SPACE STATION

SCIENCE OPERATIONS MANAGEMENT CONCEPTS STUDY

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PREFACE

This report presents alternatives for the management of Space Station science operations. The report is organized as follows:

EXECUTIVE SUMMARY
DEFINITION OF TERMS

CHAPTER I PURPOSE

States the purpose of the document and presents the precise wording of the Congressional request.

CHAPTER II THE APPROACH: SPACE STATION SCIENCE OPERATIONS MANAGEMENT CONCEPTS STUDY

Describes the Space Station Science Operations Management Concepts (SSSOMC) study performed jointly by the NASA Office of Space Science and Applications (OSSA) and the NASA Office of Space Station (OSS) in response to the Congressional request. Presents the groundrules for the study, the methodology employed, and the output of the study.

CHAPTER III BACKGROUND

Summarizes opportunities for scientific investigation on and from the Space Station. Provides an overview of science user organizations and the various scientific disciplines involved.

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CHAPTER IV SCIENCE OPERATIONS

Defines the four major programmatic phases in the "science operations" process. These include Science Planning and Payload Selection, Payload Development and Integration, Science Tactical and Increment Planning, and Science Operations and Data Management.

CHAPTER V SCIENCE OPERATIONS AND SPACE STATION

Couples and coordinates the science operations process described in Chapter IV with overall Space Station operations planning.

CHAPTER VI INSTITUTIONAL ARRANGEMENTS

Identifies the spectrum of alternative options considered for the management of Space Station science operations. Summarizes the arguments for and against various options leading to a reduced set.

CHAPTER VII SSSOMC STUDY CONCLUSIONS AND RECOMMENDATIONS

Summarizes the study conclusions and recommendations. Identifies follow-on activities needed.

CHAPTER VIII RELATED ISSUES AND RECOMMENDATIONS

Summarizes science operations issues which do not directly impact science management structures but which are relevant to the implementation of Space Station science operations. Presents associated recommendations.

DEFINITION OF TERMS

CORE STATION

The manned base, which represents the primary element of the Space Station Complex.

DISCIPLINE

A grouping of science and applications disciplines (i.e., Astrophysics, Earth Sciences, Life Sciences, Materials sciences, and Solar System Research). These groupings correspond to the OSSA Divisions: Space Astrophysics, Earth Science and Applications, Microgravity Science and Applications, Life Sciences, and Solar System Exploration. Sub-discipline is a discrete scientific area within a discipline (e.g., infra-red astronomy, atmospheric physics, space medicine, combustion science, and geosciences are sub-disciplines of the above disciplines).

FACILITY

Any item of science or applications flight hardware available for users in addition to those on the development team.

FLIGHT INCREMENT

The interval of time between Shuttle visits to the Space Station. Space Station operations are planned in units of flight increments.

INFRASTRUCTURE

The set of capabilities that are maintained to support science operations for multiple experiments. These include simulators for hardware integration and training, software tools, control centers, and data management centers.

MANAGEMENT ALTERNATIVE (OR OPTION)

A prescribed arrangement of management responsibilities assigned to different organizations (e.g., a NASA field center) for the various phases of the science operations process.

PAYLOAD INTEGRATION OFFICE

An OSSA-sponsored organization responsible for management and analytic and physical integration of payloads (need not be a NASA field center).

PAYLOAD OPERATIONS INTEGRATION CENTER (POIC)

As currently proposed by the Office of Space Station, the facility to be responsible for integrated user planning and realtime operations.

PRINCIPAL INVESTIGATOR

The developer of science or applications flight hardware. The hardware may become a facility at some later time.

RAPID-RESPONSE RESEARCH

A class of payloads or investigations with minimum Space Station resource requirements which can be introduced late in the planning cycle (sometimes referred to as "quick is beautiful").

SCIENCE CENTER

An organization responsible for instrument or facility development as well as science payload operations and data management (need not be a NASA field center).

SCIENCE OPERATIONS CENTER

An organization responsible for science payload operations and data management only (need not be a NASA field center).

SPACE STATION COMPLEX

The entire set of Space Station elements including the core Station, polar-orbiting platforms, and co-orbiting platforms.

SPACE STATION SUPPORT CENTER (SSSC)

As currently proposed by the Office of Space Station, the facility to be responsible for realtime Station systems planning and operations, including realtime resource allocations.

TELESCIENCE

A concept in which interactive, high-performance telecommunications links exist among the space-based laboratories and facilities, the on-orbit crew, and geographically dispersed ground-based investigators for purpose of remote experiment design, operations, and data analysis.

USER

One who uses a science or applications facility.

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EXECUTIVE SUMMARY

INTRODUCTION

The Space Station Science Operations Management Concepts (SSSOMC) study was performed to provide options and recommendations to the NASA Office of Space Science and Applications (OSSA) and the NASA Office of Space Station (OSS) for the implementation of their roles in managing U.S. science uses of Space Station. The study also provides the basis for response to a request by the U.S. House of Representatives' Committee on Science, Space, and Technology that NASA identify alternatives for the management of Space Station science operations. The study was performed jointly by OSSA and OSS with the participation of other NASA Headquarters offices and field centers, other federal agencies, members of the private sector, and a significant number of scientists from academia. Representatives of the other three international partners (i.e., ESA, Japan, and Canada) were included as observers. The scope of the study was limited to science operations of the U.S. space science and applications communities, but scientific involvement with the other international partners was taken into account.

The methodology employed in the study was as follows:

(1) Space Station science opportunities were identified;

(2) Planned usage of these opportunities was characterized by science discipline;

(3) The content of the "science operations" process was defined;

(4) The science operations process was coupled with current Space Station planning;

(5) A spectrum of alternatives for the management of Space Station science operations was constructed;

(6) Alternatives were evaluated on the basis of science user needs and the established modes of operation of the various science discipline communities; and

(7) A reduced set of preferred management alternatives was developed.

SPACE STATION SCIENCE OPPORTUNITIES AND PLANNED USAGE

The mature Space Station will offer four different types of opportunities for U.S. science users:

(1) Pressurized module accommodations, with crew support;

(2) Accommodations for attached payloads on the external structure of the Station;

(3) Co-orbiting and polar free-flying platforms; and

(4) A capability to assemble and service free-flying platforms and attached payloads on-orbit.

These opportunities are intended to facilitate advanced research in the physical, chemical, and biological sciences by providing routine and continuous access to space and rapid-response opportunities for research. The principal U.S. science user of the Space Station will be OSSA. Other probable U.S. science user organizations include the National Bureau of Standards, the National Institutes of Health, the National Science Foundation, the U.S. Department of Agriculture, the U.S. Geological Survey, and the National Oceanic and Atmospheric Administration.

OSSA plans to use the Space Station to advance research in the following scientific disciplines:

(1) Microgravity Research in Life Sciences: including space medicine, operational medicine, biological research, and exobiology;

(2) Microgravity Research in Materials Sciences, Physics, and Chemistry: including electronic materials, metals and alloys, glasses and ceramics, biotechnology, combustion, fluid dynamics and transport phenomena, and fundamental research in physics and chemistry;

(3) Astrophysics: including high-energy astrophysics, visible, ultraviolet, and infrared astronomy, relativity, and solar and heliospheric research;

(4) Earth Sciences: including plasma physics, atmospheric physics, upper-atmospheric research, weather and climate research, ocean and land processes, and geodynamics research; and

(5) Solar System Research: including planetary science, planetary atmospheres, and geoscience.

Life Sciences research is aimed at ensuring crew health, welfare, and productivity by studying the adaptation of humans to the microgravity environment, determining the mechanisms which lead to deconditioning, and developing subsequent countermeasures. In addition, basic research on animals and plants will contribute to our understanding of how gravity has influenced the development and evolution of life on Earth. The Life Sciences program plans to use a variety of multi-purpose facility-class payload systems in the pressurized modules of the Space Station. Candidate facilities include a 1.8-meter variable-gravity centrifuge, a 4.0-meter variable-gravity pressurized facility, and a 4-cubic meter gas-grain simulator facility. An evolutionary philosophy will be used in that these facilities will be flown on Spacelab, modified or up-graded as needed, and then transitioned to Space Station. Also under consideration is an attached payload, the cosmic dust collector, to be developed jointly with the Solar System Research program.

The Materials Sciences program will support the efforts of a large community of researchers to evolve processes and products that exploit the unique characteristics of the microgravity environment and to explore potential applications for commercialization of space. The Materials Sciences program plans to rely on an extensive array of facility-class payload systems to be housed in the Station's pressurized modules and will also rely on an evolutionary development approach. Under consideration are a containerless processing facility, a protein crystal growth facility, a multi-zone furnace facility, a fluid dynamics facility, a biotechnology facility, and a combustion science facility.

The Astrophysics Program plans to make use of the Station's attached payload accommodations, its co-orbiting platform, and its servicing and assembly capabilities. Early candidate attached payloads include the Large Area Multiple Array of Reflectors (LAMAR) and the Solar-Terrestrial Observatory Solar Instruments group. Later candidate payloads include a particle astrophysics magnet facility (Astromag) and the High-Resolution Solar Telescope (HRSO). The Space Infra-Red Telescope Facility (SIRTF) is

a candidate for the first co-orbiting platform payload. The Space Station's servicing capabilities will be used to extend the operational lifetimes of the Hubble Space Telescope and other major astrophysics observatories and to increase the scientific return of Explorers and Spartans through payload change-out.

The Earth Sciences program's top priority will be the use of the NASA and ESA polar-orbiting platforms to establish a comprehensive Earth Observing System (EOS). The Station's attached payloads capability will also be used. Candidate payloads include the plasma physics Plasma Interaction Monitoring System (PIMS) and the Tropical Rainfall Measurement Mission (TRMM) as well as other payloads, many of which will evolve from current Spacelab experiments. Servicing capabilities of the Station and of the Shuttle will also be used to extend operational lifetimes of Earth Sciences payloads.

The Solar System Research community plans to use the Station's attached payload capability, supported by its servicing capability, to fly and maintain two facility-class attached payloads: a cosmic dust collector and a high-resolution, interferometric telescope. These two payloads would be initially developed under Principal Investigator management. Also under consideration is research in the pressurized laboratory module using a 4-cubic meter gas-grain simulation facility developed in cooperation with the Life Sciences Program and using a combination of facilities developed by both the Materials Sciences and Solar System Research communities to conduct basic geosciences experiments.

THE SCIENCE OPERATIONS PROCESS

The successful implementation of these ambitious science plans for the use of the Space Station requires that the end-to-end science operations process be effectively managed. In order to develop management alternatives, the process must be well-understood. The process begins with the development of long-range science goals and culminates with the archiving of science data. The overall set of activities of which the science operations process is comprised can be readily segregated into the following four phases:

(1) Science planning and payload selection;

(2) Payload development and integration;

(3) Science tactical and increment planning; and

(4) Operations and data management.

The science planning and payload selection phase sets the stage for all subsequent activities. It determines the scientific priority of the programs proposed for the Station, ensures that the Station is the optimum site for these studies, and validates the technical approach proposed for the programs. This phase is also critical in securing program funding support and in the allocation of adequate Station resources to support individual science programs. It is during this phase that most international and inter-agency agreements are made on cooperative programs and on the sharing of data or facilities. New instruments and facilities are selected for development to provide the capabilities to conduct the planned science programs. Finally, implementation plans are developed to ensure that the necessary flight and ground systems, including the new science instruments, are available when required.

The payload development and integration phase of the science operations process converts program guidelines and ground rules, established in the science planning and payload selection phase, into action and produces the flight and ground hardware and software systems necessary for operations execution and data processing and analysis. Hardware and software are designed, produced, assembled and checked-out, tested and evaluated, and integrated into the host system. Payload system operational characteristics, requirements, constraints, and capabilities are also established and serve as inputs to the science tactical and increment planning phase.

Science tactical and increment planning is quite comparable to that set of activities referred to as "mission planning" for current Spacelab programs. However, in that there will not be discrete Space Station missions (Station operations will be continuous), the term "science tactical and increment planning" was used to maintain consistency with proposed Space Station terminology (see next section of Executive Summary).

Science tactical and increment planning takes the knowledge gained from the payload development activities and uses that knowledge to develop the detailed plans and procedures necessary for operations execution. Individual science user objectives and priorities are established, associated flight activity and support plans are developed, and these plans are integrated into an overall coordinated science timeline. Crew support plans are developed, and crew training and functionally comprehensive flight simulations are conducted.

The operations and data management phase of the science operations process produces the "payoff" for all of the preceding activities. This phase consists of realtime planning, payload command and control, crew communication and coordination, ground-truth programs, sustaining operations, and the acquisition, processing, distribution, and analysis of science data and samples. These activities enable the Principal Investigators (PIs) and facility developers to demonstrate that they have achieved the planned levels of instrument performance and that this level of performance is adequate to realize the scientific objectives defined for their instruments. A multiplicity of users conducts investigations or experiments with the instruments, under ground control or with the assistance of the crew. Finally, PIs and users alike are provided with the data and samples that they need to conduct their proposed research and produce a bank or archive of data and samples which is available to future researchers in the field.

SPACE STATION SCIENCE OPERATIONS

In order to discuss science operations in the context of Space Station, current Space Station planning must be considered. An overall Space Station operations planning process has been proposed by the Space Station Operations Task Force (SSOTF) established by the Associate Administrator for OSS. The proposed process consists of the following elements:

(1) Strategic Planning: Develops a 5-year plan for the operation and utilization of the Space Station. This is accomplished under the direction of a Multilateral Coordination Board;

(2) Integrated Tactical Planning: Converts the output from strategic planning into a detailed second-level integration plan for the upcoming 2 years. Develops increment payload assignments and Station support requirements, where an increment is defined as the interval between planned Shuttle visits (currently assumed to be 45 days). These payload assignments are, in effect, a Space Station manifest;

(3) Increment Planning: Develops the detailed crew and ground support plans and procedures necessary for the execution of payload and Station operational requirements. An Increment Manager and Increment Support Team are assigned; and

(4) Operations Execution: Provides the realtime planning and operations necessary to carry out the increment plan. Jointly performed by the Space Station Support Center (SSSC) and the Payload Operations Integration Center (POIC).

The science operations process previously discussed can be readily linked with this Space Station operations planning process. The initial linkage between the two processes must take place between the science planning and payload selection phase of science operations and Station strategic planning. This initial linkage takes the form of a coarse allocation of Station resources for the science program being planned and approved. As individual science projects enter the payload development phase, this linkage must become stronger with refined resource envelopes and ultimately with precise interface agreements being defined with the Station. In the respective tactical and increment planning phases of the two processes, many of the activities (such as the development of an overall increment timeline) will become very tightly interwoven. Ultimately, the two respective operational phases of the two processes will blend together into a single unified Space Station science operations process with shared responsibilities.

MANAGEMENT ALTERNATIVES

In order to address OSSA and OSS planning needs and to respond to the Congressional request, a spectrum of alternatives for the management of Space Station science operations was developed. Each individual alternative consisted of a particular arrangement of organizational responsibilities for the management of the different phases of the science operations process. The types of organizations to which management responsibility was assigned included OSSA, individual OSSA disciplines (i.e., divisions), clusters of OSSA disciplines, OSSA sub-discipline offices, NASA field centers, and external NASA-supported organizations (e.g., the Space Telescope Science Institute).

The spectrum of alternatives ranged from NASA's maintaining internal management responsibility for the entire science operations process to NASA's allowing an external organization to assume management responsibility for major portions of the process, with intermediate variations in which certain phases of the process (e.g., payload development) were managed by NASA and other phases (e.g., operations and data management) were managed by an external organization. Each alternative (or option) included sub-options of management at the sub-discipline level, discipline level, or at a clustered discipline level (e.g., Life Sciences with Materials Sciences).

When the various management alternatives were evaluated from a science user perspective, two major discriminators between disciplines became apparent. The first discriminator was the spaceflight experience base of the science disciplines. The traditional space science disciplines of Astrophysics, Earth Sciences, and Solar System Research have decades of spaceflight experience, and their science communities are technically sophisticated and highly organized, with strong traditions of self-reliance for instrument development and of self-government for their use. On the other hand, the Materials Sciences community has only recently entered the space arena and is drawn from a diversity of independent laboratory researchers who work in a number of tenuously connected sub-disciplines. Further, with the extended hiatus in manned spaceflight between Skylab and

the Shuttle and with the limited Life Sciences Spacelab flight opportunities over the past few years, the experience base of the Life Sciences community is closer to that of Materials Sciences than that of the traditional space science disciplines.

The second discriminator between disciplines is the manner in which each plans to use the Station. The two Microgravity Disciplines (Life Sciences and Materials Sciences), which rely most heavily on the Station's pressurized laboratories, plan to use major research facilities (such as centrifuges or furnaces) to support multiple users. Since the different user communities share common Space Station facilities, there is a significant benefit to be derived from a coordinated, centralized management approach to program planning and implementation.

The traditional space science "Observing Disciplines", which primarily plan to use the Station's attached payloads and platforms, can employ a more-distributed approach to the development of their payloads because their operations are not so closely interrelated. Even so, the different sub-discipline communities are now becoming interested in using multiple facilities, and there is increasing demand for coordinated programs and for commonality of user interfaces for operations and data analysis.

