II. RESOURCE REQUIREMENTS AND MILESTONES FOR DELIVERABLES

A. Introduction

Based on the mission scenarios available and the resources, the milestones and deliverables have been phased in where ground-based research, spacelabs and SSF provide a foundation for future human exploration missions, and the Moon transfer vehicle, orbiter and base (habitat) are considered testbeds for the Mars missions. The phased approach is recommended because:

- It is a prudent way to invest in life sciences research and technology development. Life sciences research characteristically advances through an iterative process of experimentation, data synthesis and hypothesis generation leading to the next phase of experimentation. The phased approach — starting with ground-based research and then refinement of ground models through sequential stages of flight testing and validation — makes sense because knowledge gained from research and operations in early stages can be used to focus and refine the research program in ground-based laboratories, and to define research and operational hardware and procedures for mature mission operational stages.

- It maximizes return on investment. It facilitates focused experiments and missions which fill gaps in scientific and technological knowledge as complexity gradually increases, allowing NASA and national decision makers the ability to develop realistic plans for delivering Mars exploration capability.

- It provides for near-term returns. Answers to most basic science questions which must be obtained to minimize risks during transit and planetary operations will have applications (medicine, biotechnology, agriculture, environmental management, and other human activities that require knowledge of our biological resources) that "improve the quality of life on Earth" and our industrial competitiveness. They are also necessary to fulfill our quest to understand life itself.

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 budget shortfalls and schedule compression. If timely development of deliverables described in this section 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 more focused life sciences research, thereby decreasing costs and ensuring timeliness. Schedules and deliverables are summarized for the following subcategories:

- Robotic Precursor Missions
- EHLSS — Early Missions Without Bioregenerative Life Support
- Radiation Health
- EHLSS — Later Missions With Bioregenerative Life Support
- Countermeasure Systems For Hypogravity
- Countermeasure Systems For Other Environmental Factors
- Medical Care Systems
- Basic Research and Research Enabled By Moon and Mars Missions
- Utilization of Ground-based Research, Spacelabs, SSF, Moon Base, and Free Flyers.

B. Robotic Precursor Missions

The robotic missions can provide data useful for development of regenerative life support and radiation risk assessment for both Moon and Mars missions. In addition, Mars missions will provide planetary protection information.

Mars mission plans include two Mars Site Reconnaissance Orbiters (MSRO), both launched in one year, and two Mars Surface Rovers (MSVR), launched two years apart to identify and certify locations for landing and establishing a base. The MSRO will map approximately 50 % of the Mars surface over a 20 month period. The two MSVRs involve two year explorations of candidate landing sites to collect data to: (1) verify safe landing and surface base locations; (2) determine the presence of potentially toxic materials; (3) survey the sites for construction plans; and (4) conduct initial scientific investigations (e.g., characterize resource availability).

