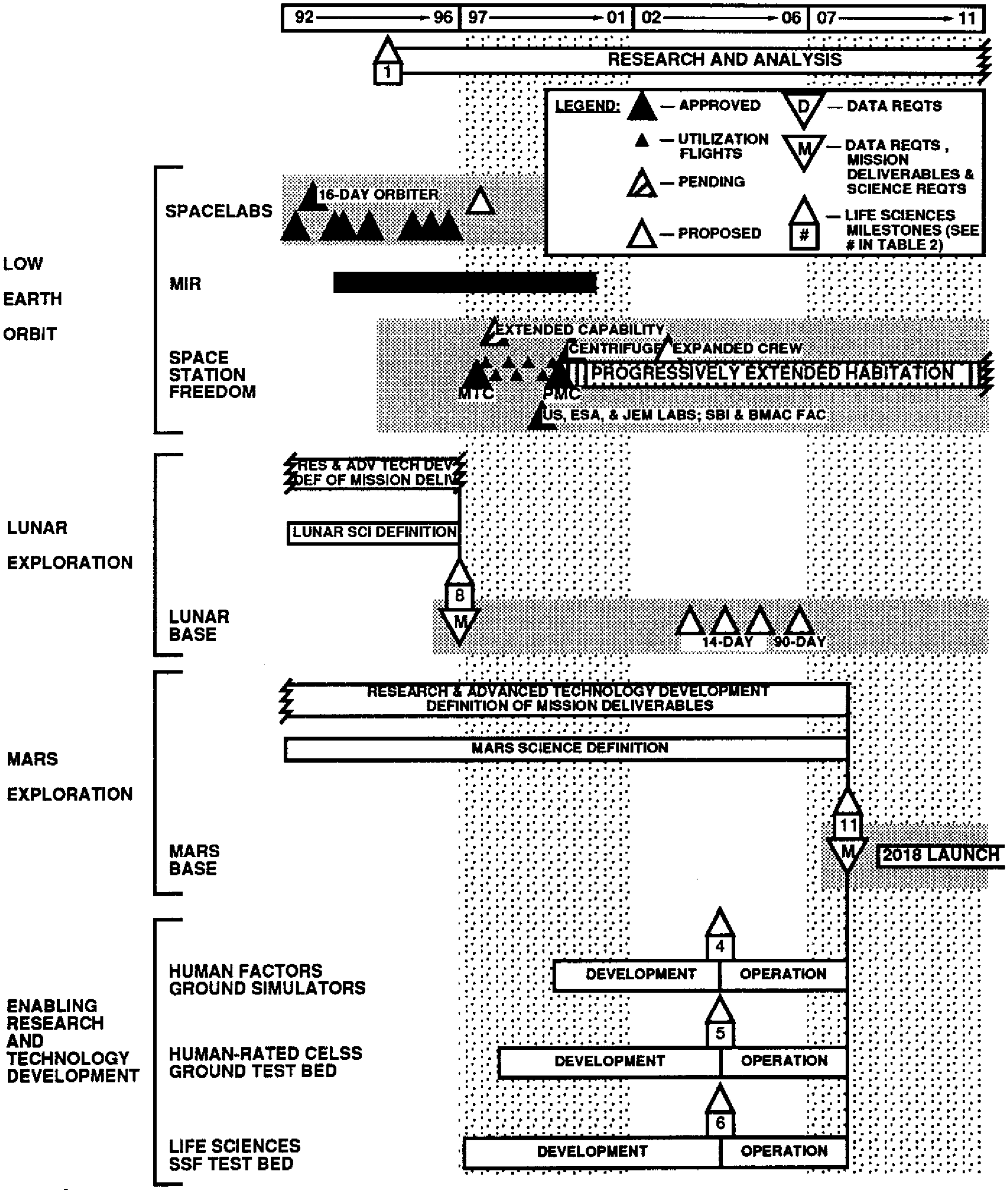
* DATES ARE NOTIONAL AND DEPEND UPON AVAILABLE RESOURCES AND TECHNOLOGY DEVELOPMENT