The evaluation of the various management alternatives yielded the following conclusions:

(1) None of the initially considered spectrum of alternatives completely described the preferred management approaches of any of the science user communities;

(2) Different science communities preferred different management approaches: Materials Sciences and Life Sciences share a high degree of commonality in their management preferences, while the Observing Disciplines of Astrophysics, Earth Sciences, and Solar System Research share (although to a lesser extent) common preferences for a different management style;

(3) The potential size of some of the larger organizations associated with certain options considered could be excessive. For reference, the Space Telescope Science Institute, with a staff of over 250 people, corresponds to a rather modest option with an

external organization responsible for only the flight operations and data management of a single sub-discipline project;

(4) NASA should continue to manage the in-house development of flight hardware and should continue to procure specific items of both PI-developed and facility-developed hardware against detailed cost, schedule, and performance specifications; and

(5) As long as the number of management interfaces with the Space Station is limited, the Space Station does not need all of the users to follow a single management approach.

Based upon the evaluation of the broad spectrum of management options initially considered and the above conclusions, two reduced sets of preferred management options were developed: a preferred set for the Microgravity Disciplines (i.e., Life Sciences and Materials Sciences) and a preferred set for the Observing Disciplines (i.e., Astrophysics, Earth Sciences, and Solar System Research).

The set of management options for the Microgravity Disciplines is characterized principally by a preference, at least initially, to maintain management responsibility for the complete science operations process within NASA. The capabilities and expertise of external organizations will be utilized for a variety of science operations activities, but this will be done within the framework of NASA management. The Microgravity Disciplines option set places major emphasis on reducing the number of independent interfaces with Space Station through the use of Payload Integration Centers. These centers will represent the interests of multiple groups of users and will serve to focus user inputs to Space Station management. This concept also acknowledges the assumed use of distributed information systems to link these centers electronically with remote users.

The set of management options for the Observing Disciplines reflects a preference to maintain within NASA the management responsibility for the science planning, payload development, and tactical and increment planning phases of science operations. However, the set does include an option in which management responsibility for flight operations and data management is assigned to an external organization like the Space Telescope Science

Institute. External organizations would be involved with the earlier phases of the science operations process, but their activities would be performed within the framework of NASA management control. As with the Microgravity Disciplines, emphasis is placed upon minimizing the number of independent interfaces with Space Station. This is particularly true during the operations phase in which distributed users could be linked to central operations centers which would serve as focused interfaces with the Space Station.

The primary difference between the two sets of options is that the Observing Disciplines prefer to delegate management responsibility to a lower level within the organizational hierarchy than do the Microgravity Disciplines. This difference is a reflection of the disparity in the spaceflight experiences of the two groups and of the much more established and distributed practices of the Observing Disciplines. In general, the Observing Disciplines prefer management at the sub-discipline- or project-level, whereas the Microgravity Disciplines prefer management at the discipline-level.

Both sets of management options assume the existence of a capable and effective science support infrastructure. This infrastructure should include a distributed information system and communication networks with linkage structures among science users, management systems, and the Space Station complex. Since time did not allow a thorough analysis of science support infrastructure needs, it is important that follow-on activities address this matter in detail.

RECOMMENDATIONS

The ultimate success of the Space Station as a multi-purpose scientific laboratory will be dependent upon the effective management of the overall science operations process. The concept of a separate science operations center, serving as a central focus for all science uses of the Space Station, is concluded to be inappropriate for Space Station science operations. This conclusion is based upon the expected diversity of the Space Station science community and the rapidly advancing capabilities of

distributed telecommunication systems. A management system which accommodates a broad range of discipline peculiarities and which is responsive to the needs of the science user should be established in the early stages of Space Station development. In this spirit, the following recommendations are offered for the management of Space Station science operations.

A. Science Operations Management

(1) Each individual science discipline should establish the science operations management structures best-suited to its research activities and community needs and traditions;

(2) Each individual science discipline should assess the advisability of clustering into a single organization the management responsibility for common program activities;

(3) The science operations management activities proposed by the Life Sciences and Materials Sciences communities should be closely coordinated. Appropriate management interfaces with Space Station should be made common, where practical;

(4) Management responsibility for NASA payload development should be maintained within NASA and should not be delegated to an outside organization; and

(5) OSSA should develop strategic and tactical plans for defining requirements for, and the long-term development of, the science infrastructure systems and capabilities needed to support the planned utilization of the Space Station.

B. Management Interfaces with Space Station

(1) OSSA should conduct a review and analysis of the SSOTF proposals, with participation from the science community. The results of this review should be incorporated into future science operations planning;

(2) If possible, OSSA should have responsibility for coordinating and focusing all U.S. science uses of the Space Station. The OSSA Associate Administrator should serve as the single science member of the U.S. Space Station User Board (SSUB). Exploratory

discussions with other Agencies on these matters should be initiated;

(3) An International Space Station User Board (ISSUB) should be established to coordinate the user resource requests of the four international partners. This board should have direct and formal access to the Multilateral Coordination Board; and

(4) The U.S. Space Station User Board and the User Operations Panel and their supporting science functions should be chartered, staffed, and in full operation early enough in Fiscal Year 1988 to meet the present Space Station timetable.

C. Follow-up Recommendations

(1) A Space Station science user's advisory group, comparable to the Task Force on Scientific Uses of Space Station (TFSUSS), should be established and report directly to the OSSA Associate Administrator. This group should be broadly based and provide guidance on scientific utilization and Station evolution;

(2) Formal working arrangements should be established between OSSA and other science agencies (e.g., NBS, NIH, NOAA, NSF, USDA, and USGS). Informal working arrangements between OSSA and user organizations of the international partners should be explored;

(3) OSSA should establish a strong centralized office to act as a focal point for coordination of all OSSA Space Station activities and to provide support services to the science disciplines within OSSA; and

(4) The SSSOMC study should be followed up with an aggressive set of actions to determine, in a substantive manner, the specifics of how Space Station science operations are to be implemented. OSSA, with support from OSS, should make Space Station planning a top priority and within 12 months should produce a comprehensive Space Station Science Utilization Plan.

D. Related Issues and Recommendations

During the course of the SSSOMC study, a number of issues were identified which do not directly impact science management structures but

which are relevant to the implementation of Space Station science operations. Such issues and associated recommendations are included in the main body of this report.

CHAPTER I
PURPOSE

The purpose of this document is to define alternate approaches to the management of Space Station science operations. It has been prepared as a joint NASA Office of Space Science and Applications (OSSA) and NASA Office of Space Station (OSS) activity as a further step in the internal NASA planning efforts and to provide the basis for response to a request from the U.S. House of Representatives' Committee on Science, Space, and Technology.

Recognizing the tremendous potential of the Space Station to support scientific and commercial research and the absolute necessity of setting in place in a timely way the management and technological framework to support such research, the U.S. House of Representatives' Committee on Science, Space, and Technology requested NASA to prepare a report on Space Station Science Operations Management. The request, which was included as an element in a broader statement* on the Role of Science and the Station, reads as follows:

> "It is clear that the successful fulfillment of the Space Station development program will result in a major international science facility in orbit. It is therefore appropriate to consider how science operations will be managed. For example, traditional science institutional approaches which include permanent and visiting scientists, long-term and short-term science program's overall science coordination, and an administrative structure for processing funding proposals may be appropriate for the Space Station. Experience with the Space Telescope Science Institute has demonstrated that such a science operations concept must be established at an early stage if it is to be incorporated successfully. Otherwise, science operational requirements identified late in the development phase may be difficult to implement. Therefore, the Committee requests that NASA submit to Congress a report recommending alternative approaches to science operations management including the practicality of a separate science operations center."

*From the House of Representatives' Committee on Science, Space, and Technology Report 99-829, Sept. 16, 1986.

CHAPTER II
THE APPROACH: SPACE STATION SCIENCE OPERATIONS MANAGEMENT CONCEPTS STUDY

2.1 STUDY CHARTER

To support OSSA and OSS planning efforts and to provide a basis for response to the Congressional request, the Space Station Science Operations Management Concepts (SSSOMC) study, a joint activity of OSSA and OSS, was initiated. Mr. Warren Keller (Chairman), Director of Suborbital Projects and Operations at the Goddard Space Flight Center, and Dr. John Bartoe (Vice Chairman), Space Station Chief Scientist, were assigned responsibility for the study. A Steering Committee was established to lead and focus the activity; its membership is listed in Appendix A. The objective of the study was to develop and recommend "alternative approaches to science operations management, including the practicality of a separate science operations center". Consideration was given to:

(1) Scientific user requirements;
(2) Space Station planning for science operations;
(3) OSSA planning for Space Station science operations;
(4) Science operations of existing national laboratories and science institutes as possible models for the Space Station;
(5) Scientific use by other government agencies such as NBS, NIH, NOAA, NSF, USDA, USGS, etc.;
(6) International plans and agreements; and
(7) Evolution and progress in computer and communications technology.

2.2 STUDY GROUND RULES AND ASSUMPTIONS

In order to maintain the focus of the study activity, the steering committee established the following operating ground rules and assumptions:

(1) Science operations considered were limited to those of the U.S. space science and applications communities sponsored by

NASA, other government agencies, and, possibly, U.S. industry;

(2) The probable collaboration between U.S. scientists and their counterparts from the international partners was considered;

(3) The "science operations" process was assumed to encompass the entire set of end-to-end activities required to conduct scientific investigations on the Station. The process begins with long range science planning and culminates with data archiving;

(4) The currently approved Space Station includes three pressurized laboratories, accommodations for two externally attached payloads, and an associated polar platform. In addition, the basic principle of an evolutionary Space Station was recognized, and ultimate provisions for numerous attached payloads, on-orbit servicing capabilities, and a co-orbiting platform were also assumed;

(5) Science operations were considered for a fully assembled and operating Station (i.e., the study deals with steady state Station operations and not the assembly phase);

(6) There will be intense competition for Station science opportunities and associated funding. Peer review will be an essential element of the science selection process; and

(7) Any NASA institutional re-arrangements for the management of Station science operations will not adversely impact users.

2.3 STUDY PROCESS

The approach employed by the committee was first to characterize the nature of Space Station science opportunities, identify planned science uses of the Station, review current plans for overall Station operations, define in detail activities which comprise the "science operations" process, analyze these science operations activities in the context of Station operations, formulate a spectrum of alternative candidate strategies for the management of science operations, and, finally, to pare the candidates down to a smaller number of preferred alternatives.

In order to expand its base of knowledge and broaden its perspective, the steering committee conducted two science operations workshops, the first at the Wallops Flight Center (July 13-17) and the second at the Goddard Space Flight Center (August 12-14). These workshops provided a forum for inputs from the science community, other government agencies, and Station user representatives from ESA, NASDA (Japan), Canada, and NASA. Special emphasis was placed on participation by scientists representative of the user community outside of NASA. A listing of workshop participants is provided in Appendix A. In addition to the workshops, the steering committee received briefings on the management of science operations for analogous programs (e.g., the NSF Antarctica Program) and other subjects related to science operations (see Appendix B).

2.4 OUTPUT OF THE STUDY

This document represents the principal output of the SSSOMC study. The salient scientific characteristics of the various Space Station elements are identified, and probable utilization scenarios for each of the traditional space science disciplines and emerging disciplines are described. An in-depth treatment and formulation of the science operations process, taken in the broadest sense as the complete set of end-to-end spaceflight activities is provided. It begins with the development of long-range science goals and culminates with the archiving of data. Alternative architectures for the management of this science operations process in the Space Station era are presented, along with a qualitative listing of pros and cons. Recommendations, including a plan of action for the detailed evaluation of the management alternatives and ultimate selection of an optimal management architecture(s), are also presented. In addition, key issues associated with the management of science operations and the general management of Space Station operations are identified.

This document represents the consensus position of the SSSOMC study participants and is intended to lay the groundwork for the detailed planning which must follow in order to conduct science operations effectively on the Space Station. The recommendations included in this

document are offered in the spirit of maximizing the scientific utility of the Space Station and do not take into consideration associated manpower and budget implications. Thorough analysis of such implications must be an integral element of the follow-up activities to the SSSOMC study.

CHAPTER III
BACKGROUND

3.1 STATEMENT OF PROBLEM

The Space Station presents the space science and application communities with unique new research capabilities. Not since the highly successful Skylab program, in the early 1970's, have U.S. researchers had the opportunity to conduct man-tended experiments for extended periods in the microgravity environment of space. This capability is particularly important for the two microgravity research disciplines of Life Sciences and Materials Sciences, where the processes to be studied may be too long or too complex to be completed successfully during the relatively short flights of the Space Shuttle.

The physical space, power, and communications available to house and operate the planned array of Life Sciences and Materials Sciences facilities and the multi-disciplinary attached payloads also provide the Space Station users with a much improved capability over both Skylab and the Shuttle. In addition, the Space Station is designed to evolve in capability over time, providing increasingly exciting and challenging opportunities for scientific research over the projected lifetime of the Station.

These very capabilities can create problems unless NASA devises new operational approaches and employs new technologies to use them. The integrated operational support requirements of the many science and applications facilities and instruments housed on the Station could easily overwhelm the modestly-sized Space Station crew if not supplemented by automation and by direct user operations made possible through introduction of "telescience". The international operations of the Station, coupled with the multiplicity of commercial and scientific investigations planned for the facility, could result in an incredibly complex management interface, "a management nightmare" for the prospective user, unless steps are taken at an early stage to simplify this interface. Both the simplification of the user interface and the concept of "rapid-response

research" should be important aspects of the current Space Station planning efforts.

3.2 SPACE STATION SCIENCE OPPORTUNITIES

The Space Station promises to play a key role in the Civilian Space Program of the 1990's and beyond. The objectives of the program are to provide a permanently manned Space Station by the mid 1990's; to provide useful and affordable capabilities; to design for evolution; to foster the development of automation and robotics; and to incorporate the potential for man-tended activities.

The program will be truly multi-national, with the U.S. ultimately providing the planned dual-keel structure, the habitability module, logistics elements, a laboratory module, the nodes interconnecting the pressurized modules, the flight telerobotic servicer, the platforms, the servicing facility, and the Station's subsystems including power, pointing and control, communications, and data management. The European Space Agency (ESA) will provide a pressurized laboratory module, a polar platform, and a pressurized, man-tended free-flyer; the Japanese will provide an experiment module (JEM) consisting of a pressurized module, exposed facility, and experiment logistics module; and Canada will provide the Mobile Servicing System. The Shuttle will be the primary transportation system.

A phased development of the Station is planned. In the first phase, only the transverse-boom section of the structure will be assembled on-orbit. All of the habitability and laboratory modules (including those of ESA and Japan) will be launched as integrated units, together with the interconnecting nodes and the first phase of the Canadian Mobile Servicing System. The Station will be powered by the solar array portion of the planned power system, and two polar platforms and the man-tended free-flyer will be provided. During the subsequent phase of development, the solar dynamic power system will probably be added, together with the dual-keel and upper and lower booms, the servicing facility, and the co-orbiting platform. Thus, by the end of this subsequent development phase (which is

not yet authorized by the Administration or approved by Congress), the Station should offer four different types of user opportunity:

(1) Pressurized module accommodations, with crew support;

(2) Co-orbiting and polar free-flying platforms;

(3) Accommodations for attached payloads on the external structure of the Core Station; and

(4) A capability to assemble and service free-flying platforms and attached payloads on-orbit.

These opportunities are discussed in more detail below.

3.2.1 Pressurized Modules

Three pressurized laboratory modules provided by NASA, ESA, and Japan will be available for use by science investigators, subject to agreements specified in the Memoranda of Understanding among these partners. The primary users of these modules will be the Microgravity Research communities, including Life Sciences and Materials Sciences, and the modules will be equipped with facilities to support their research. These laboratories will be operated and maintained on-orbit by the Space Station crew and on the ground by development and operations teams and users.

Preliminary assessment of science plans for the Microgravity Research disciplines indicate a possible need to plan quiet and busy Space Station periods and to cluster the investigations by discipline within the Space Station elements. The institutional arrangements proposed by the Space Station Operations Task Force (SSOTF) and the SSSOMC Steering Committee should allow for this approach.

3.2.2 Platforms

The ability to achieve extended operational lifetime through use of on-orbit servicing is an important element of the Space Station's capabilities. However, such servicing requires considerable inventories of spares, tools, and associated support equipment on the ground and in space, as well as special procedures and training.

There is much to be gained from increasing use of common spacecraft components and systems, both to reduce inventory requirements

and to simplify servicing training. For this reason, the international Space Station program is planning to make available two polar platforms and one co-orbiting platform.

Use of free-flying platforms offers the science community the advantage of independent pointing and control, freedom from disturbance by other payloads, a cleaner operating environment, and orbit selection. High-priority OSSA platform candidates are the NASA/NOAA/ESA Earth Observing System (EOS) and the Astrophysics Space Infra-red Telescope Facility (SIRTF).