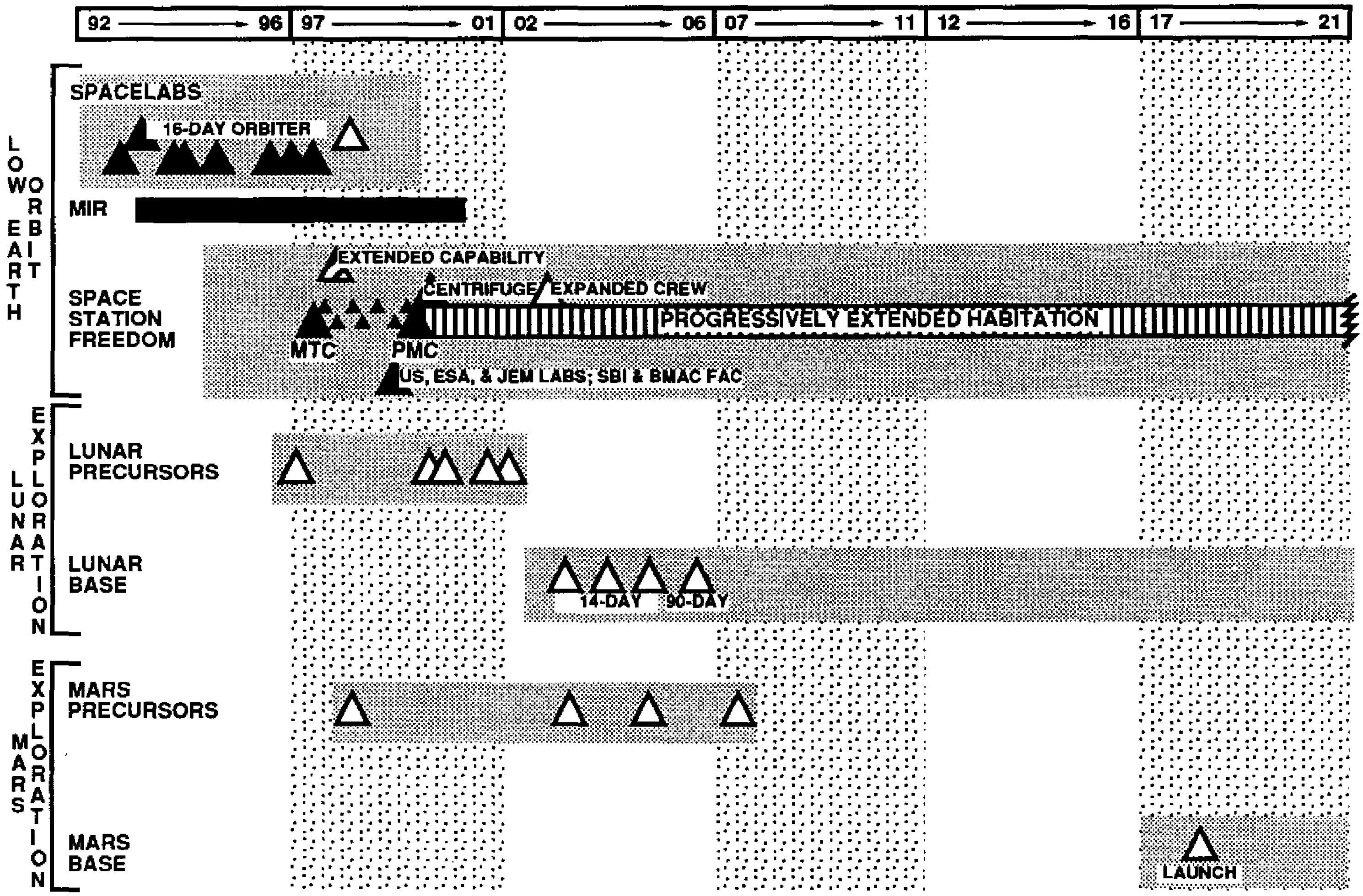
These precursor missions must determine suitability for human habitation and provide *in situ* resource information necessary for development of EHLSS requirements in time to meet delivery schedules for Moon and Mars mission designs. In addition, life sciences must deliver the science requirements necessary for MSRO and MSVR designs. The Planetary Protection Program must enable robotic precursor missions and protect the scientific value of Mars for exobiology studies. Volume II, Table 8 lists the critical questions which would utilize precursor missions. See Tables II-1 and II-2 for deliverables and Figure II-2 for a notional schedule.

C. EHLSS — Early Missions Without Bioregenerative Life Support

Figure II-3 provides a notional schedule for life sciences deliverables and facility requirements in relationship to current flight resources and exploration missions.

Deliverables From Life Sciences. Ground-based research and technology and results from Spacelab missions are being used to generate the deliverables for SSF. Experience and research on SSF will form the basis for deliverables for Moon missions which will, in turn, be used for Mars missions (Table II-3).

FIGURE II-1 SPACE EXPLORATION MISSION SCENARIO AND FLIGHT RESOURCES*



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

Table II-1
Robotic Precursor Missions — Deliverables From Life Sciences

Data and science requirements for robotic missions:

- •• Determine the planetary and transit radiation environment, including fluence, flux, energy, and linear energy transfer spectra of the radiation
- •• Provide data on radiation shielding characteristics of regolith
- •• Provide data necessary to utilize regolith as a raw material for bioregenerative life support
- •• Identify potentially toxic materials
- •• Provide data on sources of water and oxygen
- • Identify potential sources of back contamination by biological materials
- •• Equip orbiters and rovers to study effects of radiation, microgravity, and magnetic fields on suitable organisms
- •• Equip orbiters and rovers to incorporate appropriate exobiology studies
- • Develop sterilization technologies for vehicles landing on Mars
- • Develop technologies and protocols for sterilizing, sealing, and monitoring samples returning to Earth
- • Conduct risk analysis for development of policy regarding planetary contamination

• = Required for Mars
•• = Required for Moon and Mars

Table II-2
Robotic Precursor Missions — Deliverables To Life Sciences

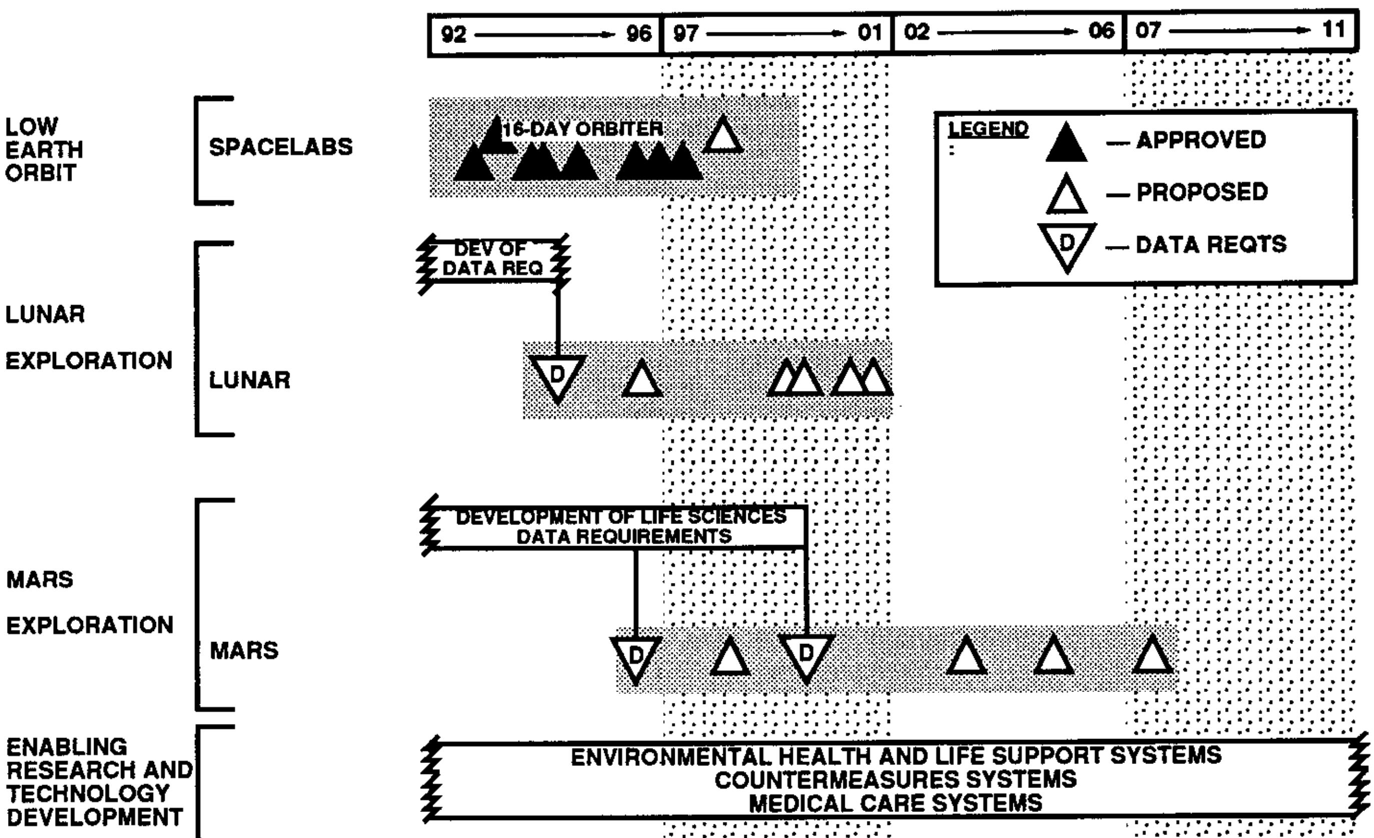
- •• Data from robotic missions required for EHLSS, CS, and MCS
- • Data for Planetary Protection Program
- •• Experimental results from Exobiology

