both basic research and the development of countermeasures. Larger SSF crew size (e.g., eight) and longer rotation periods (e.g., >180 days) are needed when the SSF Life Sciences Testbed is operational. If microgravity countermeasures are ineffective for longer durations, a low Earth orbit artificial g testbed will be required (Table II-5).

Initiatives or Major Enhancements. Ground-based and flight programs will have to be enhanced to conduct fundamental microgravity research and to take advantage of operational experience on SSF. An initiative to determine the consequences of long-duration exposure to 0.16g and 0.38g (especially after a period in microgravity) is essential for planning and execution of Moon and Mars missions. An initiative to evaluate the usefulness of human centrifuges on planetary and transit vehicles might provide enormous benefits to human safety and performance, and could potentially decrease the complexity of countermeasure systems.

G. Countermeasures to Other Environmental Factors

Figure II-7 provides a notional schedule for life sciences deliverables and facility requirements in relationship to current flight resources and exploration missions.

Deliverables From Life Sciences. Russian and U.S. space flight experiences suggest that improved countermeasures are more critical for longer duration missions. Life sciences must deliver increasingly sophisticated and complex systems as the missions proceed from long-duration SSF to the Moon base and to Mars bases (Table II-12).

Table II-12
Countermeasures to Other Environmental Factors
Deliverables From Life Sciences

•• Provide the criteria for design and operation of countermeasures for human responses to space vehicle and planetary base environments not specifically related to hypogravity (e.g. atmosphere, toxins, food quality, confined volume, light, restricted human interaction, privacy, recreational activities, esthetic diversity, and stress)

•• Provide criteria and protocols for crew selection, training, and scheduling to mitigate affects of space flight environmental factors

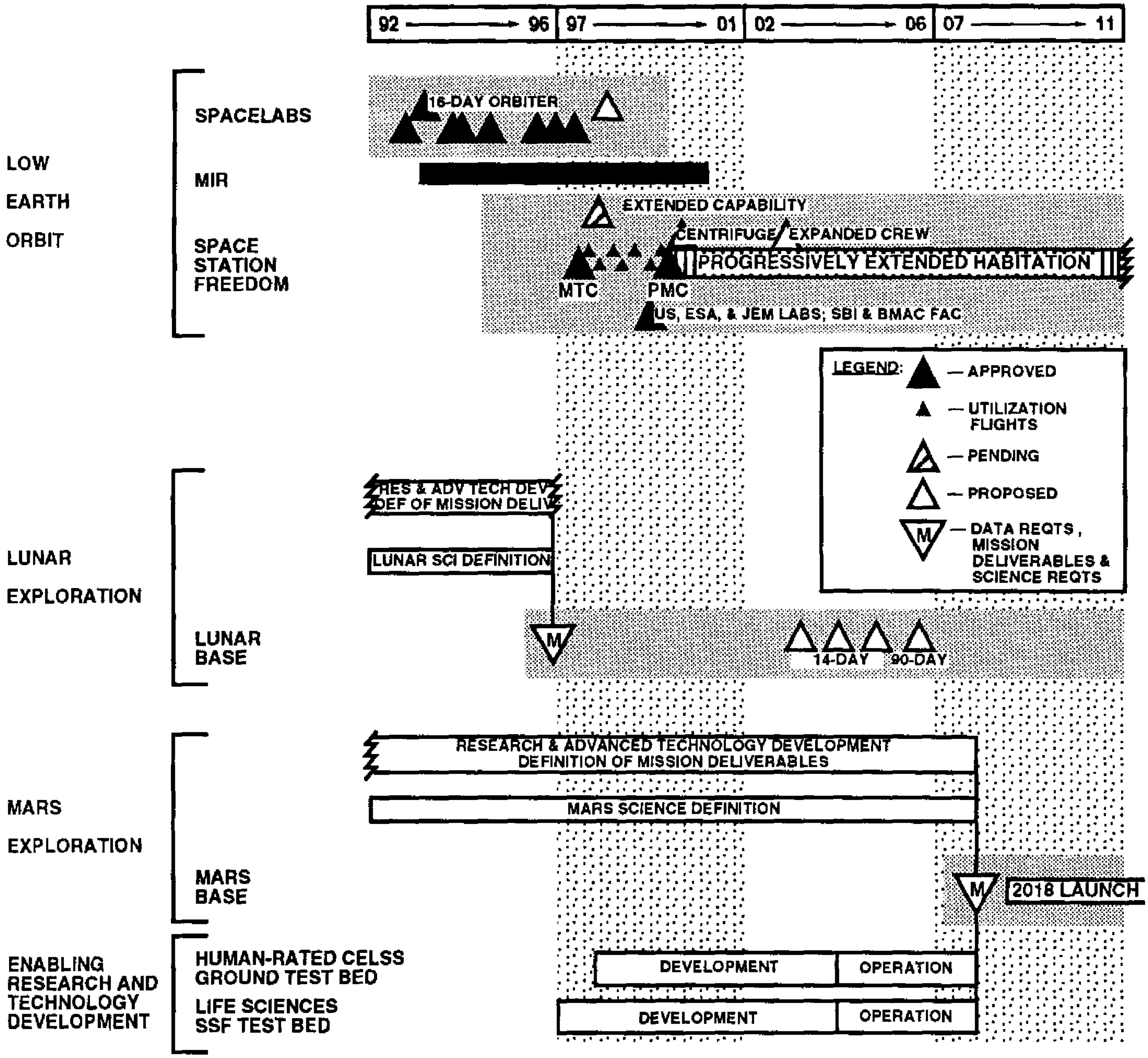
•• Provide trade-off studies for countermeasure alternatives