3.2.3 Attached Payloads

The Space Station will initially offer the possibility of four attach points. In addition, two payload interface assemblies will be provided by the Station for use at any of these points. These assemblies will provide thermal, power, and communications interfaces. A coarse-pointing system will also be provided. The second phase of the Station will provide 20 attach points on the dual-keel, three additional payload interface assemblies, and an additional coarse-pointing system. Additional interface assemblies and fine-pointing systems, such as the Spacelab Instrument Pointing System (IPS), must be provided by the users.

The Station's attached payload capability will be used by space science and applications user communities as a means of conducting numerous programs in Astrophysics, Earth Sciences, Life Sciences, and Solar System Research. It will be particularly useful for large payloads (either large collectors or groups of several complementary instruments) which must be assembled on-orbit or for low-cost flight opportunities which may involve modified Spacelab payloads. The capability will also be used for payloads which require crew control and interaction or need frequent resupply of consumables or reconfiguration of payloads.

3.2.4 Servicing and Assembly

The external servicing and assembly capability, planned to be provided by the mature Space Station, will be used to achieve extended operational lifetimes and operational flexibility for a number of attached and free-flying payloads. In the case of the large free-flyers, like the

astrophysics community's Hubble Space Telescope (HST) or Advanced X-Ray Astrophysics Facility (AXAF), the primary servicing functions will be:

(1) The replacement of degraded spacecraft systems to maintain spacecraft performance;

(2) The replacement of science instruments to maintain state-of-the-art scientific capability for these missions; and

(3) The replenishment of consumables (cryogens and propellants) to maintain operational capability.

Similar requirements exist for the smaller free-flyers such as Spartans and Explorers. However, in this case, additional emphasis is placed upon using the small spacecraft as multi-user, mini-platforms by extending their operational lifetimes and supplying a variety of interchangeable science payloads.

On the other end of the scale, large free-flyers, like the Large Deployable Reflector (LDR), may be transported to the Station in several pieces and assembled on-orbit. This will allow the science community to fly larger instruments than can be accommodated in a single flight of the Shuttle or to launch in segments payloads which cannot withstand the launch and landing environment of the Shuttle in their integrated form.

Free-flyers, serviced at the Station, will be retrieved from orbit by the Orbital Maneuvering Vehicle (OMV), returned to the Station for servicing, and subsequently reboosted using the OMV. The servicing plans for the attached payloads are quite similar to those of the free-flyers; however, in this case, servicing may be done at the attachment point, using a mixture of extra-vehicular activity (EVA) and robotics.

Finally, repair and servicing of Life Sciences and Materials Sciences research facilities and equipment, housed in the pressurized modules, may be accomplished on-site or in a workshop area within the pressurized module. If such a workshop is provided, it may also be used to repair small modules and instruments, belonging to attached payloads and free flyers, which are brought into the Station to be serviced by the workshop.

3.3 SCIENCE USER ORGANIZATIONS

Several different organizations within the U.S., as well as the International Partners, plan to use the Space Station as a base for scientific research. In the U.S., the primary sponsor for such research is the NASA Office of Space Science and Applications (OSSA). Other U.S. government agencies interested in using the Station as a research base include: the National Oceanic and Atmospheric Administration (NOAA), the National Institutes of Health (NIH), the National Science Foundation (NSF), the National Bureau of Standards (NBS), the U.S. Department of Agriculture (USDA), and the U.S. Geological Survey (USGS). Each of the International Partners (ESA, Japan, and Canada) will also sponsor scientific research as well as commercial activities. This study did not consider potential scientific investigations sponsored by NASA program offices other than OSSA or by independent commercial programs.

3.3.1 NASA/OSSA

The Office of Space Science and Applications (OSSA) within NASA consists of five major science divisions. Their represented disciplines are:

(1) Microgravity Research in Life Sciences: including space medicine, operational medical and biological research, and exobiology;

(2) Microgravity Research in Materials Sciences, Physics, and Chemistry: including electronic materials, metals and alloys, glasses and ceramics, biotechnology, combustion, fluid dynamics and transport phenomena, and fundamental research in physics and chemistry;

(3) Astrophysics: including high-energy astrophysics, visible, ultraviolet, and infra-red astronomy, relativity, and solar and heliospheric research;

(4) Earth Sciences: including plasma physics, atmospheric physics, upper-atmospheric research, weather and climate research, ocean and land processes, and geodynamics research; and

(5) Solar System Research: including planetary science, planetary atmospheres, and geoscience.

Most of these disciplines make use of a diversity of space flight opportunities to conduct their research, and all plan to use the Station as a research base. In particular, the microgravity research disciplines of Life Sciences and Materials Sciences both require the presence of humans as operators, subjects, or observers for many of their research activities, as well as needing an extended period of low-gravity or microgravity conditions and significant quantities of electrical power. Thus, for these disciplines, Space Station presents the first opportunity for long-duration research since the Skylab program of the early 1970s.

The OSSA science programs are planned and selected with significant levels of scientific community participation (see Section 4.2). Community advice is provided through a series of external and internal advisory groups such as the National Academy of Sciences (NAS) Space Science Board (SSB) and Space Applications Board (SAB) and the NASA Space and Earth Sciences Advisory Committee (SESAC), Life Sciences Advisory Committee (LSAC), and Space Applications Advisory Committee (SAAC). Community participation also occurs in the peer review and selection of proposals to develop and use flight instrumentation and to conduct archival research using the data sets produced by this instrumentation.

3.3.2 Other Government Agencies

Space Station provides new national facilities for research on, from, and in space. Space Station will open a new era for the biological, physical, chemical, and materials sciences.

NASA is recognized as the national and world leader for research on, from, and in space. For biological, physical, chemical, and materials research in space (i.e., microgravity research), other government agencies have extensive scientific expertise and resource capabilities and are recognized as national and, in many areas, world leaders in the broader aspects of research. Thus, it is important to establish management structures for Space Station that encourage and foster the full and effective utilization of the research ideas, expertise, and capabilities of all agencies for microgravity research on Space Station. If the agencies are to be expected to assign significant human and financial resources to

Space Station experiments, each participating agency must have an equitable role in the selection and prioritization of the experiments. NASA would provide the space transportation and available Space Station facilities for the experiment and would retain responsibility for the allocation of Space Station resources as well as for the compatibility and integration of the experiments with the Shuttle and Space Station.

For Space Station research on, from, and in space, an analogous process could also be instituted. However, in these research areas, NASA is recognized as having the primary national charter, demonstrated expertise, and resources. Any added benefits of a revised management approach for Space Station experiments in these research areas (versus the present management approach of interagency MOUs for specific activities) should be carefully weighed against the added complexities and the possible reduction of timeliness, efficiency, and effectiveness.

3.3.3 International Users

Each partner will select, prioritize, and then manage the development and operations of their user instruments and investigations for the Space Station. Utilization of the Space Station by ESA will be under the auspices of the ESA Director of Space Station and Platforms, and the selection of payloads will be through the various user boards of the member states. The research activities contemplated in Europe include a continuation of their long-term interest in astronomy and astrophysics, as well as their work in solar-terrestrial relationships and planetary exploration. Remote sensing is certainly high on their agenda as shown by the inclusion of a polar platform as part of the Columbus Project which comprises part of the ESA Space Station common elements. Microgravity research forms the backbone of the planned use by ESA of the pressurized volume to be provided in both the module and man-tended free-flyer. Sub-discipline research in all these areas is very similar to anticipated research by the U.S. and may form the basis for cooperative agreements.

The scientific research that Canada plans to pursue on the Space Station will be conducted under the auspices of the National Research Council of Canada. It is expected that they will continue to draw on their

past activities centering on solar-terrestrial physics, aeronomy, and the study of the chemistry and physics of the upper atmosphere. Extensive work has, in the past, been undertaken in the understanding of the ionosphere and the aurora and will probably continue. Interest has been expressed in microgravity research, both in the field of space adaptation and in materials. Canada has performed much of its prior research through cooperative arrangements with the U.S. and others; it is reasonable, therefore, to anticipate that this will continue.

In Japan, the Space Activities Commission (SAC), chaired by the Minister of the Science and Technology Agency of Japan and reporting directly to the Prime Minister, will control Space Station mission requirements and select the Japanese users. While they are relatively new to manned-space science, the Japanese are clearly planning an aggressive science program as demonstrated by the conceptual design of their attached module. This single module will consist of a pressurized portion in which to perform materials and Life Sciences research as well as an exposed portion from which to perform observational research. The materials research will be a follow-on to the work planned for the First Materials Processing Test (FMPT) scheduled to fly on Spacelab in the early 1990s, while, on the exposed portion, one would expect to see a continuation of the excellent X-ray and plasma physics research which the Japanese have conducted in the past. Additionally, the Japanese plan to have a robotic manipulator arm on the exposed portion which will be used not only for instrument changeout but also to test advanced technological programs. Although the Japanese will not launch their own polar platform during Phase One, their scientists have been informally discussing cooperative research in remote sensing on the NASA and ESA platforms.

3.4 SCIENCE DISCIPLINE USERS

3.4.1 Microgravity Research in Life Sciences

The primary objectives of the U.S. Life Sciences program will be to use the unique microgravity environment of the Station's pressurized laboratories and the availability of the crew as operators and subjects to:

(1) Ensure crew health, welfare, productivity, and adaptation in space and upon return to Earth (by resolving questions about the physiological effects of on-orbit operations of durations ranging from months to years);

(2) Provide the capability for an extended human presence in space through the initiation of both basic and applied research;

(3) Develop new knowledge underlying disease processes that may be applied to improving the health of the general population on Earth; and

(4) Conduct basic research to add to the knowledge and understanding of the basic properties of life (i.e., the origin and evolution of life in the Universe).

A variety of facility-class systems located primarily in the pressurized modules of the Space Station will be used to accomplish these objectives. An evolutionary philosophy will be employed for the development of these facilities. The facilities will be built, flown on Spacelab where they will be tested and evaluated, and then modified or upgraded as needed prior to transition to the Space Station. Currently planned facility-class systems include a 1.8-meter variable-gravity centrifuge for conducting biomedical and biological research, a 4.0-meter (or larger) variable-gravity pressurized facility, and a rack-mounted gas-grain simulator facility. An unpressurized attached payload, the cosmic dust collector (to be developed jointly with the Solar System Research program), is also under consideration.

These facilities have been identified on the basis of user community input. Users of the facilities will be solicited and selected through an announcement and peer review process. Additional facilities may be developed as required in response to user demands. These facilities will be complemented as necessary with PI-class instrumentation.

3.4.2 Microgravity Research in Materials Sciences, Physics, and Chemistry

The objectives of the Materials Sciences program are:

(1) To investigate the behavior of materials and fluids and the effect on processes carried out in the microgravity environment;

(2) To provide a better understanding of the effects and limitations imposed by gravity on processes carried out on Earth;

(3) To evolve processes that exploit the unique characteristics of the microgravity environment of space to accomplish results that cannot be obtained in unit gravity; and

(4) To explore and determine potential applications for commercialization of space.

Like the Life Sciences program, the U.S. Materials Sciences program plans to rely heavily on an extensive array of facility-class systems which will be housed in the Station's pressurized modules and will use the same evolutionary philosophy in the development of their facilities. The candidate set of planned facility-class systems includes: a containerless processing facility, a protein crystal growth facility, a multizone furnace facility, a fluid dynamics facility, a biotechnology facility, and a combustion science facility. The Materials Sciences program may, as it matures, transition certain systems to free-flying platforms.

This integrated set of Materials Sciences facilities has been identified with user community input. Users of the facilities will be solicited and selected through an announcement and peer review process. Additional facilities may be developed as required in response to user demands. Unique PI instruments will also be developed to complement these facilities.

3.4.3 Astrophysics

The overall scientific objectives of the Astrophysics Program are to achieve an unprecedented understanding of:

(1) The origin of the Universe;

(2) The laws of physics that govern it; and

(3) The nature and evolution of galaxies, stars, planets, and life.

The Astrophysics Program plans to use the Station's attached payloads accommodations, its co-orbiting platform, and its servicing and assembly capabilities. Emphasis will be placed on providing less-complicated attached payloads for early flight opportunities. Early candidate attached payloads include the X-ray community's Large Area Multiple Array of Reflectors (LAMAR) and the Solar-Terrestrial Observatory Solar Instruments group. Later candidate payloads include a particle astrophysics magnet facility (Astromag) and the High-Resolution Solar Telescope (HRSO). Other attached payloads are expected to evolve from previously flown Spacelab instrumentation.

The Astrophysics community's Space Infra-Red Telescope Facility (SIRTF) will probably be the first co-orbiting platform payload. Like the other Great Observatories (the Hubble Space Telescope (HST), the Gamma Ray Observatory (GRO), and the Advanced X-Ray Astrophysics Facility (AXAF)), SIRTF plans to use the Space Station's servicing capabilities to achieve extended operational lifetime. These capabilities would also be used to service the attached payloads and to increase the scientific potential of the Explorers and Spartans by making them multidisciplinary miniplatforms through scientific payload exchange.

With the exception of major facilities like the SIRTF mirror and cryogenic cooling systems, the Astrophysics Program on Space Station plans to use primarily Principal Investigator (PI)-developed attached and free-flying payloads. These payloads would be solicited by announcement of opportunity and selected by peer review. Once developed, use of the instruments would be made available to a broader spectrum of the community through a guest investigator program, with participation arrangements decided through peer review.

3.4.4 Earth Sciences

The overall objectives of the the Earth Sciences program are:

(1) To increase knowledge and understanding of the physical, chemical, and biological processes on the Earth;

(2) To study the interactive, non-linear processes that govern the behavior of space plasma in the magnetosphere of the Earth and other planets, in interplanetary space, and at the Sun;

(3) To use the space environment as a laboratory for furthering fundamental knowledge of plasma physics;

(4) To determine what changes are taking place in the global environment; and

(5) To achieve a more-complete understanding of the Earth's physical/chemical/biological system.

The international Earth Sciences community primarily plans to use the morning-crossing and afternoon-crossing NASA and ESA polar orbiting platforms as research tools to carry comprehensive payloads of PI-class and facility-class instruments. They will share this Earth Observing System (EOS) with the more-operationally oriented NOAA payloads. Later, additional polar platforms may carry solar-terrestrial payloads since these require slightly different orbital characteristics than EOS does.

Plans also call for use of the Station's attached payload capabilities to fly payloads such as the Tropical Rainfall Experiment and the plasma physics community's Plasma Interaction Monitoring System (PIMS). Many of these payloads will evolve from current and planned Spacelab payloads. The Earth Sciences program also plans to use on-orbit servicing and assembly to achieve extended lifetimes for its science payloads.

Programs will be initiated through an announcement of opportunity to develop PI-class instruments or to participate in the development of facility-class instruments. Subsequent competitions would be held for guest users of the facilities and instruments and for researchers using the data sets generated by them.

3.4.5 Solar System Research

The Solar System Research community currently plans to use the Station's attached payload capability, supported by its servicing capability, to fly and maintain two facility-class attached payloads: a cosmic dust collector and a high-resolution, interferometric telescope. Both of these instruments and any subsequent community attached payloads

would initially be developed as facilities under Principal Investigator management. Facility users would subsequently be solicited and selected using peer review.

The Solar System Research community also plans to use elements of the pressurized laboratory facility to conduct basic research. The Solar System Exploration Division is cooperating with the Life Sciences Division in the development of a 4 cubic meter gas-grain simulation facility and is currently supporting studies to better define the experiments which might be flown in the Space Station era. The Solar System research program is also exploring possible collaboration with the Materials Sciences program in the conduct of basic research in the geosciences. Planetary science investigators might have access to equipment (such as furnaces) provided by the Materials Sciences program, while materials scientists might have access to miniaturized equipment originally developed for flight opportunities on planetary missions.

3.5 SPACE STATION OPERATIONS PLANS

Science operations, although a primary Station activity, will be but one of several aspects of overall Station operations. Station operations must also support commercial applications, technology developments, Station housekeeping and maintenance, Station evolution, and, of course, crew health and safety. Space Station operations will draw upon the combined space flight experience of NASA and its international partners. Lessons learned from the Skylab, Shuttle, and Spacelab programs, as well as the major unmanned science observatories and planetary probes, will help shape Space Station operational practices. However, these experiences, taken collectively, fall short of the operational challenges which will be brought forth by the Space Station. These challenges include the following:

(1) Permanent operations
- Long-term on-orbit servicing and maintenance
- Multiple large-scale activities

(2) Multi-partner international involvement

- Resource sharing
- Cost sharing
- Multiple operations infrastructures

(3) Evolution

- Capability expansion flexibility
- Utilization flexibility
- User and crew autonomy
- Partnership flexibility over time

(4) Emphasis on reduced operating costs

Given the significance of the shortfall in operational experiences, the Associate Administrator for the Office of Space Station established a Space Station Operations Task Force (SSOTF) in September, 1986 to lay the preliminary groundwork for an integrated management approach to Space Station operations planning. The SSOTF activity (which included participation from within and outside of NASA) is nearing completion. The report will include a proposed end-to-end operations control concept and an operations management structure with defined organization roles and missions.