• = Required for Mars
•• = Required for Moon and Mars

Deliverables To Life Sciences. Until physico-chemical and food storage capabilities are proven, it is prudent for ground-based bioregenerative life support research and development to proceed on a schedule that could support the early manned Mars mission. At that time, effort on bioregenerative systems could be rescoped for later missions and resources could be focused on other high priority early mission requirements. In general, regular updates on planned mission scenarios, crew activities and design decisions will allow focus on optimum use of life sciences resources (Table II-4).

Facility Requirements. Human-rated ground based testbeds will be required to develop and validate the equipment and procedures (including EVA and EHA) under simulated mission conditions to optimize: (1) performance and mental health; (2) crew selection; and (3) environmental health and habitability criteria and monitoring; (4) food, atmosphere, and water suitability; and (5) impact of humans on EHLSS (Table II-5).

FIGURE II-2 LIFE SCIENCES PRECURSOR MISSIONS MILESTONES *



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

Table II-3
Environmental Health and Life Support Systems
Deliverables From Life Sciences

- •• Define acceptable human health and safety limits for quality and quantity of water, food, and atmosphere
- •• Identify requirements and technology for food storage, processing, and preparation
- •• Verify life support system capability for EVA and EHA, and provide enhanced technologies
- •• Identify requirements and technology for real time monitoring systems for air, water, and surfaces quality
- •• Determine requirements for lighting, work-rest schedules, privacy, odor, etc.; and identify means to design habitable facilities
- •• Provide basis for optimum design of human-machine interfaces

• = Required for Mars
•• = Required for Moon and Mars

Table II-4
Environmental Health and Life Support Systems
Deliverables To Life Sciences

- •• Verify sufficiency of expendable supplies and physico-chemical regenerative technologies for early missions
- •• Regular update and refinement of mission scenarios, planned crew activities, and design decisions

• = Required for Mars
•• = Required for Moon and Mars

Research Initiatives or Major Enhancements. Ground-based programs will have to be focused, expanded, and accelerated. Enhanced, focused flight programs are essential to take advantage of SSF operational experience and research opportunities, and to validate equipment and procedures for extended duration in the microgravity environment. Opportunities on Mir should be aggressively pursued.