FIGURE I-3 COUNTERMEASURES SYSTEMS MILESTONES*



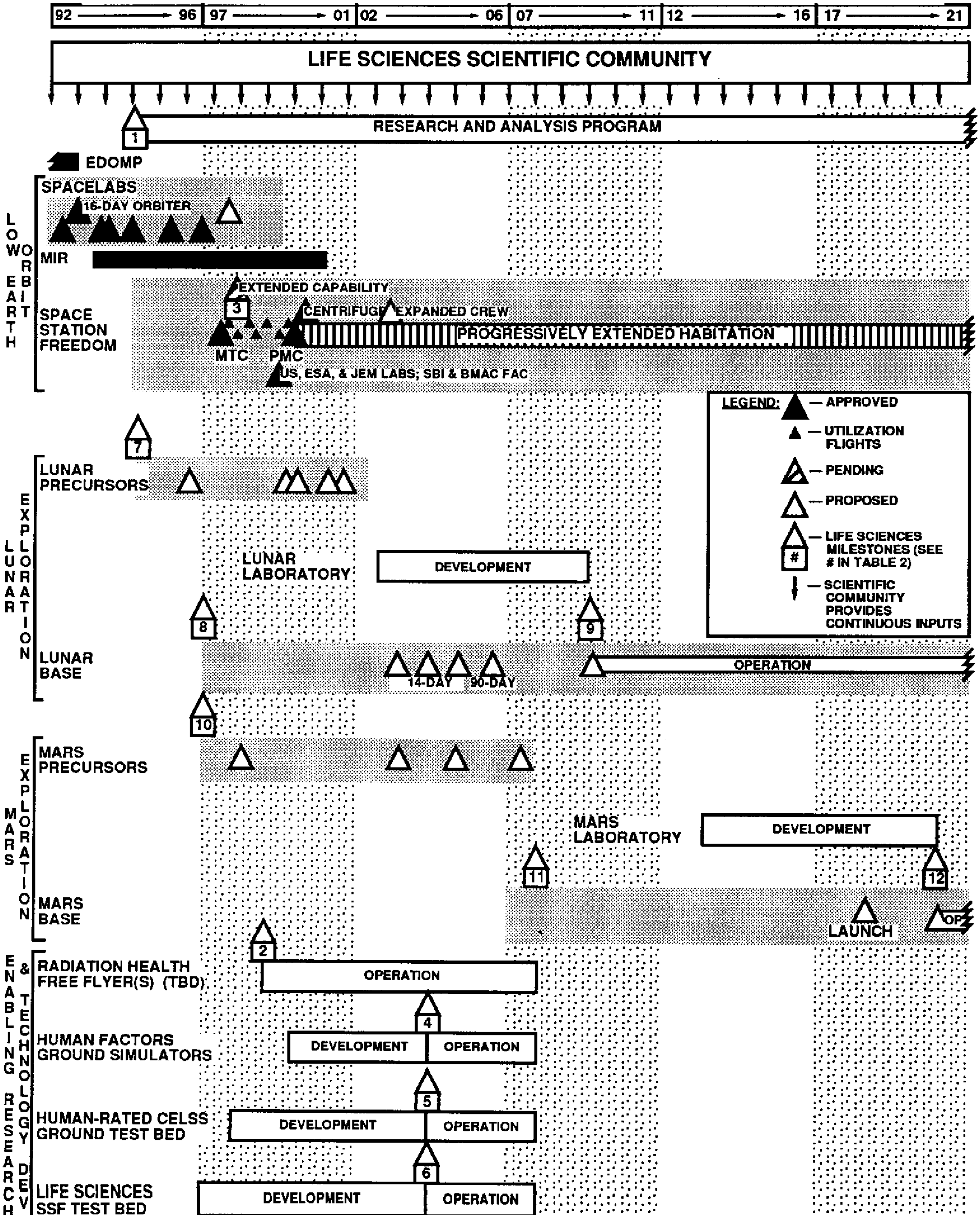
* DATES ARE NOTIONAL AND DEPEND UPON AVAILABLE RESOURCES AND TECHNOLOGY DEVELOPMENT

FIGURE I-4 MEDICAL CARE SYSTEMS MILESTONES*



* DATES ARE NOTIONAL AND DEPEND UPON AVAILABLE RESOURCES AND TECHNOLOGY DEVELOPMENT

FIGURE I-5 ACQUISITION OF KNOWLEDGE MILESTONES*



* DATES ARE NOTIONAL AND DEPEND UPON AVAILABLE RESOURCES AND TECHNOLOGY DEVELOPMENT