A thorough analysis of the SSOTF report has not yet been possible, and the detailed implications to science users are not fully understood. However, the proposed Space Station operations control concept does provide an appropriate backdrop against which alternative science operations management concepts can be evaluated. Therefore, the following overview is provided, based on the SSOTF concept, international MOU considerations, and current OSS plans.

3.5.1 Space Station Operations Control Concept

The operations control process will be led by NASA but will be international in scope with full participation by each of the international partners. The process will consist of four stages: strategic planning, integrated tactical planning, increment planning, and operations execution. Figure 1 presents a simplified flow diagram of the process.

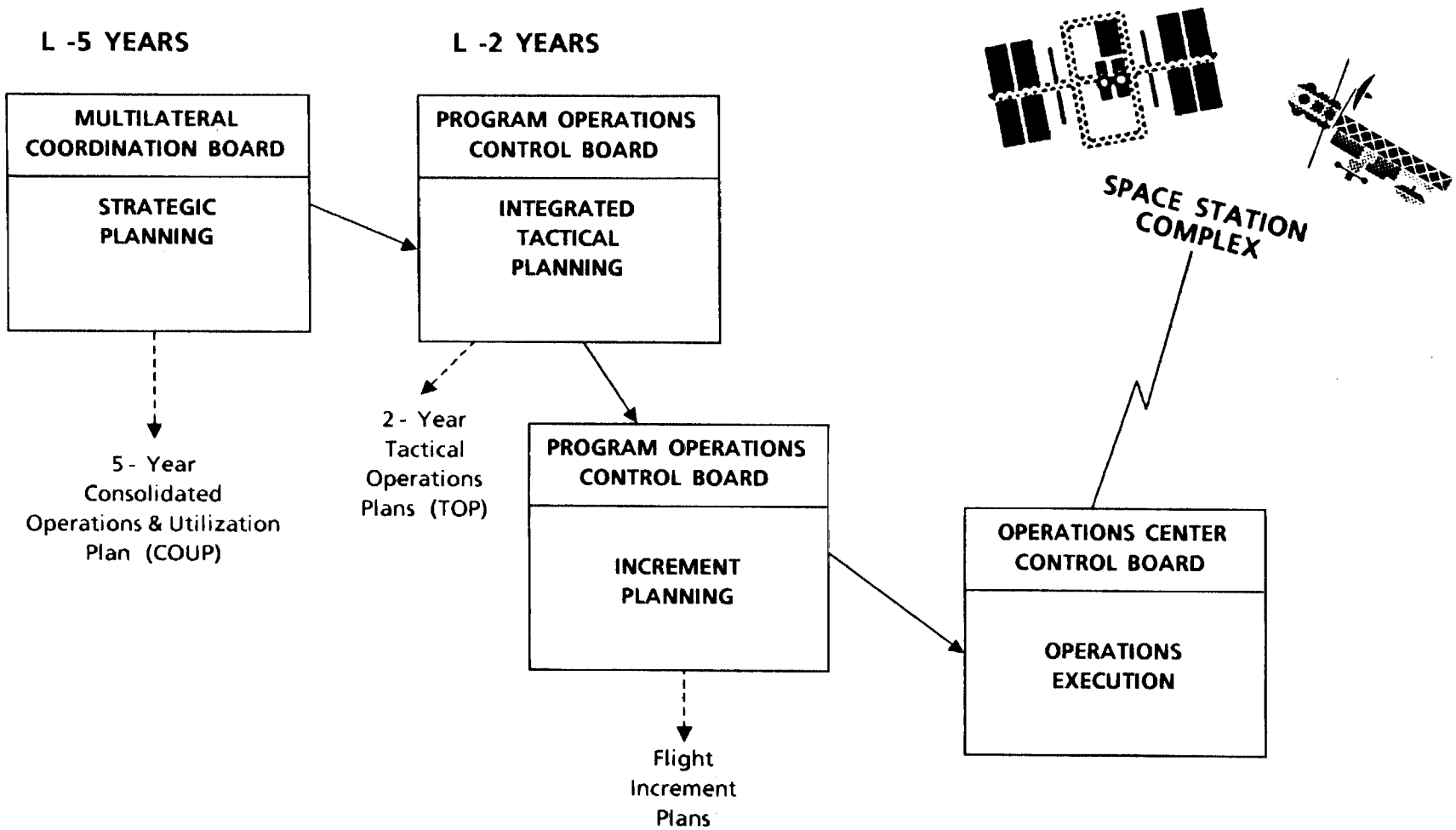

Figure 1. Space Station Operations Control Concept (SSOTF Proposal)

3.5.2 Strategic Planning

Strategic planning will be under the control of a Multilateral Coordination Board (MCB) with representative membership from NASA, ESA, Japan, and Canada. The primary task of the MCB will be to approve the Station utilization plans and system operations plans and deliver them to the tactical planning level. Utilization plans from the four international partners will first be submitted to the MCB's User Operations Panel (UOP), again with membership from NASA, ESA, Japan, and Canada. The UOP will be responsible for identification and resolution of technical or operational incompatibilities between the proposals prior to submittal to the MCB. The flow of information and relationships of these groups is depicted in Figure 2. The organization and detailed workings of the U.S. Space Station User's Board have not yet been formulated.

The MCB will operate by consensus of the International Partners, with the NASA chairman making decisions in instances where a consensus can not be reached. The principal product of the strategic planning process will be a five-year Consolidated Operations and Utilization Plan (COUP) which will be updated annually. The COUP will include:

(1) A five-year Station and user resource allocation plan which outlines what proportion of Station resources will be dedicated to users and what proportion will be dedicated to Station operations and housekeeping.

(2) A list of selected users with year and priority assignments. This list constitutes the current users who have not, as yet, been manifested or assigned a flight increment. This list is primarily for the use of the tactical operations functions which will determine who flies on what increment.

(3) A list of major Station capability enhancement plans. This list describes the current plans for enhancement of the Station payload handling capabilities. Just as the user list describes the overall allocation of the resources to the user community, this list describes the overall

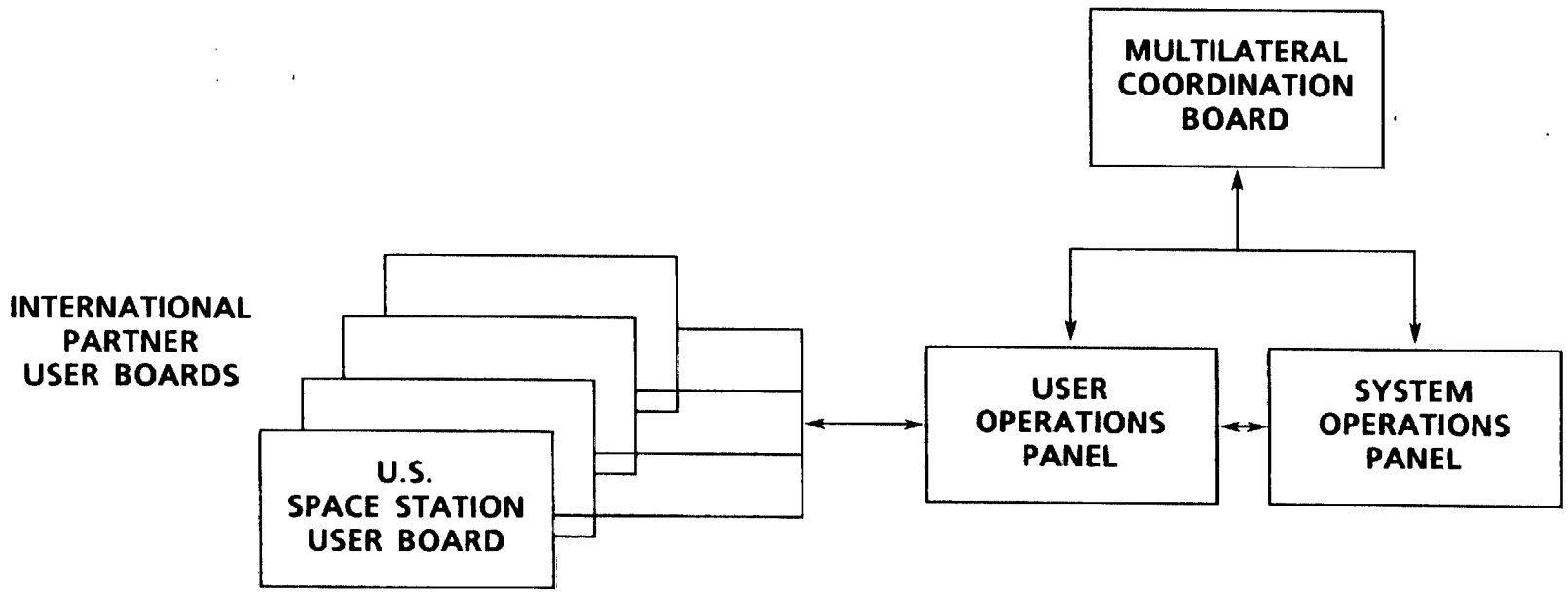

Figure 2. Space Station Strategic Planning Control

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allocation of Station resources for the improvement of the capability of the Station to accommodate users.

(4) A five-year transportation plan which includes projected launches of the Space Shuttle and ELV's supporting Space Station transportation needs.

3.5.3 Tactical Planning

The tactical planning stage performed for a two-year horizon will convert the COUP into a much more detailed second-level integration plan. Planning is performed in units of flight increments, where an increment is taken as the nominal interval between Shuttle visits to the Station. This time period is driven by crew change-out and is currently planned to be 45 days (i.e., one-half of the 8-person crew will be changed every 45 days). Tactical planning will be performed under the direction of the Program Operations Control Board, and the principal product will be a Tactical Operations Plan (TOP) to be updated at the beginning of each new increment. Typical TOP products will include:

(1) Incremental payload assignments and allocated resources;

(2) Incremental crew skill requirements and number;

(3) Transportation vehicles, schedules, and mass/element assignments;

(4) Incremental Station activity assignments including maintenance, modifications, and test and checkout activity; and

(5) Logistics assignments and up/down manifest.

3.5.4 Increment Planning

The most-detailed planning activities take place as part of the increment planning process which is initiated two years prior to the beginning of the increment in question. For each increment listed in the TOP, an Increment Manager is assigned along with an increment support team consisting of the following individuals:

Increment Support Team

Space Operations

1. Increment Flight Director
2. Payload Operations Director
3. Payload Accommodation Managers
4. Flight Control Teams (SSSC and POIC)
5. Crew
6. Data Management Manager

Ground Operations

1. Launch Site Support Manager
2. Logistics Support Manager
3. Ground Processing Support Team

Increment Staff

1. Critical Path Scheduling Support
2. Administrative Staff

The Increment Manager has overall responsibility for increment planning and implementation. Payload Accommodation Managers (PAMs) serve as single points-of-contact for individual users.

The Flight Increment Plan includes:

(1) Launch site processing plans for Station elements and payloads;
(2) Milestone schedules for accomplishment of increment activity;
(3) Crew and Flight Controller training plans;
(4) Crew activity plans;
(5) Payload-to-Station ICDs; and
(6) Station and payload systems checklists.

The Flight Increment Plan, which will evolve over its two-year life, serves as the central source of direction to the Station execution organization.

3.5.5 Operations Execution

Space Station user operations are, quite naturally, still in the formative planning stage. Ground operations support and flight operations

support will rely strongly on the experience gained from the Shuttle and Spacelab programs. Operations execution will be the joint responsibility of the Space Station Support Center (SSSC) and the Payload Operations Integration Center (POIC). The SSSC will have responsibility for realtime Station systems planning and operations (including realtime resource allocations) while realtime user planning and operations will be the responsibility of the POIC. It is intended that the SSSC and POIC function in a coordinated manner to deal with resource allocations, logistics, space operations, and data systems operations. Fundamental goals will be to maintain a safe and consistent environment for the execution of crew operations and to maximize the return of user payload operations.

It is anticipated that the POIC will be supported by investigator working groups (IWGs). Some IWG representatives will be located at the POIC, but the majority of science users will be electronically linked to the POIC, either directly or via an intermediate science operations center.

CHAPTER IV
SCIENCE OPERATIONS

4.1 INTRODUCTION

In order to address the management of "science operations", it is necessary first to reach an understanding of the scope of the activity. This can best be done by identifying the various functional processes and activities of which science operations is comprised. As previously stated, for the purpose of this study, science operations is taken to encompass the complete set of end-to-end activities associated with a space science program. These activities may be organized into the following four functional phases:

(1) Science Planning and Payload Selection;

(2) Payload Development and Integration;

(3) Science Tactical and Increment Planning; and

(4) Science Operations and Data Management.

The following sections of this report describe each of these functional phases.

The integrated set of activities presented is intended to be a general description of the science operations process. For clarity, Space Station interfaces are shown, where appropriate; however, the process could be applied to other types of science missions as well. For the purposes of this presentation, no discrimination is made between facility-class and PI hardware, nor are the peculiarities of individual science disciplines addressed. The ordering of the activities maintains a sense of chronological consistency, but many of the activities discussed may take place concurrently rather than serially.

4.2 SCIENCE PLANNING AND PAYLOAD SELECTION

4.2.1 Overview

The first phase in the science operations process is science planning and payload selection (see Figure 3). This phase sets the stage for all subsequent activities. It includes activities which determine the scientific priority of the programs proposed for the Station, ensure that

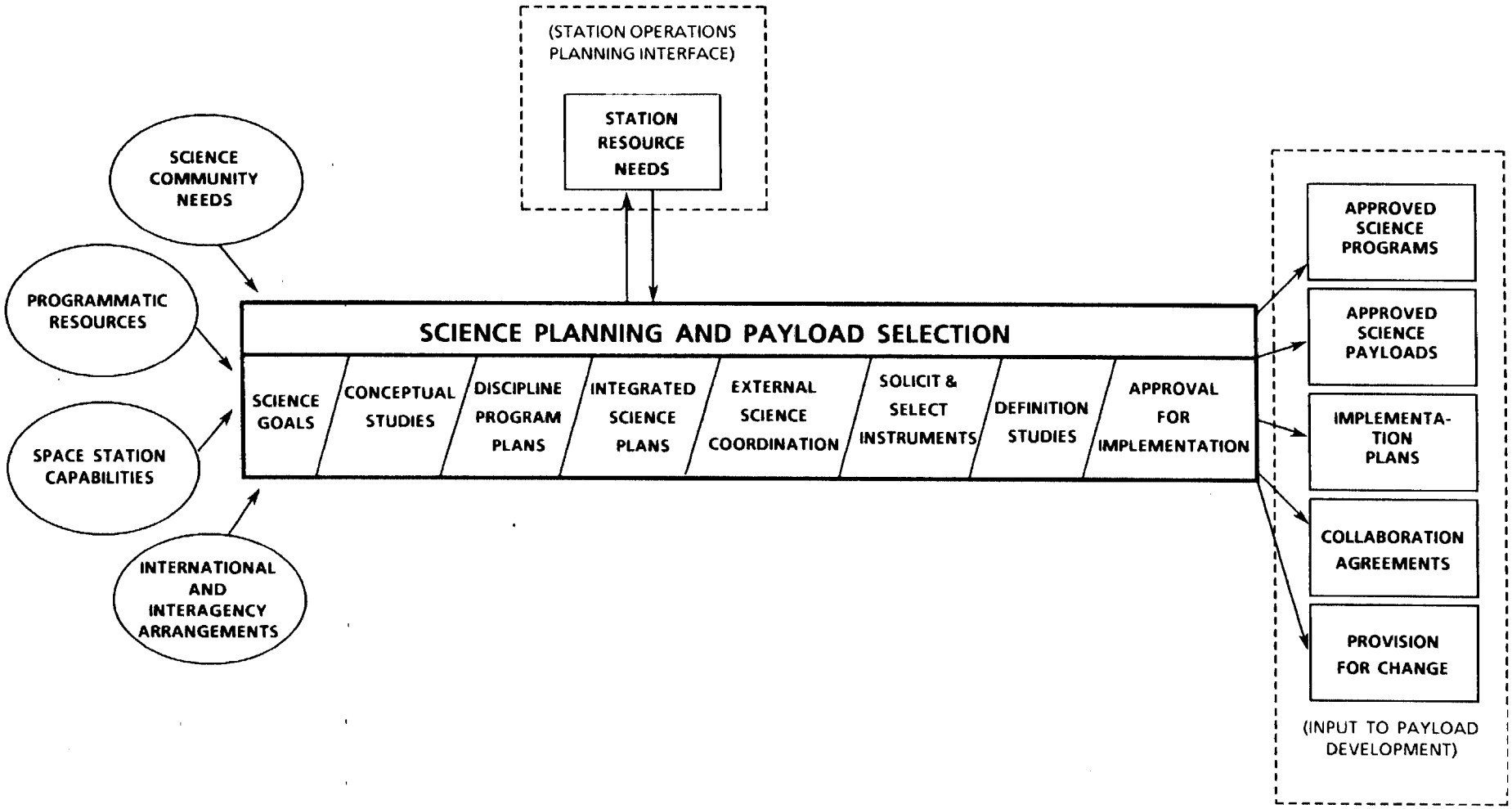

Figure 3. Science Planning and Payload Selection

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the Station is the optimum site for these studies, and validate the technical approach proposed for the programs. This phase is also critical in the development of the rationale for the request of funds to develop, operate, and maintain the planned instruments and facilities and in the allocation of adequate Station resources to support them.