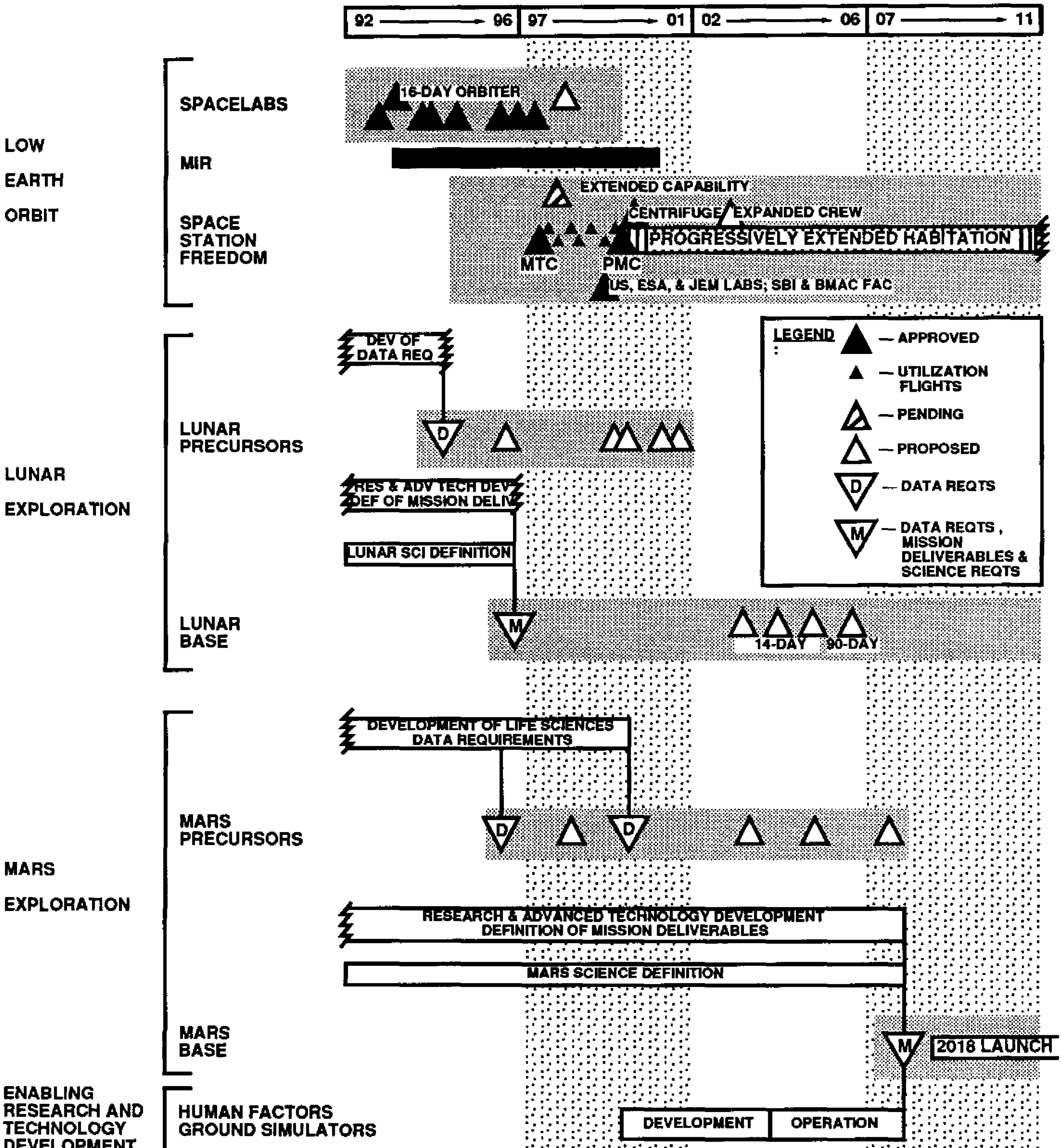
Table II-5
Description of Facility Requirements

Human Factors Simulators
Ground-based analogs including transit vehicle simulators and planetary habitats simulators will be used as testbeds for medical protocols and countermeasures development.

Human-Rated Ground-Based CELSS Testbed
Will be used to develop and validate research and technologies required for an operational bioregenerative life support system and to address environmental, health, and safety issues.

Life Sciences SSF Testbed
Will be used for validation of life support, medical care and countermeasures under operational conditions for transit vehicles.

FIGURE II-3 ENVIRONMENTAL HEALTH AND LIFE SUPPORT — EARLY MISSIONS MILESTONES *



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

D. Radiation Health

Figure II-4 provides a notional schedule for life sciences deliverables and facility requirements in relationship to current flight resources and exploration missions.

Deliverables From Life Sciences. Life sciences must provide the human dose limits for space missions (proton and GCR) and the science and technology base necessary to design transit vehicles and planetary bases with shielding and safe havens that satisfy those limits (Table II-6).

Table II-6
Radiation Health — Deliverables From Life Sciences

- •• Characterize deep space radiation environments
- •• Determine the human radiation dose limits for space missions (protons and GCR)
- •• Provide solar event warning capability
- •• Provide protection from radiation (protons and GCR)

• = Required for Mars
•• = Required for Moon and Mars

Deliverables To Life Sciences. Life sciences research and advanced technology programs require data which characterize the deep space radiation environment; and the radiation shielding characteristic of spacecraft materials and regolith (Table II-7).

Facility Requirements. Availability of sufficient beam time at an HZE ground source facility is absolutely essential. A free flyer capable of supporting appropriate biological specimens outside the Earth's magnetosphere would allow early characterization of the radiation environment and its biological effects. Early experimental data would allow focused research, reduce risk, and resolve the uncertainties regarding HZE particles (Table II-6).