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

Deliverables To Life Sciences. Except for a central core, scheduling and focus of life sciences research is dependent upon mission scenarios and crew activities including EVA and EHA (Table II-13).

Facilities Requirements. Applicable research will be conducted in the Human Factors Simulators, Human-Rated CELSS Testbed, and SSF Life Sciences Testbed discussed in Section II - C, E and F. However, task-specific instrumentation and hardware will be required (Table II-5).

FIGURE II-6 HYPOGRAVITY COUNTERMEASURES SYSTEMS MILESTONES*



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

Table II-13
Countermeasures to Other Environmental Factors
Deliverables To Life Sciences

•• Mission scenarios including timelines for activities including EVA and EHA

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

Initiatives or Major Enhancements. Ground-based programs will have to be enhanced. Countermeasure capabilities will evolve as the duration of Spacelab and SSF missions increases. Enhancements will be required for long-duration Moon orbiter, Moon base, and Mars missions.

H. Medical Care Systems

Figure II-8 provides a notional schedule for life sciences deliverables and facility requirements in relationship to current flight resources and exploration missions.

Deliverables From Life Sciences. Development of Medical Care System deliverables will be phased, evolving from increasingly longer duration experience on SSF (Table II-14).

Table II-14
Medical Care Systems — Deliverables From Life Sciences

•• Provide the criteria necessary to design and equip health maintenance facilities (including EVA and EHA risks) for Moon and Mars transit vehicles and bases
•• Develop preventive medicine, and monitoring, therapy and treatment protocols for exploration missions
•• Provide telemedicine capability for medical contingencies
•• Provide medical criteria for crew selection
•• Develop the medical training protocols for exploration mission crews
•• Provide protocols for post mission health monitoring and care