It is during this phase that most international and inter-agency agreements are made on cooperative programs and on the sharing of data or facilities. Requirements are also identified for new ground systems, new data systems, new standards, or for modifications and upgrades to existing flight systems, including those that are part of the Station itself. New instruments and facilities are selected for development to provide the capabilities to conduct the planned science programs. Finally, implementation plans are developed to ensure that the new and modified flight and ground systems, including the new science instruments, are available when required.

4.2.2 Guidelines

Three major factors guide the development of science plans for space science and applications research and the selection of investigations to support these plans. As indicated in Figure 3, these factors are:

(1) The needs and desires of the space science and applications communities and the scientific priorities of their programs;

(2) The availability of funds and manpower to develop, operate, and maintain the space flight hardware and supporting ground and space systems needed to conduct this research; and

(3) The ability of the Station, its management, and its supporting systems (e.g., Shuttle and the Tracking and Data Relay Satellite System (TDRSS)) to support the planned research on a timely basis.

Other factors which strongly influence the planning process are:

(1) The agreements made between the Station management and its four International Partners, particularly where they overlap with interdisciplinary agreements of users at the working level; and

(2) The international or interagency agreements already existing between the U.S. and international science users of the Station.

Payload selection shares many of the same groundrules. Funds and resources should be available to support the planned research (or should be highly probable) before payloads are selected for detailed design and development. The scientific objectives of the payload should have received approval and endorsement from the appropriate scientific communities using the Station, and all international and interagency agreements pertaining to the development and use of the payload should be in place. In addition, sufficient information should be known about the host environment of the payload, whether it be the Station or a platform, so that the technical approach proposed for the payload elements can be adequately evaluated.

4.2.3 Activities

The basic elements of the science planning and payload selection phase are shown in Figure 3. The first step in the process is the establishment of science goals for the U.S. civilian space program. These goals are established by the various space science and applications research communities which use space as a vantage point from which to make observations or which require the space environment as a research tool. The goals are formalized by the OSSA Division Directors and their counterparts in the other participating government agencies who represent the various space science and applications disciplines into which the communities may be divided. They provide the basis on which to build international and inter-agency agreements which may lead to cooperative programs.

Once the goals have been established for the various disciplines, programs can be defined which contribute to their realization. A strategic plan can then be laid out which places these programs in some logical sequence. This generally requires some understanding of how the programs may be implemented. Conceptual studies are, thus, conducted to determine the scientific and technical approaches which may be adopted for each of the programs, to identify technical challenges which must be overcome, and

to estimate rough order-of-magnitude costs for these options. Once these studies have been completed and the feasibility of one or more approaches has been determined, the disciplines may develop their strategic program plans.

An integral part of this planning process is the identification of international and inter-agency opportunities for coordination or cooperation. Other international programs which may duplicate or rival the planned U.S. initiatives are also identified, and their potential impact on the plans is assessed. The priorities and timeliness of each element of each plan are considered, and the impact of advanced technology requirements is determined. Integrated program resource requirements are also estimated, including development and operating funds, civil service manpower, and Shuttle, Expendable Launch Vehicle (ELV), Tracking and Data Relay Satellite System (TDRSS), and Space Station support requirements. Finally, to be successful, the resulting discipline plans should take into account NASA and national interests and those of other U.S. government agencies.

Once each discipline has established its strategic plans, these are integrated into an Office of Space Science and Applications (OSSA) Plan. Other agencies participating in the program have a similar integration process. Such an integrated planning process provides NASA and its sister agencies with early visibility into the funding levels required to support the planned programs. It enables the Agency to review and revise its plans for long-term Shuttle, ELV, TDRSS, and Station support, to project its facility and manpower needs, and, hence, to assess the programmatic feasibility of the total program proposed.

The planning process enables NASA to formalize the proposed international and inter-agency agreements and to negotiate and establish budgetary responsibilities for the various program elements. It also provides the necessary input to the Space Station 5-year planning process, enabling OSSA to request and be allocated the Station, Shuttle, and TDRSS support required to conduct the Space Station-associated portion of the program. Both the OSSA and the Space Station plans made at this time have

to remain flexible so that they can respond to new scientific imperatives or to changes in budgetary situations, community priorities, or support capabilities.

Once a program is an accepted element in the OSSA strategic plan, it must be defined in sufficient detail that the next formal steps in the development process may be taken. First, responsibility is assigned for the subsequent design, development, and operations phases. Proposals are then solicited from the scientific community for instrument development and scientific investigations, where appropriate. The Announcement of Opportunity (AO) is the vehicle most frequently used to solicit investigations which include science instrument development or provision of guidance in the design and development of major facilities. Because of the fierce competition for such opportunities, scrupulous care is taken to protect the proprietary rights of the proposers during and after the proposal evaluation and selection process. Care is also taken to ensure that the scientific evaluation of the proposals is fair and is of the highest quality possible. Typically, the evaluation is undertaken by peers of the proposers who have no conflict of interest in the selection process. Technical and management reviews of the proposals are also conducted by government experts.

Once the proposal's scientific, technical, and management reviews are complete, the managers of the program prioritize the proposals and assemble a payload which is technically feasible, achieves the scientific objectives of the program, and remains within the established budget and schedule constraints. The payload is reviewed once more, as a total package, by government technical experts to ensure compatibility with all supporting systems (flight, transportation, and ground) prior to final approval of the selected investigations.

Feasibility and preliminary design studies (Phase A/B) are conducted, both for the supporting systems and for the payload elements or facility elements selected as a result of the AO competition. Scientists selected in this competition to develop scientific instruments conduct preliminary design studies of their proposed instruments in parallel with

the government's study activities. They also, generally, form science (or investigator) working groups (SWGs or IWGs) which provide the government study team with expert scientific guidance throughout the study process. Together, the government team and SWG evaluate technical options and assess technical risks for the total program. The government study team also confirms the methods of implementation and support proposed for the program and develops detailed resource requirements, including allowance for program contingencies.

Finally, when the details of the program have been defined and a plan for its implementation has been developed, it is presented for inclusion in the OSSA implementation plan. The funds necessary for program development may be obtained from an existing budget line item or as the result of a request for funding as a "new start" in NASA's annual budget process. Once funds have been approved, the detailed design and development of the program (Phase C/D) can start.

4.2.4 Outputs

The outputs of the science planning and payload selection process include:

(1) A scientifically excellent, community-endorsed, and Agency-approved plan for science on the Station and elsewhere in space for the next five to ten years;

(2) Scientific payloads, selected by peer review, whose capabilities satisfy the established scientific goals of their disciplines and whose technical and management approaches, development costs, and schedules of availability, are approved by NASA;

(3) Technically sound plans for the implementation of all of the program elements which constitute the plan;

(4) Signed and sealed Memoranda of Understanding (MOUs) or Memoranda of Agreement (MOAs) among all participating international and inter-agency partners; and

(5) Provision for moderate changes to the plan, including the late addition of modest, short lead-time investigations.

4.3 PAYLOAD DEVELOPMENT AND INTEGRATION

4.3.1 Overview

The payload development and integration phase of the science operations process converts program guidelines and groundrules, established in the science planning and payload selection phase, into action and produces the flight and ground hardware and software systems necessary for operations execution. Payload system operational characteristics, requirements, and capabilities are also established and serve as inputs to the tactical and increment planning phase. There is an extremely strong coupling between payload development and science tactical and increment planning, with considerable overlap in the skills and knowledge needed to support both sets of activities. While, for the purposes of presentation, this document treats the two sets of activities serially, they actually overlap in time and should not be viewed as independent and separable activities. Figure 4 depicts the inputs to payload development and integration, the activities of which it is comprised, and the outputs of the process.

4.3.2 Guidelines

The payload development and integration phase of the science operations process requires the collective creativity and inventiveness of a highly competent team of scientists, engineers, and managers. This creativity and inventiveness must, however, be realized within a well-defined set of boundary conditions. The boundary conditions consist of the guidelines and constraints resulting from the decisions, plans, and agreements developed in the science planning and payload selection phase as well as the programmatic realities with which approved programs are confronted. First and foremost, the performance of the payload hardware and software systems must support the science objectives of the selected and approved payloads. These objectives are the soul of the program which have withstood the scrutiny, and have captured the endorsement, of the science community through the peer review process. The ambitiousness of such objectives invariably produces extremely difficult technological development challenges. Systems must be made compatible with available

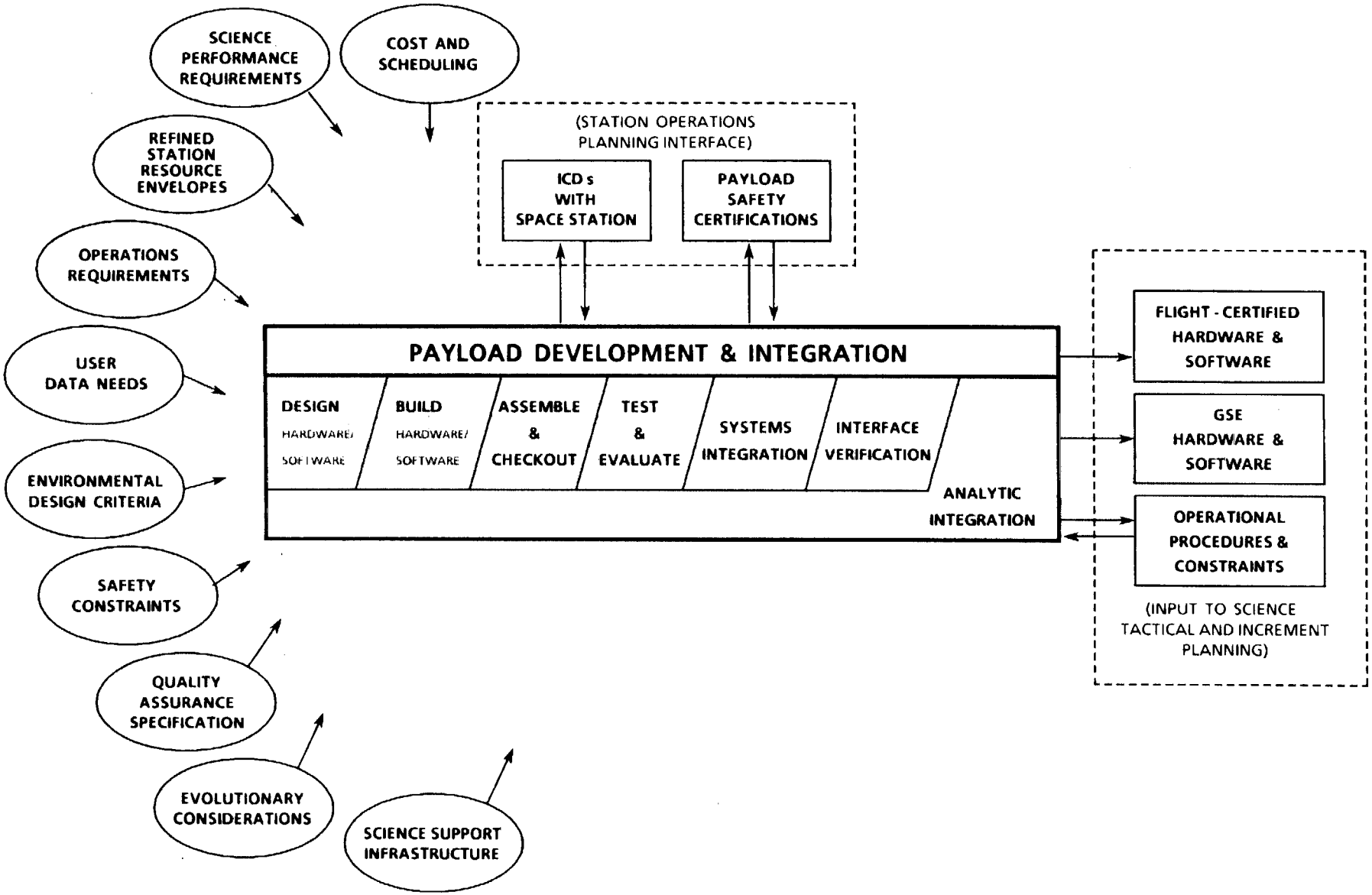

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Figure 4. Payload Development and Integration

resource envelopes for weight, volume, power, data rates, etc. provided by the host system (i.e., Space Station). User data needs and operational requirements (e.g., telescience) must be accounted for in the initial stages of development. Science infrastructure capabilities and characteristics such as information systems and communication networks should be incorporated into the design of flight and ground systems. The ability to withstand the environmental conditions to which the payload will be subjected (e.g., vibration, temperature, electromagnetic interference, particulate contamination, etc.) must be engineered into the payload. The payload must also be made consistent with safety constraints and quality assurance and reliability requirements. Finally, of particular importance in the Space Station era, the payload design must allow for evolutionary growth necessary to support long-term science needs.

All of these challenges must be met within programmatic constraints. The budgets and schedules output from the science planning, program design, and payload selection activities often appear naive when confronted with the real challenges of payload development. Consequently, the payload development and integration phase is frequently characterized by continual trade-off analyses aimed at balancing the opposing requirements of scientific and technical performance on one hand and cost and schedule performance on the other.

4.3.3 Activities

The initial activity of the payload development and integration phase is the detailed design of hardware and software systems. The design activity must provide not only for flight systems but also ground support systems required for test, integration, and operations. Design products include detailed engineering drawings, equipment lists, parts and materials lists, data management flow diagrams, a hierarchy of payload command structures, data and telemetry formats, and software protocols.

With these design outputs, the hardware and software can now be produced. Engineering drawings are used to fabricate hardware, equipment and parts are procured, and software designs are converted into lines of code. Next, individual elements are assembled into payload sub-systems,

and functional checkouts are performed. After basic functionality is verified, more involved testing and evaluation, such as simulated environmental exposures (e.g., vibration, thermal vacuum, etc.) is performed. If failures occur, design modifications are developed, and the process is repeated. Once the integrity of the various payload subsystems has been demonstrated, payload systems (i.e., all-up instrument-level) integration is performed. Dependent upon the nature of the payload, additional testing and evaluation may be required at this point. Next, payload-to-host interface compliance is verified. Options for demonstrating compliance range from connecting the payload to a "suitcase simulator" (which merely mimics interface connections) to actual installation into a high-fidelity mock-up with interface connections and interface functionality.

Analytic integration is the linkage among the various activities within payload development and integration and between these activities and subsequent functional phases of the science operations process. Analytic integration consists of the entire set of supporting analyses (e.g., coupled loads analysis) and documentation (e.g., the Payload Integration Plan) necessary for user compliance with the management and technical requirements of the Space Station management control system.

4.3.4 Outputs

The payload development and integration phase produces the detailed technical information and payload data necessary to begin merging the science operations and Station operations processes. The payload data, coupled with the corresponding Station payload accommodation data, produce a set of Interface Control Documents (ICDs) which collectively represent the engineering contract between the payload and the Station. The payload data (i.e., design features, test results) also are used to provide verification of compliance with Station safety requirements, a major milestone in the overall Station utilization process. However, the principal products of the payload development and integration phase are flight- and ground-based hardware and software systems, certified ready to support flight operations. Operational capabilities, constraints, and

requirements of these hardware and software systems are suitably defined for the science tactical and increment planning phases of the science operations process. Additionally, science infrastructure support requirements are defined and levied on the science organizations responsible for the development and operation of such systems.

4.4 SCIENCE TACTICAL AND INCREMENT PLANNING

4.4.1 Overview

The science tactical and increment planning phase of the science operations process is quite comparable to that set of activities referred to as "mission planning" for current Spacelab programs. However, in that there will not be discrete Space Station missions (Station operations will be continuous), the term science tactical and increment planning is used to maintain consistency with Space Station terminology (see Section 3.5.3).

The tactical planning portion of this phase consists of the development of top-level program strategies pertaining to payload priorities and related manifest decisions. These strategies, developed in concert with Space Station considerations, yield compatible groupings of science payloads and specific increment assignments for these payloads. The increment planning portion of this phase takes the knowledge gained from the payload development activities and uses that knowledge to develop the detailed plans and procedures necessary for increment operations execution. Figure 5 depicts the inputs to science tactical and increment planning, the activities of which it is comprised, and the products of those activities.