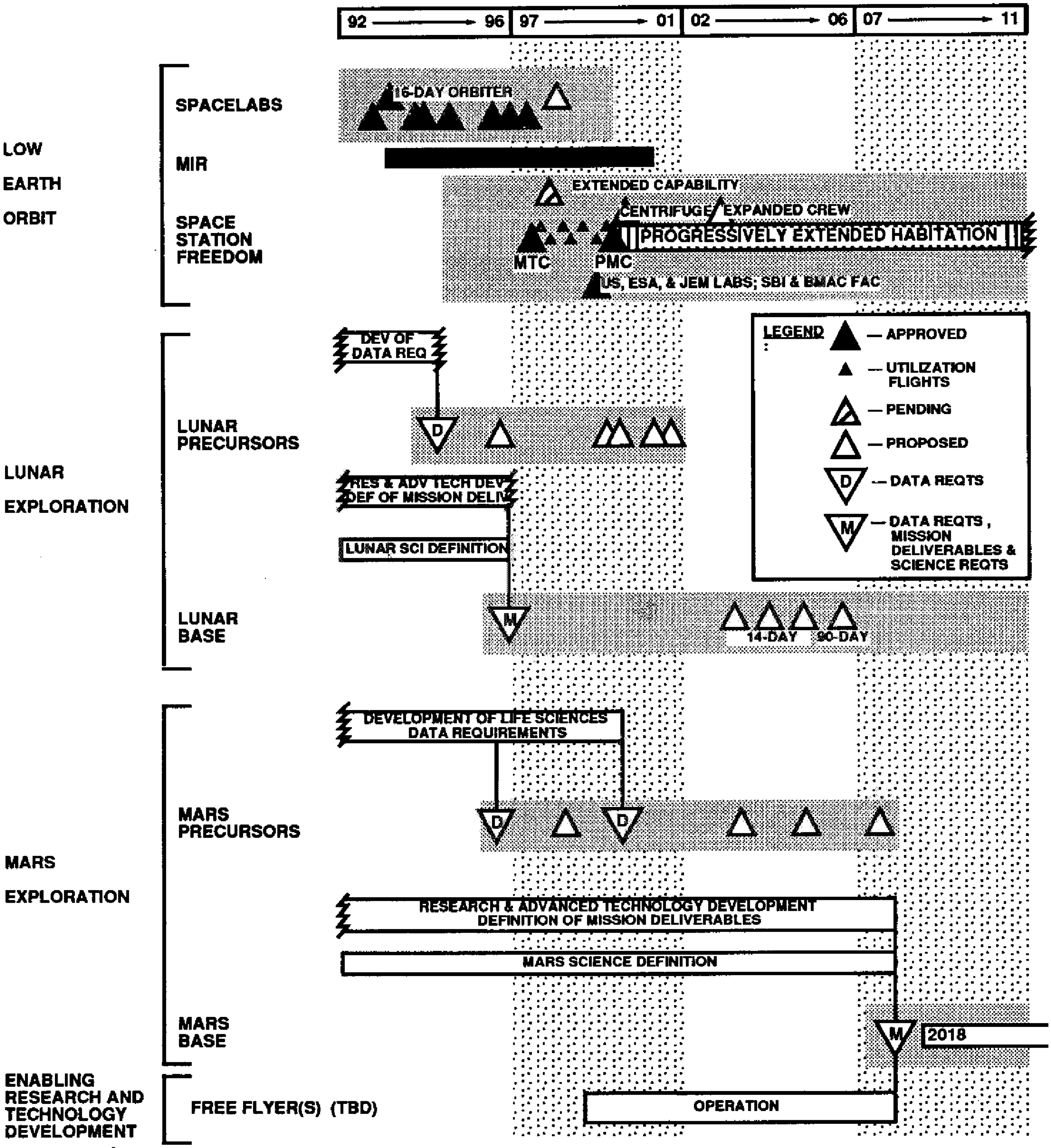
Table II-7
Radiation Health — Deliverables To Life Sciences

- •• Data on deep space radiation environment from precursor missions and any other deep space missions
- •• Data on the radiation shielding characteristics of spacecraft materials and regolith

• = Required for Mars
•• = Required for Moon and Mars

Initiatives or Major Enhancements. Ground-based and flight research and technology programs must be accelerated and expanded to provide timely inputs to planning and design of Moon and Mars missions.