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

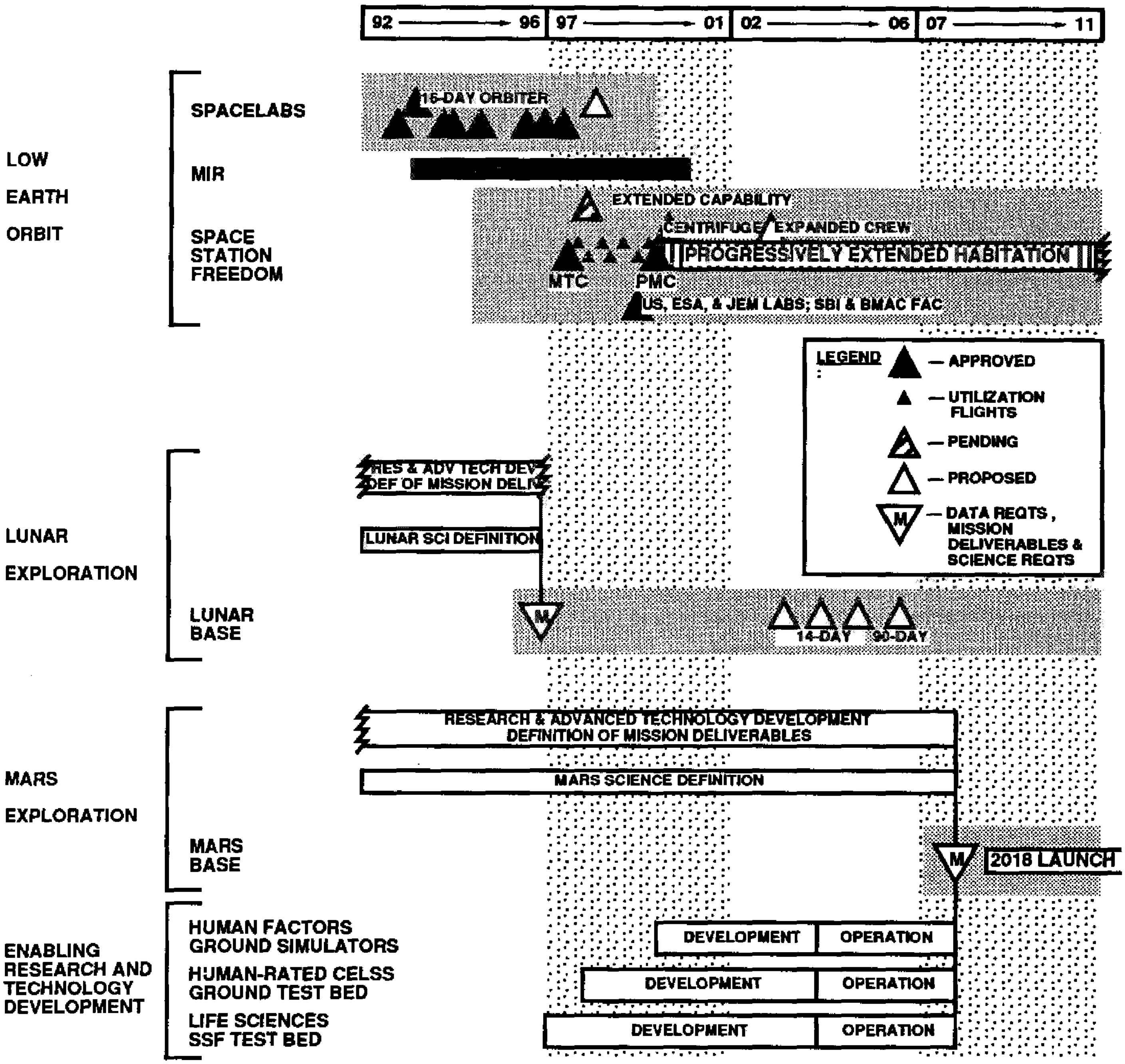
Deliverables to Life Sciences. Medical care requirements are dependent on mission scenarios. For example, they may be minimized for Earth orbit and Moon operations, where rescue times are short (Table II-15).

Table II-15
Medical Care Systems — Deliverables To Life Sciences

•• Mission scenarios including timelines and activities such as EVA and EHA.

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

FIGURE II-7 OTHER COUNTERMEASURES SYSTEMS MILESTONES*



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

Facilities Requirements. Medical Care Systems development will be conducted in the Human Factors Simulators, Human Rated CELSS Testbed, and SSF Life Sciences Testbed discussed in Section II-C, E and F. Medical Care System specific instrumentation and hardware will be required (Table II-5).

Initiatives or Major Enhancements. Extended durations and extremely long distances will require an unprecedented level of inflight medical care capability. Current resource levels cannot support development of those systems.

I. Acquisition of Knowledge

Planning for scientific investigations is an integral part of operations and systems development planning for Moon and Mars missions. The university, commercial, and private scientific community will participate in establishing specific Science Plans and development of Science and Technical Requirements Documents that will be used to design Moon base, Mars transit, and Mars base laboratories (Table II-16). Figure II-9 provides a notional schedule for life sciences deliverables and illustrates its continuous significant involvement of the life sciences scientific community.