4.4.2 Guidelines

Science tactical and increment planning should yield plans and procedures which satisfy the payload science objectives. These objectives were formulated during the science planning and payload selection phase but often require further refinement, given knowledge of actual payload performance gained from payload development. Planning must account for the data needs of the science user and should directly reflect the

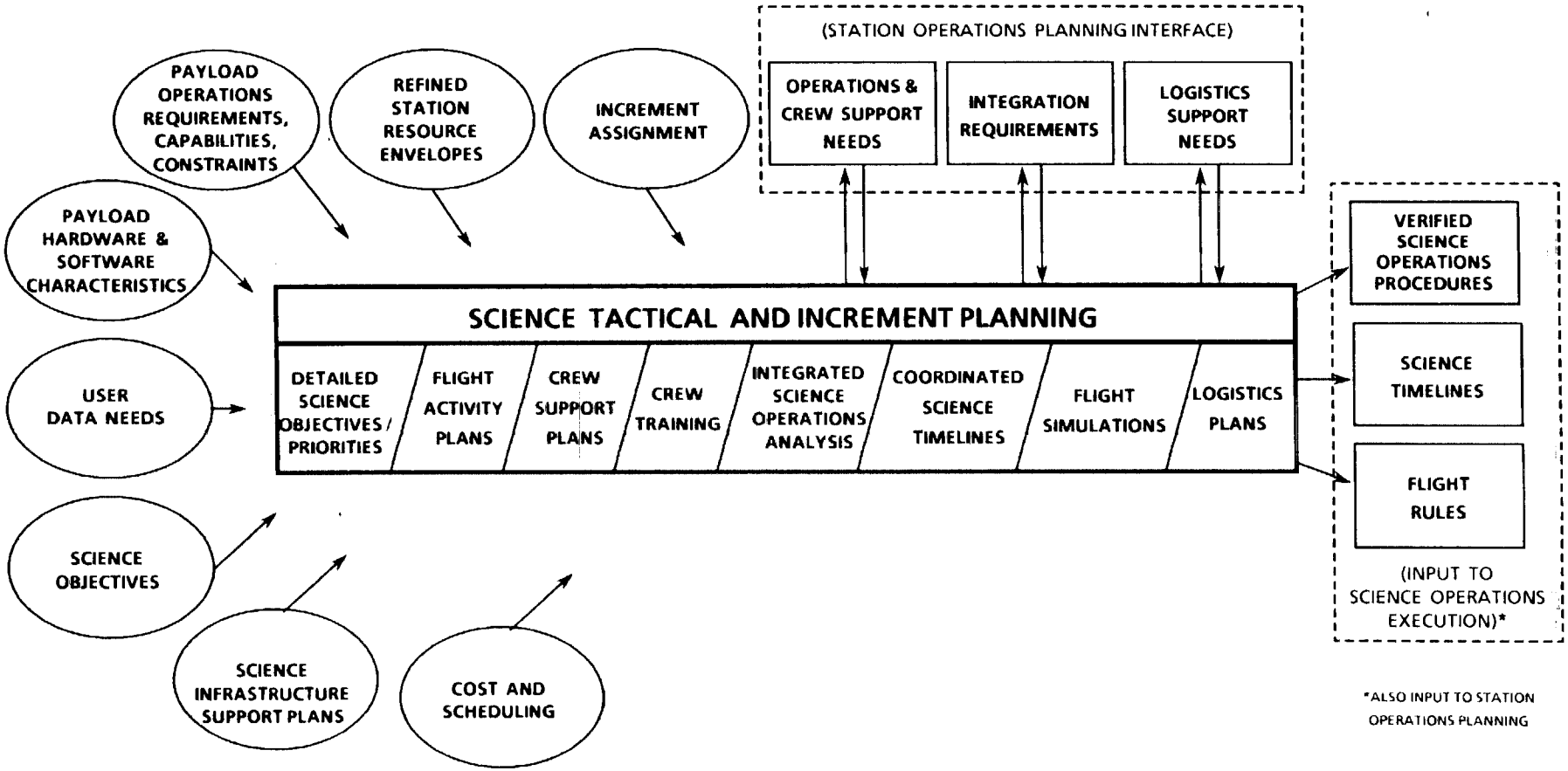

Figure 5. Science Tactical and Increment Planning

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characteristics of the payload hardware (e.g., power requirements) and software systems (e.g., command protocol). Payload operational requirements, such as the need for telescience for the pointing control of an Earth-viewing camera or the need for real-time video in support of a materials science experiment, must be accommodated and satisfied by science increment planning. The operational procedures developed in increment planning must consider, in great detail, the specific Station resources which can be made available as a function of time. For example, on-orbit operations should be consistent with crew availability and should also be compatible with the mix of skills and training levels within the crew. Increment planning must also be based upon the availability of the supporting science infrastructure and the shared use of these systems with other on-going and future science programs.

In addition to this multiplicity of guidelines and constraints, science tactical and increment planning must be accomplished in accordance with the schedule and available budget. These resource allocations were initially established in the latter stages of the science planning and payload selection phase and may have been adjusted during development and testing based on programmatic problems and tradeoffs made during that phase.

4.4.3 Activities

The initial activity of the science tactical and increment planning phase is the refinement of broad program objectives into detailed objectives for each science investigator. A clear understanding of the minimum science objectives for each investigator must be developed. Relative science priorities also need to be established in order to facilitate science trade-off analyses. Given the probable multi-disciplinary nature of the science objectives and the diversity of sponsoring organizations which are apt to be involved, prioritization will be a technically and politically complex task. This prioritization, in conjunction with available Station opportunities, is used as the basis for manifest decisions. These decisions are coordinated with the Space Station tactical planning organization and are iterated as necessary to develop specific and compatible payload increment assignments.

Next, detailed flight activities plans are developed for each of the payloads assigned to a particular increment. Examples might include a prescribed crew exercise program coupled with cardiovascular measurements for a Life Sciences experiment or a specific program of celestial observations for an astrophysics telescope. Crew support required for the execution of the activity plans are identified and negotiated. A program of crew training must be formulated and executed to ensure adequate knowledge and understanding of science objectives and proficiency in the operation of payload systems.

The individual flight activities plans, crew support requirements, and prioritized objectives are collected, organized, and analyzed in an integrated fashion in relation to available resources. If the aggregate set of plans and objectives cannot be captured within available resources, individual activity plans must be reworked and descoped, as necessary. This process, which is apt to require several iterations, will ultimately yield an overall coordinated increment timeline of science operations.

Verification of flight operations plans and procedures is best demonstrated with a program of pre-mission flight simulations. The greater the fidelity of the simulation and the greater the extent to which all functional elements of the end-to-end system are exercised, the better the verification. A well-structured program of flight simulation is also crucial for developing techniques and groundrules for dealing with on-orbit contingency situations. Spacelab experience has clearly demonstrated the need for pre-defined "flight rules" for dealing with anomalous conditions.

Concurrent with the planning activities discussed above, plans must be developed to accommodate payload logistics needs. Such needs include transportation to and from the Station, sparing and associated stowage on the Station, in-flight servicing and maintenance, and post-flight storage and/or refurbishment.

4.4.4 Outputs

The principal products of the science tactical and increment planning phase are detailed operations procedures on an increment-by-increment basis. These procedures describe the step-by-step actions

required of the crew and ground support teams to implement the precise payload command and control sequences needed to satisfy the science objectives. Taken as an integrated set, these procedures yield an overall coordinated and unified timeline of science operations. Another significant product of science increment planning is a set of flight rules which prescribe the groundrules for dealing with anomalous and contingency situations, thereby simplifying the real-time decision and replanning process.

These products set the stage for operations execution and are ready for handover to the responsible execution organizations. As with the relationships among other phases of the science operations process, this can not be a blind hand-off. A continuity of knowledge and skills must be maintained between science tactical and increment planning and operations execution.

4.5 SCIENCE OPERATIONS AND DATA MANAGEMENT

4.5.1 Overview

The operations and data management phase of the science operations process produces the "payoff" for all of the preceding activities. It enables the Principal Investigators (PIs) and facility developers to demonstrate that they have achieved the planned levels of instrument performance and that this level of performance is adequate to realize the scientific objectives defined for their instruments. This phase facilitates the long-term operation of these instruments through ground return and refurbishment or through on-orbit maintenance and servicing. It enables a multiplicity of users to conduct investigations or experiments with the instruments, under ground control or with the assistance of the crew. Finally, PIs and users alike are provided with the data and samples that they need to conduct their proposed research, and a bank or archive of data and samples (available to future researchers in the field) is produced.

Figure 6 shows the complete range of activities of which the phase is comprised, together with the inputs and outputs of the process. These will be discussed in more detail below.

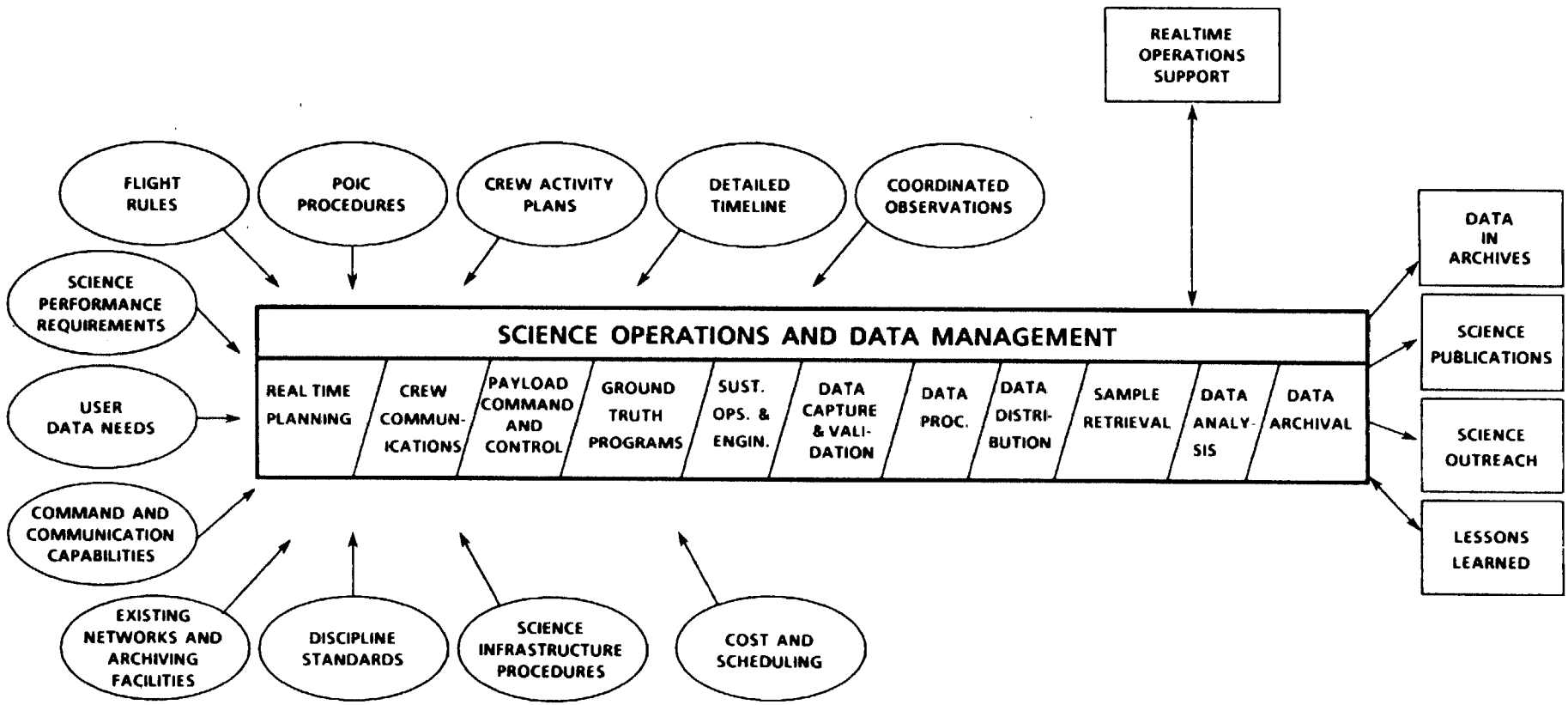

Figure 6. Science Operations and Data Management

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4.5.2 Guidelines

In common with the preceding phases, operations and data management are governed by numerous guidelines and constraints which originate from four main sources:

(1) The prior tactical and increment planning phase of the science operations process as integrated with Station tactical and increment planning;

(2) The user communities;

(3) The sponsoring organizations (OSSA and its equivalent organizations in other agencies); and

(4) The existing Station science user support systems.

The integrated science and Station tactical and increment plans establish the ground rules for the planning and operating interfaces between the Station and the user as well as the frequency, content, and level-of-detail in the operating plans. Limited Station resources, such as power, communications and data links, and crew time can limit the autonomy of instruments and facilities operated on the Station, necessitating the development of a detailed integrated timeline for all Station operations. The Station management can also alter plans on short notice in response to problems with the Station and its support systems or with other Station users. Finally, the Station must be managed to honor the international agreements with its partners, giving operational preference, where necessary, to satisfy these agreements.

The user communities likewise impose a number of ground rules and constraints on the operations of their instruments and facilities and on the management of their data. First, they require that the scientific performance of the instruments and facilities flown meets specifications, that the instruments are maintained or upgraded to maintain their scientific capabilities, and that the data or samples produced satisfy their research requirements. They may also require certain coordinated, complementary sequences of operations involving several different instruments or facilities which are located on the Station or at some remote site, like an observatory. Additionally, there is an increasing

effort on the part of many of the more well-established user communities towards uniformity of user interfaces, uniformity in the operation of the instruments and facilities, and uniformity in the access of data bases and archives to enable users to use several different instruments or archives. To further assist in this effort, standards are being established for data formats, for software development, and for data archive and distribution systems which must be followed by the user support organizations. Finally, many user communities are recognizing the operational implications of modern trends in networking and communications and are demanding that Space Station science operations employ these new systems. Candidate activities benefiting from such new developments include: "telescience" (the direct interaction between the PI or user and the instrument from a site remote from the Station operations center), the flexible clustering of operations and research activities around some natural node (e.g., a university-based PI-instrument development organization), or the remote accessing of multiple data bases. All of these practices and trends are dependent upon the existence of an effective science support infrastructure to service the needs of multiple science programs.

The third family of guidelines and constraints comes from the agencies sponsoring the science research on the Station. Sponsoring organizations (e.g., OSSA and its divisions) control the budgets which support both PIs and users and which fund the systems which must be developed, maintained, and operated to support them. The sponsoring organizations are also, typically, the originators of inter-agency and international agreements regarding the sharing of instruments, facilities or data and have obligations to ensure that these agreements are fulfilled.

Finally, PI and user operational and data requirements must be influenced by the availability of existing support systems, the cost of new systems or modifications to the existing systems, and the impact of the proposed changes on other users.

4.5.3 Activities

The initial activity in operations and data management is short-term planning and replanning of detailed operations timelines. For

pressurized laboratory facilities and attached payloads, this is done as part of increment planning. Updates to the original plan (due to problems on the Station, changes in operating plans of other Station users, or the results of preliminary experiments) are continually generated throughout the extended operation of a facility. Ideally, attached payloads may be allowed to plan and execute operations independent of the Station, provided they do not exceed previously defined resource allocations and provided the Station and its other users do not have contingency requirements which impact these allocations. In the case of platforms, considerably more operational autonomy should be possible.

The operations planning both for attached and platform payloads is likely to be quite complex. Not only must the observing requirements of the PIs and users be taken into account, but platform housekeeping (e.g., battery charging, momentum dumping, software reprogramming, and problem detection and analysis) must also be accommodated. For astronomical instruments and the EOS payloads, other factors (like the day/night cycle or the ground track) play critical roles in the planning process, as does the availability of command and control links. This is particularly true for telescience. The lack of continuous command and control links to the Station due to the zone of exclusion of the TDRSS will also complicate the planning process.

Typically, the detailed observing plans for payloads are generated weeks to months in advance of the actual observations and are subsequently refined and iterated in response to changing conditions up until the commands are generated for the planned observations and are uplinked to the facility or platform. This command and control activity is the second major element of the operations and data management phase.

For the platform payloads, the translation of planned operations to commands and their transmittal to the platform should be an autonomous activity independent of Station command and control activities. This may not be the case for the attached payloads and pressurized module facilities whose operations, although possibly generated in the telescience mode, must be compatible with overall Station operations management procedures.

Monitoring of the facility and instrument operations (in real- or near-realtime) is a function which should be manned continuously to ensure correct operation of the space-based equipment. When problems are detected, immediate corrective action is required to prevent the loss of valuable observing time, experiment time, or science data.

An extension of this activity is the communication with the Station crew who are conducting an experiment or are maintaining or servicing user equipment. Such communication should be planned in advance but will occur directly between the user or user support organization and the crew. This may result in real-time modifications to preplanned activities and will be immensely valuable for such programs as Materials Sciences in which the results of experiments conducted in space are quite uncertain and crew observation and intervention is necessary to fine-tune the experiment.

Upon successful capture of data from the space-based instrumentation, the next step is to strip out the data and to send them to each user through a hierarchy of data links and nodes. Once this has been done, the science and engineering teams may validate, reduce, and analyze their data. The validation of the data is an important step. If errors in performance, incorrect selection of instrument parameters, or noisy data links are detected in a timely way, corrective actions can be taken and the experiment repeated, assuming that there is sufficient flexibility to accommodate such repeats.