FIGURE II-4 RADIATION HEALTH MILESTONES*



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

E. Life Support — Later Missions With Bioregenerative Life Support

Figure II-5 provides a notional schedule for life sciences deliverables and facility requirements in relationship to current flight resources with focus on the Mars exploration missions.

Deliverables From Life Sciences. Life sciences will provide the design criteria, models, and trade-off studies for crew sustenance for different spacecraft and habitat designs (Table II-8).

Table II-8
Life Support — Deliverables From Life Sciences

- •• Provide criteria for design and operation of bioregenerative components of a life support system that, as a minimum, provides partial recycling of oxygen, water, carbon dioxide, and waste
- •• Provide trade-off analysis comparing expendable, PC, integrated PC-bioregenerative, and predominantly bioregenerative life support systems
- •• Provide criteria for design and operation of a predominantly bioregenerative life support system
- •• Identify storage, processing, and preparation technologies for food produced in bioregenerative life support systems
- •• Provide mathematical models for simulation, design, and operation
- •• Provide technologies to use regolith as a resource in bioregenerative life support systems
- •• Establish nutritional and behavioral requirements for fresh food on long duration missions

• = Required for Mars
•• = Required for Moon and Mars

Deliverables To Life Sciences. Data on regolith and radiation environments necessary for design of regenerative life support systems (Table II-9).

Table II-9
Life Support — Deliverables To Life Sciences

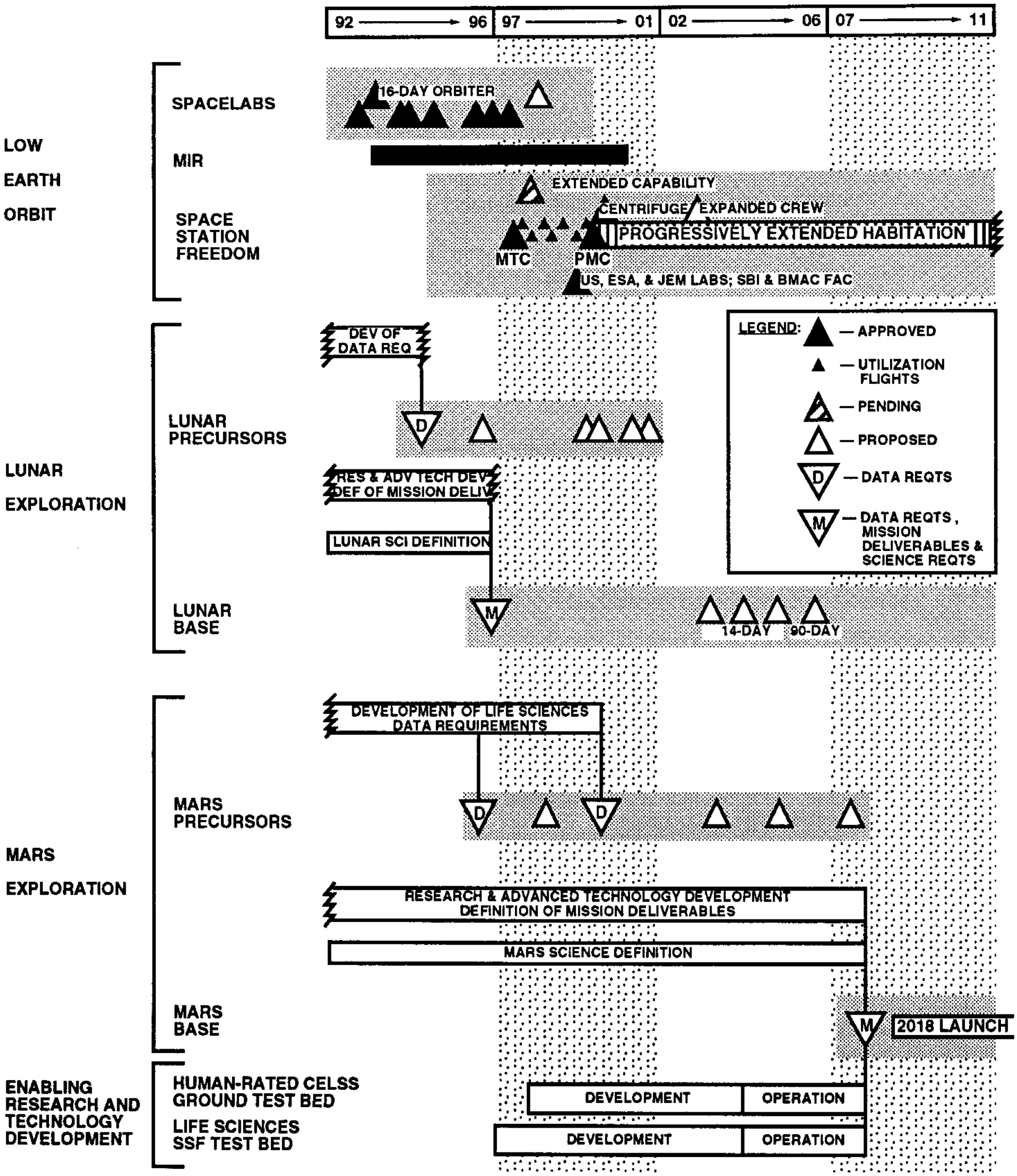
- •• Data on oxygen and water availability
- •• Data on composition and characteristics of regolith
- •• Data on radiation environment throughout mission scenario