Table II-16
Acquisition of Knowledge — Deliverables From Life Sciences

- •• Provide science and technology requirements necessary to design the laboratory for Moon base
- • Provide science and technology requirements necessary to design Mars transit vehicle research facilities
- • Provide science and technology requirements necessary to design laboratory for Mars base
- •• Provide research proposals for SSF, Moon, Mars transit vehicle, and Mars base laboratories

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

J. Utilization of Ground-Based Research, Spacelab, SSF, Moon Base, and Free Flyers

Research and technology development for exploration missions will involve a wide diversity of ground-based research and flight platforms. Requirements for the constrained programs for EHLSS, CS, and MCS are summarized in Appendix H; and for robust programs, in Volume II, Table 2. The notional schedule in Figure II-9 identifies the flight resources available to support specific phases of the exploration program. Existing Life Sciences Programs are appropriately balanced between human exploration and basic science.

1. Ground-Based Research

Ground-based research provides the science and technology foundation for flight research. In fact, it is used extensively to develop alternatives and screen options in order to reduce the risk and need for costly space flight experiments. Accordingly, 95% of the critical questions require additional ground-based research (Volume II, Table 3).

2. Spacelabs

A continued Spacelab mission series with extended duration is required to obtain information for environmental life support and monitoring of critical health parameters, countermeasure development and testing, and verification of medical care procedures. If Spacelab resources were available, they could contribute to addressing 66% of the critical questions (Volume II, Table 4). They would be particularly useful for technology validation and testing for EHLSS, and for characterizing the "normal" physiological and behavioral responses to space flight essential for CS and MCS. They will continue to provide the experimental foundation necessary to elucidate the mechanisms whereby gravity or its absence affect living systems.

3. Space Station Freedom Utilization

Permanent presence in space on SSF is the first step in the Mission from Planet Earth (MFPE). SSF will provide the U.S. and its international partners the ability to develop, test, and validate prototype Moon and Mars EHLSS, CS and MCS. Beginning during MTC:

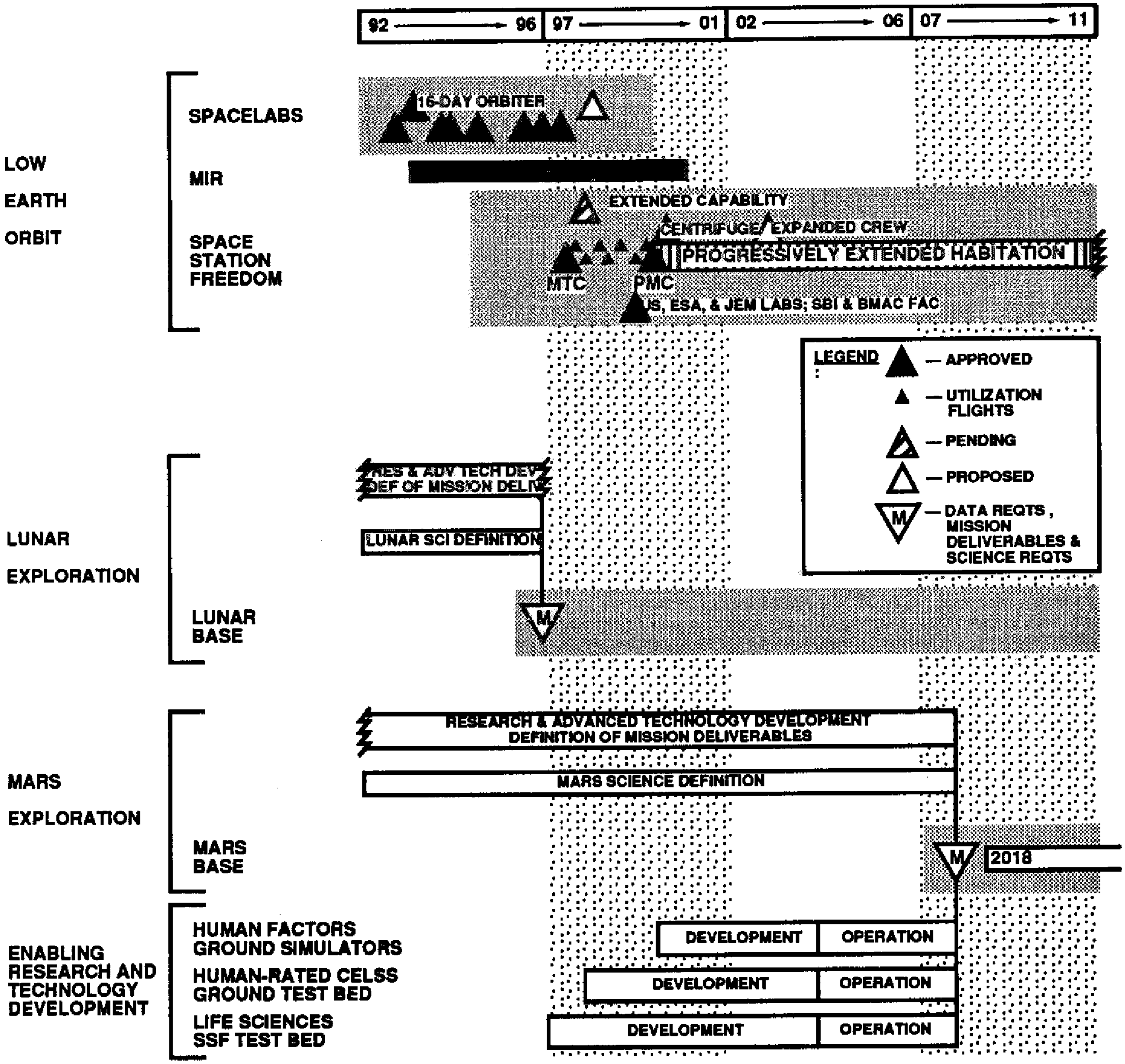
(1) The BMAC Program will focus on developing and validating countermeasures for progressively longer duration on-orbit crew times
(2) Research programs will focus on the physiological and behavioral adaptations to flight in order to: (a) define the normal envelope for parameters in the space flight environment; (b) understand the underlying mechanisms; and (c) develop models and simulations
(3) Repeated EVA during the construction phase will allow accumulation of data and experience which will facilitate advanced equipment and procedures for exploration
(4) Gravitational biology studies will focus on microgravity and radiation interactions and the impact of microgravity on plant structure and function.