An important element of many of the planned Station science programs for most of the user disciplines is ground truth. In the Life Sciences and Materials Sciences research areas this may involve ground-based experiments using the same equipment that is used in space. In the case of the EOS, this may mean in-situ measurements using ocean buoys, aircraft, sounding rockets, balloons, or ground-based radars to measure local conditions. For astronomy or Solar System research, "ground truth" may be complementary measurements of selected celestial objects using ground-based observatories, sub-orbital experiments, or other space-based systems. Not all such measurements need be simultaneous with the Station

and platform-based activities; however, the concept of coordinated ground truth measurements is extremely important and should be factored into the Station's science operations planning and execution process.

A major new capability offered by the Station and Shuttle is that of on-orbit servicing. Such servicing enables many free-flying satellites, platforms, attached payloads, and pressurized laboratory facilities to achieve extended operational lifetimes on-orbit without returning to Earth. This avoids the hazards of the Shuttle or ELV landing and launch environments, eliminates the possibility of extended ground servicing "because its there", and reduces the cost of transportation. However, such servicing should be prepared for in advance by the intelligent design of the space systems and instruments, by the use of common modules and systems (where possible), by the development of extensive records on the as-built configuration of the hardware, and by the provision and maintenance of a suitable complement of spares, support equipment, test equipment, tools, and servicing procedures. Even when an instrument is to be returned to Earth for servicing, such a support base must be available.

Throughout the extended operation of an instrument or facility, its health and performance should be continuously monitored by engineers and scientists who understand how it works and can detect and diagnose problems. When such problems occur, these engineers and scientists should evaluate their severity, devise contingency operating procedures, and at some point, decide whether some maintenance or servicing activity is required. For many pressurized laboratory payloads and for some attached payloads, platform payloads, and free-flyers, regular maintenance may also be required to replenish consumables or to replace limited-lifetime systems. When a maintenance mission or activity is required, this must be factored into the operational plan.

The magnitude of the servicing activity dictates the lead-time required to accommodate it in the planning process. Replacement of a Life Sciences or Materials Sciences facility computer or power system may require a very minor modification to an existing plan, particularly if there is commonality in instrument systems and a spare is available on the

Station for immediate installation. For the servicing of a free-flyer like the HST, a much longer lead-time is required to allow for the retrieval of the spacecraft from its orbit at a time when the orbital nodes of the spacecraft and Station intersect, to ensure the availability of Station resources (particularly crew time) for the servicing activity, and to allow the necessary spares and tools to be transported to the Station.

When operations of an instrument or facility are successfully completed and the observation and data quality are validated, the data must be "processed". This includes formatting the data in a way appropriate to the user needs, providing appropriate ancillary engineering and orbital information to allow the user to interpret the data correctly, and applying calibrations (or calibration instructions) for the reduction of the data to useful scientific parameters. The role of the PI or facility support scientist is critical in this step for all space programs, and it is assumed that these individuals will continue to play a central role in designing, developing, and maintaining the data reduction and analysis algorithms and software associated with their instrument throughout the lifetime of their Space Station instruments. The users of the data, if different from the PI or facility support scientists, may choose to visit the PIs or facility scientists and to process their data prior to returning with the processed data to their home institutions. Alternatively, they may communciate with the PIs and facility scientists through communications links and have their data sent to their home institutions through data networks, together with any software required to reduce and analyze the data. The users may then analyze the data using this software plus any special analysis tools that they have developed.

With the growing interest in long-term studies of global variations in the Earth-observing communities, in multispectral studies of celestial objects in the Astrophysics communities, and in the development of experience and statistical data bases in the Materials Sciences and Life Sciences communities, the need to archive the data collected in space and in the associated ground-truth activities becomes increasingly important.

Further, the data must be archived in a format which will make it easy to use for future analysis and must be locatable through directories and catalogs accessed remotely by potential users. The Station user communities are currently defining data format, archive, and catalog standards to ensure that the cataloging and archiving planned for the Space Station era can satisfy their requirements.

For the Life Sciences and Materials Sciences communities, sample return plays an important part in the research process. Frequently, such sample return will have to occur in a timely way to avoid damage to the sample. This implies special packing and handling procedures on the Station, expeditious manifesting of some samples on a returning Shuttle, a mechanism for fast removal of some samples from the Shuttle after landing, and provision of laboratory facilities at the landing site for immediate processing. Last-minute delivery to the Shuttle of samples for transportation to the Station may also be required and may require use of launch site laboratory facilities plus special manifesting provisions by the Shuttle. Finally, where samples have an archival value, some archival storage of samples may be required.

For film-based instrumentation, similiar handling and retrieval problems must be addressed. Film is used by many disciplines as a recording medium and represents a particular problem when used for attached payloads in that retrieval or change-out could require an EVA.

4.5.4 Outputs

The outputs of the operations and data management activities include reports and analyses of the operational performance and status of flight instrumentation; results published in scientific publications; presentations at professional societies; exciting public information releases and products; an increasing fund of human knowledge and understanding of the Universe; an invaluable archive of data on which to base future studies; and an experience base on which to build future space science initiatives. It is this last phase in the science operations sequence that ensures the value and rewards of all preceding activities, and, hence, preparation for and investment in this phase is a critical factor in the success of Station science operations.

CHAPTER V

SCIENCE OPERATIONS AND SPACE STATION

5.1 OVERVIEW

Management of science operations on Space Station must be addressed in the context of overall Space Station operations. Figure 7 attempts to couple the science operations process with the Space Station operations control concept summarized in Section 3.5. It should be pointed out, once again, that the Space Station operations concept has not been thoroughly reviewed by the science community.

The figure illustrates in a time-consistent manner, the parallel flow of activities for science operations and Space Station operations. Consistent with the emphasis of this document, a finer degree of granularity is presented for the science operations flow. For the purposes of this figure, the payload development and integration activity is begun approximtely 4 years prior to launch. Such a schedule is felt to be reasonably representative of Space Station payloads, but, dependent upon the nature of the payload, considerably more or less schedule time could be required. Shown between the two flows are the negotiated agreements, joint documents, and shared responsibilities in which the two processes are brought together.

5.2 A UNIFIED PROCESS

The science operations and Space Station operations flows shown in Figure 7 grow closer with time, reflecting the real need for the flows to blend ultimately into a single unified operation. In the earliest phases of the two flows, OSSA integrated science plans need to be in accordance with the coarse allocation of long-term Space Station resources established by Space Station strategic planning. With time, the allocation of Space Station resources has to become more precise. Upon finalization of OSSA implementation plans and prior to the start of payload development,

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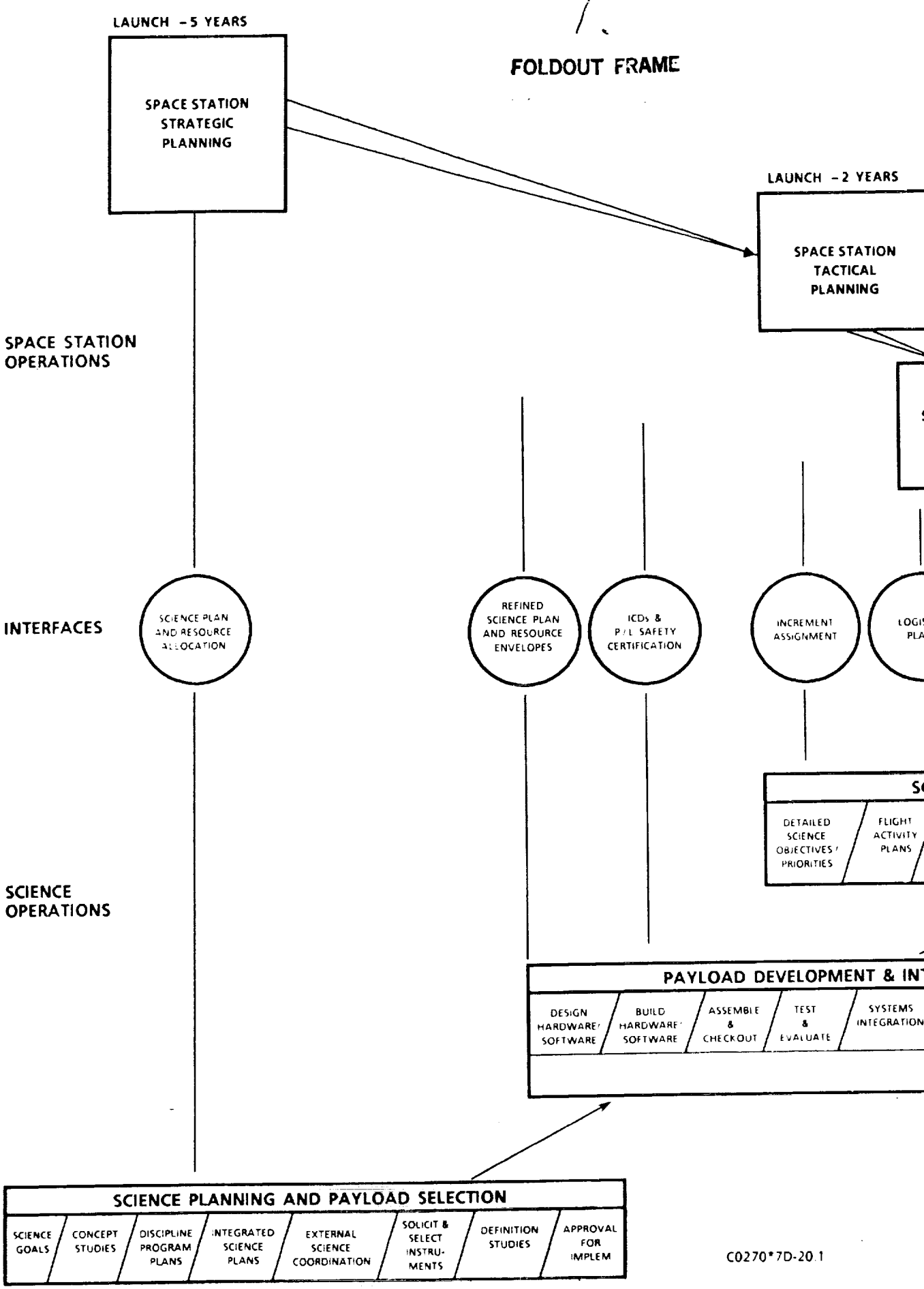

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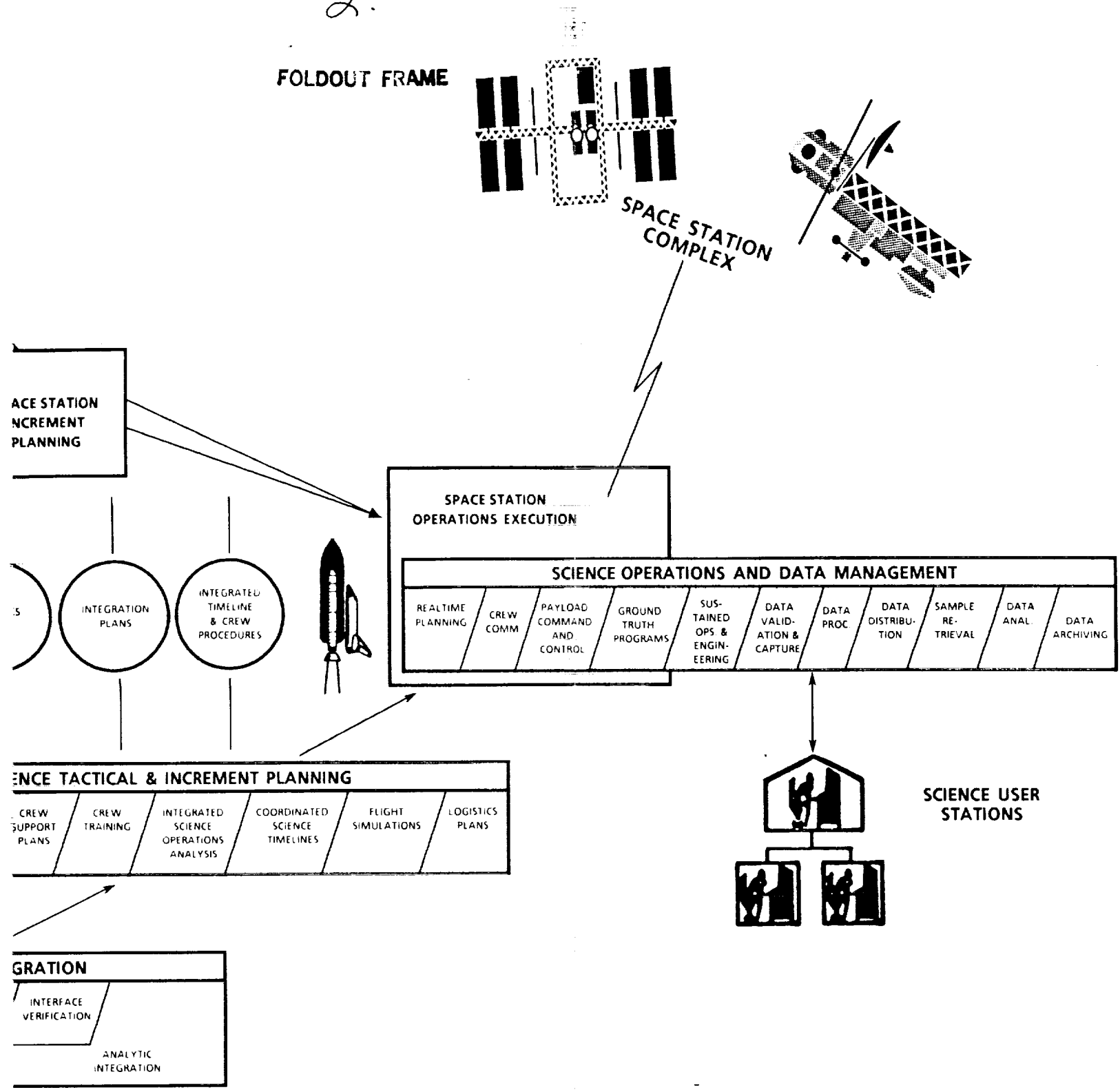

Figure 7. Space Station Science Operations

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more specific resource envelopes are needed for individual payload projects. In order to ensure proper payload design and accommodation, frequent interaction between OSSA and the Space Station Program is needed.

During payload development, detailed Interface Control Documents (ICDs) should be established between the user and Space Station organization. Normally, this needs to occur prior to completion of design and before the start of the payload fabrication activity. However, the provision of Station-supplied interface design guidelines and criteria could delay the need for finalized ICDs until later in the process. Certification of payload safety compliance represents another required confluence of efforts which should occur during payload development.

During the tactical and increment planning phases of the two flows, plans for transportation, ground integration, increment assignment, and detailed operational timelines are mutually developed. When the flows have progressed to the launch and operations execution phases, they are blended into a single coordinated operation.

CHAPTER VI
INSTITUTIONAL ARRANGEMENTS

6.1 GENERALIZED APPROACH

In order to evaluate the institutional arrangements whereby NASA and its collaborating government agencies might manage science operations on the Space Station, six generalized science management options were initially defined. These options are identified in Table 1. The options divided the end-to-end science operations activities into the four functional phases previously identified in Chapter IV and assigned management responsibilities for each group. It is important to note that the material that follows assumes that a significant infrastructure capable of supporting science management, planning, and operations effectively is in place.

6.1.1 Option Definition

Three different-sized organizations were considered: sub-discipline (e.g., infrared astronomy), discipline (e.g., astrophysics), and clustered discipline (e.g., astrophysics and solar system research). For each case, two further possibilities were considered. These were:

(1) NASA (or another participating government agency) manages the development of flight hardware in-house at a NASA field center (or equivalent government facility). An in-house or an external organization may manage the in-flight operations and data management portion of the program. This organization is given the title "science operations center"; and

(2) NASA (or another participating government agency) allows either an in-house or an external organization to manage both the flight hardware development and the in-flight operations and data management of the program. This organization is given the title "science center".

TABLE 1. NASA* SCIENCE OPERATIONS MANAGEMENT OPTIONS

	OPTION 1	OPTION 2	OPTION 3	OPTION 4	OPTION 5	OPTION 6
DISCIPLINE TYPES	SUB-DISCIPLINE	SINGLE DISCIPLINE	CLUSTERED DISCIPLINES	SUB-DISCIPLINE	SINGLE DISCIPLINE	CLUSTERED DISCIPLINES
PLANNING AND SELECTION	PLANNING - OSSA DIVISIONS AND AA PI SELECTION - OSSA DIVISIONS AND AA USER SELECTION - OSSA DIVISIONS OR SCIENCE (OPERATIONS) CENTER					
DEVELOPMENT	DEVELOPMENT CENTER (NASA FIELD CENTER)			SCIENCE CENTER (NASA FIELD CENTER OR EXTERNAL ORGANIZATION)		
SCIENCE TACTICAL / INCREMENT PLANNING	DEVELOPMENT OR SCIENCE OPERATIONS CENTER (NASA FIELD CENTER)					
OPERATIONS AND DATA MANAGEMENT	SCIENCE OPERATIONS CENTER (NASA FIELD CENTER OR EXTERNAL ORGANIZATION)					

*** COULD APPLY EQUALLY TO OTHER U.S. GOVERNMENT AGENCIES**

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Options 1 through 6 increasingly:

- -- Facilitated commonality in user operations interfaces, data interfaces, and data products across science communities for which this makes sense;
- -- Minimized the number of independent interfaces with the Space Station organization for flight program planning, development, and execution;
- -- Maximized the use of common hardware (e.g, power systems or computers) and minimize the number of simulators required, to ease the financial burden of integration, test, and on-orbit servicing; and
- -- Simplified the interface between the development organization and the science operations organizations.