• = Required for Mars
•• = Required for Moon and Mars

Facilities Requirements. Applicable research will be conducted in the ground-based human-rated controlled Environmental Life Support System Testbed. SSF Life Sciences Testbed (including an evolutionary prototype operational CELSS) (Table II-5).

Initiatives or Major Enhancements. The ground-based CELSS (e.g., CELSS Breadboard Test Facility, CELSS RTOP) and plant biology research programs will require significant enhancements. Ongoing (Spacelab) and planned research (SSF

FIGURE II-5 BIOREGENERATIVE LIFE SUPPORT — LATER MISSIONS MILESTONES*



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

CELSS Test Facility and plant research in the Gravitational Biology Facility) should be accelerated and enhanced.

F. Countermeasures for Hypogravity Effects

Figure II-6 provides a notional schedule for life sciences deliverables and facility requirements in relationship to current flight resources and exploration missions.

Deliverables From Life Sciences. It is very likely that human adaptation and thus countermeasure requirements will be different for SSF, Moon, and Mars missions (Table II-10).

Table II-10
Countermeasures for Hypogravity Effects
Deliverables From Life Sciences

- •• Provide the criteria for design and operation of CS (e.g., exercise, dietary, pharmacological, mechanical, physiological, training) for human adaptations (e.g., musculoskeletal, cardiovascular, physiological, neurological, and cellular) to microgravity
- •• Provide the criteria for design and operation of CS for human adaptations to the Moon (0.16g) environment
- •• Provide the criteria for design and operation of CS for human adaptations to the Mars (0.38g) environment
- •• Provide criteria for design and operations of CS for readaptation to Earth

• = Required for Mars
•• = Required for Moon and Mars

Deliverables To Life Sciences. The expected timelines are necessary because human adaptation and appropriate countermeasures will vary with sequence, gravity level, duration of exposure, and human activity. Limited resources must be focused on a restricted set of highly probable scenarios (Table II-11).

Table II-11
Countermeasures for Hypogravity Effects
Deliverables To Life Sciences

- •• Mission scenarios, including a timeline with duration of exposure to the various levels of hypogravity and a description of the expected activity (including EVA and EHA) during increments

• = Required for Mars
•• = Required for Moon and Mars

Facilities Requirements. Countermeasure systems will utilize the SSF Life Sciences Testbed. However, equipment specifically for developing, testing, and verifying countermeasures will be required. Neurolab, a Spacelab mission already included in the Life Sciences Division Strategic Plan, will provide scientific knowledge and information necessary for design of countermeasures applicable to SSF, Moon, and Mars missions. Advanced instruments (e.g., nuclear magnetic resonance (NMR) imaging, virtual reality) specifically designed for compatibility with SSF, will facilitate