Extended Man-Tended Capability (EMTC) may provide information on long duration exposure. This gradual buildup of duration will provide early data for exploration and will improve the productivity of SSF during early Permanently Manned Capability (PMC).

During PMC, the Crew Health Care System (CHeCS) will provide operational medical care experience. Subsystems include a Health Maintenance Facility (HMF), Environmental Health System (EHS), and a supporting hyperbaric chamber.

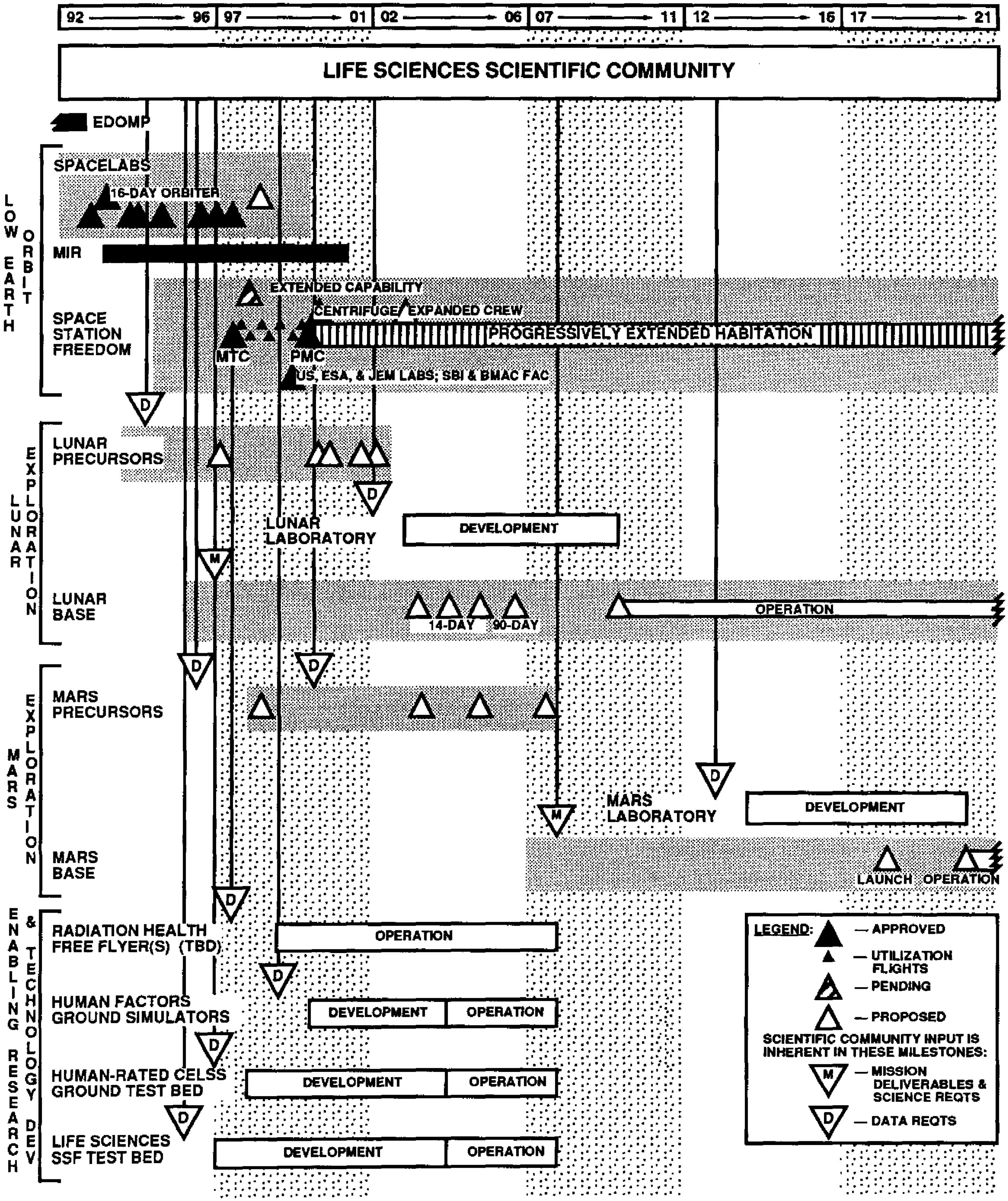
During PMC, SSF provides unique space flight advantages — extended duration, technically advanced facilities, inflight sample preservation and analysis, sufficient sample size (replications), variable g — to address biological questions. While some questions can be investigated on short-duration space flights provided by Spacelabs,

FIGURE II-8 MEDICAL CARE SYSTEMS MILESTONES*



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

FIGURE II-9 ACQUISITION OF KNOWLEDGE MILESTONES*



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

recoverable satellites, and even sounding rockets, many questions require a long-duration facility such as SSF. For example, many biological processes (e.g., organism development, multigeneration cycles, and adaptation) simply require extended periods of time to occur. Also, the answers to many biological questions can only be provided through extended duration experiments where the results of on-orbit observation and analysis can be used to modify experimental parameters of ongoing or sequential follow-on experiments. Technically advanced facilities and on-orbit analysis will, for the first time, allow investigations involving key unstable biological components that require immediate analysis, and structures, products, and phenomena that are modified during reentry and return. Advanced sample preparation and preservation technology will greatly enhance the science return from on-orbit experiments by increasing the preservation options and variety of samples available for more sophisticated ground-based analysis.

Inherent biological variability requires that sufficient time and sample number be provided for an effect to be unambiguously manifested. Our ability to clearly interpret past U.S and international life sciences flight experiments and provide operational remedies has often been limited because there are too few replications. SSF capabilities promise to provide the time and number of samples for clear interpretation of statistically valid results. Furthermore, a continuously operating laboratory in space will allow replication of experiments and eliminate the current two-plus year delay required to manifest follow-up experiments to take advantage of exciting discoveries.

SSF will allow scientists to take advantage of biological diversity by selecting from the full spectrum of biological species to address questions. Most importantly, it will allow them to match the question to the most appropriate biological model. The ability to use well characterized specimens that have been used extensively for research on Earth will: (1) enhance the interpretability of results and development of a consensus in the scientific community because extensive knowledge bases already exist; (2) decrease the need for NASA-sponsored preparatory ground-based experiments; and (3) shorten the time course and reduce the cost of acquiring answers to critical life sciences questions. Furthermore, access to species not previously available in space flight will attract an expanded scientific community and enrich the program. The Space Physiology Facility, Gravitational Biology Facility, Centrifuge Facility, CELSS Test Facility, and BMAC equipment on SSF will greatly enhance our ability to conduct the kinds of interspecies comparative studies that have always been a fundamental tool of life sciences research.

Small centrifuges for lower organisms, cell cultures, and small plants and animals in conjunction with the Centrifuge Facility for larger plants and animals will provide the ability to manipulate gravitational levels from near zero to 2g for a broad diversity of species. This capability will allow control of gravity as a variable in a manner analogous to the way light intensity, temperature, nutrient levels, drug dosages, etc., have always been manipulated to elucidate the fundamental mechanisms and processes involved in the structure and function of living systems. Furthermore, they will allow us to explicitly evaluate the effect of Moon (0.16 g) and Mars (0.38 g) gravity levels on candidate organisms for bioregenerative life support systems for Moon and Mars bases. In addition, experiments with animals as surrogates for humans will allow predictions of the effects of Moon, Mars, and transit vehicle gravity regimes on humans.

When the Life Sciences SSF Testbed becomes operational it will be used for validation of life support, medical care, and countermeasures under operational conditions for transit vehicles.

Finally, SSF provides the real lessons learned from the experiences of building, operating, living, working, and conducting research in a large, increasingly complex, long-duration facility in space. The Advisory Committee on the Future of the U.S. Space Program, 1990, and the Report of the Synthesis Group on America's Space Exploration Initiative, 1991, recommendations on the importance of SSF are substantiated by the fact that over 83% of the critical questions in life sciences need SSF (Volume II, Table 5). The Centrifuge Facility will support over 36% of the critical questions (Volume II, Table 6).

4. Moon Base Utilization

Moon base facilities will provide the opportunity to expand research that will reduce the logistics burden for Moon operations and enhance human performance on Moon and Mars surfaces. A research site outside the Earth's magnetosphere will facilitate detailed study of GCR, and the base will be an operational test of radiation shielding. Moon operations will accelerate the development, testing, and validation of CS and MCS, and will provide extensive information on 0.16 g operations. Extensive experience with life support systems will accelerate and refine EHLSS. A Moon base testbed for bioregenerative components of an integrated PC-bioregenerative system will accelerate CELSS development. Moon bases allow evolutionary development, testing, and verification of EHLSS, CS and MCS systems for the Mars missions. Research equipment for Moon missions will allow study of the effects of radiation and hypogravity (microgravity and 0.16g) on suitable organisms; and the conduct of early exobiology experiments. Even after consideration of the advantages of conducting research in low Earth orbit, 65% of the critical questions would benefit from access to Moon bases (Volume II, Table 7).

Exploration planning includes an Initial Operating Capability (IOC) on the Moon that provides a single, integrated habitat that supports a crew of five for 14 days. External shielding will provide radiation protection, and the habitat will include life support, crew accommodations, health care equipment, science facilities, and utilities.

The life support system is expected to be an advanced SSF regenerative system, with greater than 98% oxygen recovery, hygiene water processor, and nonexpendable water polisher/bacteria barrier. The Next Operating Capability (NOC) will extend the surface infrastructure to support crews for up to 90 days and could include prototype Mars technology. The NOC2 habitat at a second site will utilize life support technology planned for the Mars mission. This advanced system will incorporate waste processing to reduce requirements for consumables. It will also include advanced countermeasure and medical care systems.

5. Free Flyers

The utilization of reusable, low cost, free-flying platforms should be considered to address the research thrusts that cannot be accommodated with the previously described facilities. Planning for free flyers should be tailored to the priorities and schedules necessary to accelerate or increase the efficiency of efforts to develop solutions for Moon and Mars missions. They would enable investigations of microgravity and radiation effects on living organisms, including plants, rodents, cell and tissue cultures, and other biological specimens. A recoverable should have the capability for access to unique orbits (e.g., polar) for extended periods (e.g., 30 to 60 days). A recoverable would enable real-time active measurements of all components of GCR and investigation of the interaction between microgravity and radiation. These studies would validate ground-based predictions and models in the space environment. Thirty percent of the critical questions would benefit from access to free flyers (Volume II, Table 9).