Institutionally, each option increasingly:

- -- Clustered the experience gained in dealing with the Station hardware and operations interfaces; and
- -- Created user-oriented science support capabilities to which users could go for advice on how to plan and conduct their research, for operations and data processing equipment (or equipment specifications), and for support in setting up "telescience" activities.

The responsibilities for overall program planning, Principal Investigator and user selection, and science tactical and increment planning were allocated appropriately for each option.

6.1.2 Option Evaluation

Each option was then evaluated in the context of the needs and desires of the various user communities, and pros and cons were identified for each case. The major conclusions arising from this exercise were that:

- -- None of the options completely described the preferred management approaches of any of the science user communities;
- -- Different science communities preferred different management approaches because of the kinds of research that they

planned for the Station and because of their varying backgrounds and traditions (see Section 6.2);

-- An information system infrastructure must be provided by OSSA to facilitate the distribution and interchange of science data and to provide basic tools, standards, prototypes, and approaches to facilitate inclusion of users into a telescience environment. However, for subdiscipline- and discipline-unique data system and software requirements, many of the operational and data commonality benefits of clustering disappeared beyond the discipline-level organization because of the very different data types and data uses of the various disciplines; and

-- As long as the number of interfaces with the Station is limited, the Station does not need all of the users to follow a single management approach.

Institutionally, it was also recognized that:

-- The potential size of some of the larger organizations being considered might create a management and coordination nightmare. For reference, the Space Telescope Science Institute (STScI), with a staff of over 250 people, qualifies as a sub-discipline science operations center (Option 1 in Table 1); and

-- The government should continue to manage the development of flight hardware in-house and should continue to procure specific items of both PI-developed and industry-developed hardware against detailed cost, schedule, and performance specifications.

A final conclusion of the study group was that the subdivision of activities shown in Table 1 was not fine enough to allow all of the management options important to the disciplines to be considered. The participants, therefore, decided to review the activities at a far more detailed level and to use this "grass roots" analysis to identify the management options best suited to the Space Station opportunity.

6.2 SCIENCE DISCIPLINE CONSIDERATIONS

In defining possible approaches for managing science operations on the Space Station, it is important to take into consideration the very different backgrounds of the communities planning to use the Station. For example, visible light and infra-red astronomers have come to space astrophysics with many decades of experience using ground-based observatories, and their preferred methods of managing their facilities and selecting observers reflect this tradition. Segments of the space astrophysics community have been developing space instrumentation since the earliest days of NASA. In recent years, this community has increasingly favored a mix of facility-class and PI-class missions. Hence, today's space astrophysics community is technically sophisticated and highly organized, with strong traditions of self-reliance for instrument development and of self-government for the use of their facilities.

At the other end of the spectrum lies the Materials Sciences community which is interested in conducting research into the behavior of materials (liquids, solids, gases) in space. This community is drawn from a diversity of independent researchers located in numerous university, government, and industry laboratories. Only recently acquiring significant momentum with its space program efforts, the community has not had the opportunity to establish integrated research initiatives, nor have its researchers had extensive experience in the development of space-qualified instrumentation. Consequently, the Materials Sciences community must take the most expeditious route to the use of this new field of research and must capitalize on NASA's vast experience in integrated program management and space system development to avoid an extended learning curve.

A further discriminator in management comes from the way in which the various communities plan to use the Station. For example, the two microgravity research communities which rely most heavily on the Station's pressurized laboratories (Life Sciences and Materials Sciences) plan to use major research facilities such as centrifuges or furnaces to support multiple users. Since the different communities share common Station facilities, there is a significant benefit to be derived from a

coordinated, centralized management approach to program planning and implementation. Further, since these facilities represent a large, integrated, and semi-permanent fixture within the Station's laboratories, a community-wide or laboratory-wide OSSA integration center for these pressurized laboratory facilities might also make sense.

Other OSSA Space Station user communities (like Earth Sciences or Astrophysics) which primarily plan to use the Station's attached payloads and platforms can employ a more distributed approach to the development of their facilities. However, different sub-discipline communities are becoming increasingly interested in using multiple facilities, and there is increasing demand for coordinated programs and for commonality of user interfaces for operations and data analysis. The effects of this demand can be seen in the proposed management of the Earth Observing System (EOS) in which multiple Earth Science sub-disciplines are collaborating to develop comprehensive Earth, oceans, atmosphere, weather, and climate research facilities.

In addition to considering this diversity of community backgrounds and approaches, it is important to bear in mind that the Station is a multi-national enterprise and that U.S. scientific use of the Station will probably extend beyond the traditional NASA family of users to include substantial research activities sponsored by other U.S. government agencies. Any science operations management approaches seriously considered for the Station must, therefore, lend themselves to such multi-national and multi-agency participation.

Options for the management of science operations for the Station, developed by the study participants, are presented below. The user-derived options are divided into the same four functional phases as in the case of the generalized options. These phases are: science planning and investigator selection, payload development and integration, science tactical and increment planning, and science operations and data management. For each of the four phases, major program activities are identified for which management options exist, and these options are described. The management preferences of both the Microgravity Disciplines (Life Sciences and Materials Sciences) and the Observing Disciplines

(Astrophysics, Earth Sciences, and Solar System Research) are also discussed, and a rationale for these preferences is provided. Finally, a summary of all preferred options is presented in Chapter VII.

6.3 SCIENCE PLANNING AND PAYLOAD SELECTION

6.3.1 Introduction

As indicated in Section 4.2, science planning and payload selection are the first steps in the science operations process. They are activities which have traditionally been undertaken by NASA and the other participating agencies to plan their science programs. The Station strategic planning process imposes a new requirement on this process. Formal assessments of Station resource requirements, for both science and non-science programs, will be required five years before flight in order for the Station and its multiplicity of users to plan their programs. Only when the Station resource allocations are known may investigations be safely selected for the Station pressurized laboratories, attached payloads, and platforms.

The following sections discuss the management options available to the U.S. Space Station science users for the development of their strategic plans and for the subsequent selection of investigations. The discussion includes the selection of both science payload developers (Principal Investigators (PIs)) and of facility users because of the similarity in the two processes. A summary of the options considered and of the preferences of the two major classes of Station science users, the Microgravity Disciplines (Life Sciences and Materials Sciences) and the Observing Disciplines (Astrophysics, Earth Sciences, and Solar System Research), is provided at the end of this section in Table 2.

The following discussion pertains to NASA science program planning and payload selection only. It is assumed that the other U.S. agencies planning to use the Station as a base for scientific research have similar options and must make similar decisions. In addition, it is possible that some of the planning and selection activities described below

will be undertaken jointly by several agencies according to formal agreements reached among those agencies.

6.3.2 Science Strategic Planning

The strategic planning process for Space Station science programs may be divided into three main steps:

(1) Development of discipline goals and plans and the integration of these plans into an OSSA Space Station user plan;

(2) Development of an integrated U.S. Space Station utilization plan; and

(3) Negotiation of the latter plan with the users from the International Partners and with the Station.

Each of these steps has several possible management options which are presented below and in Figure 8.

6.3.2.1 Integrated Program Planning

OPTION 6.3.2.1 A:

The science planning process was discussed in Section 4.2. A schematic representation of a proposed NASA planning approach is shown in Figure 8a. The process consists of six basic steps:

(1) The development of science goals by the agency discipline representatives and their user communities;

(2) Conceptual studies to identify alternate technical approaches to realize these goals;

(3) The integration of promising project concepts into discipline strategic plans which take into account science priorities and apply some constraints on the program size based on discipline estimates of available resources;

(4) The combination of these plans into an integrated Strategic Plan for OSSA-wide science programs which takes into consideration program priorities and anticipated available resources (including those of the Space Station) and

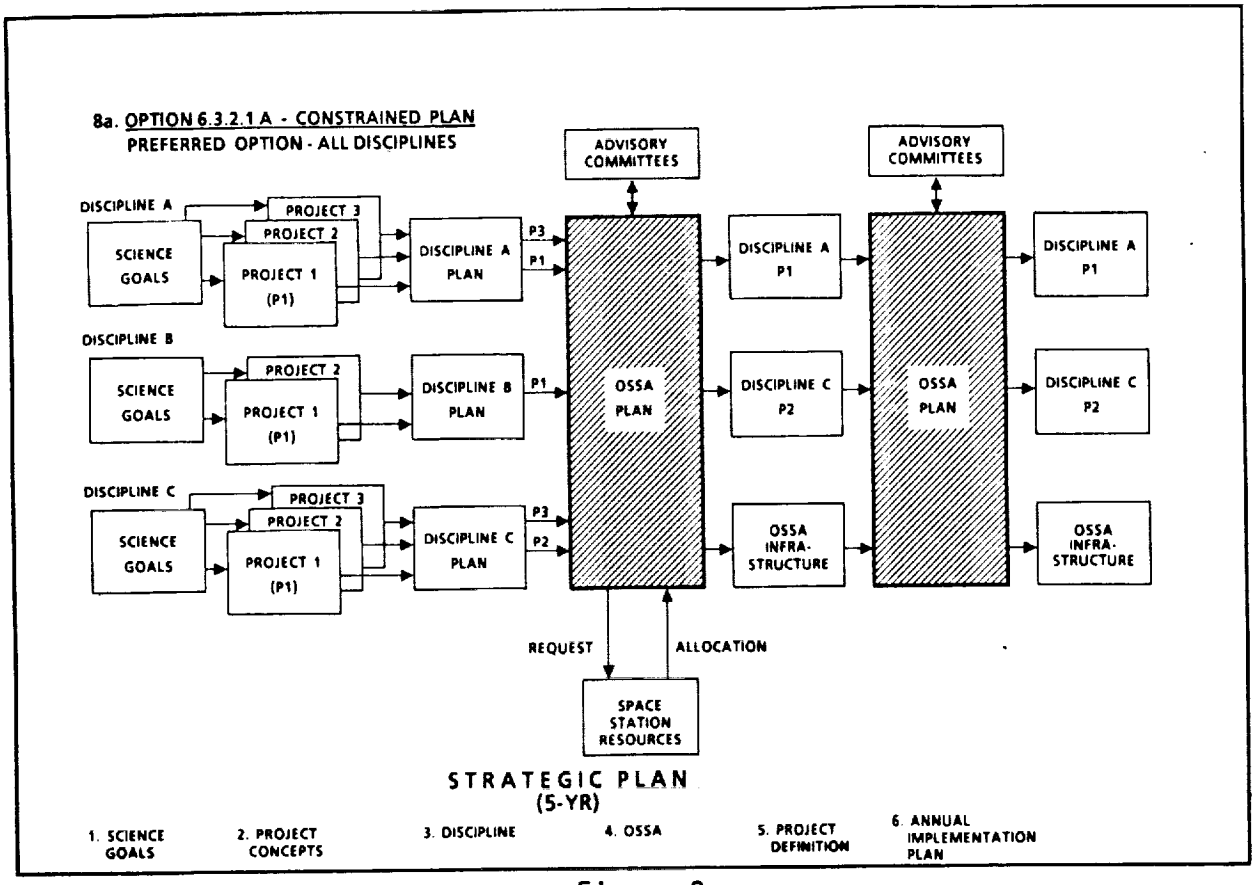

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Figure 8a.

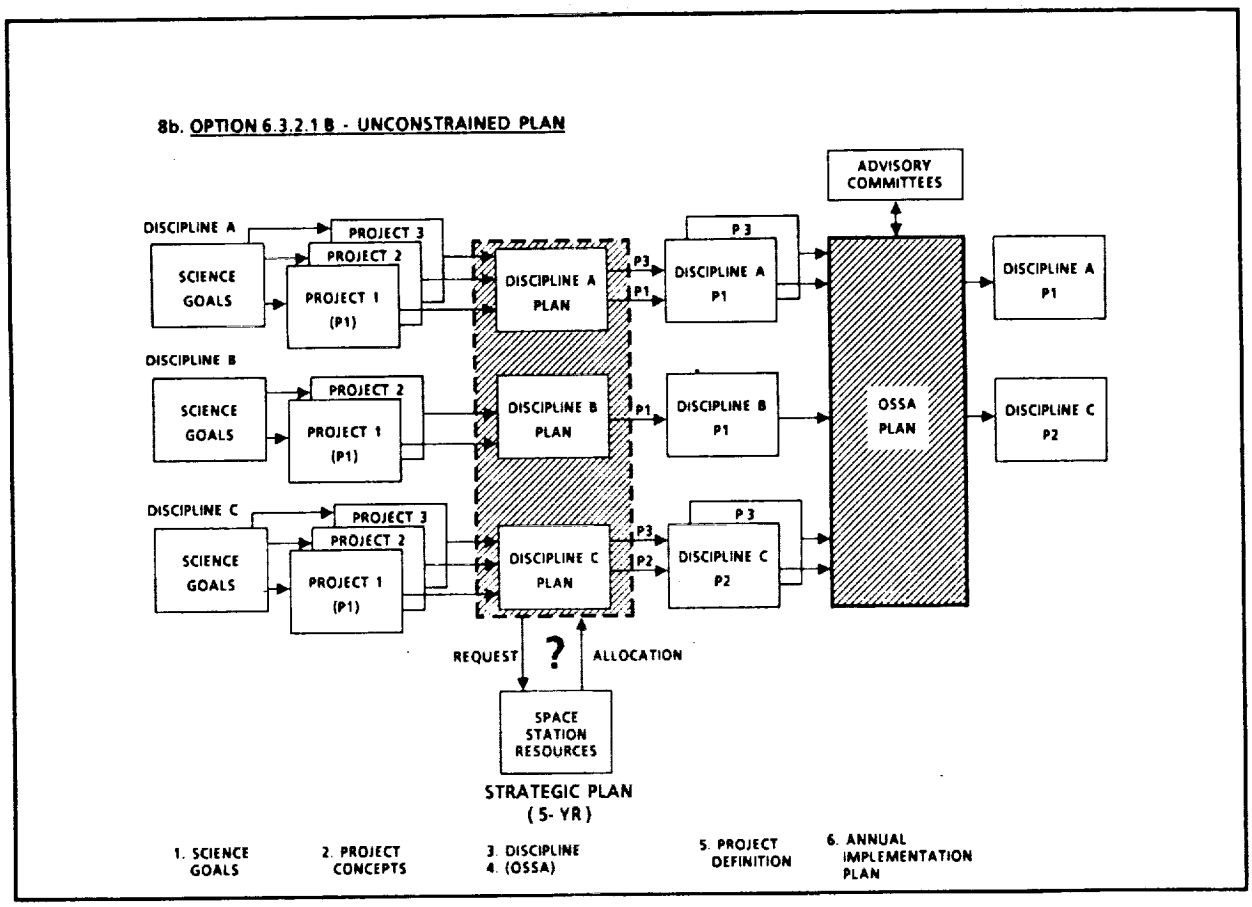

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Figure 8b.

Figure 8. Integrated Science Program Planning Process

includes plans for the infrastructure needed to support the discipline plans;

(5) The further definition of those projects included in the OSSA-wide plan to develop accurate cost estimates and to prepare for the formal design and development process; and

(6) The development of an OSSA-wide implementation plan which includes both discipline projects and the infrastructure required to support them.

The activity would be primarily a NASA Headquarters responsibility because, in addition to the development of overall science goals, there are also programmatic and financial implications in the planning process. Major inputs would be obtained from the user communities in the definition of science goals and strategic plans and from the NASA field centers in the definition of the project concepts and the preliminary design studies. Advisory committees, consisting of representatives of the various science user communities, would assist NASA and the other agencies in the evaluation and prioritization of discipline plans and in their integration into a single OSSA strategic plan. They would provide similar advice in the development of the implementation plan.

As indicated in Figure 8a, the two strategic planning steps (#3 and #4) would be formal steps. The development of the constrained OSSA-wide strategic plan would result in the early elimination of lower-priority project concepts. It would result in a realistic OSSA strategic plan which would be used as the basis for Station resource requests and negotiations. The constrained plan would also reduce the yearly cost to OSSA of Phase B studies by phasing the studies such that they more closely fit the project implementation opportunities. Finally, it would further increase the involvement of the science communities in NASA's science program planning process by allowing formal advisory committee inputs both to the strategic plan development and to the implementation plan development. This was the preferred option of the study group participants.

OPTION 6.3.2.1 B:

The alternate management for the development of the OSSA strategic plan is shown in Figure 8b. The process is very similar to that discussed above, with the exception of the OSSA-wide strategic planning step which is less constrained and less formal. In this case, the OSSA-wide strategic plan would be a compilation of the discipline plans with little additional attempt made to prioritize and eliminate projects at this stage. Instead, most projects would be allowed to continue through the preliminary design stage, and competition between projects and disciplines would be maintained until the implementation plan is developed. The competition between projects and the elimination or postponement of a large fraction of the candidate programs would occur at this stage.

While this option would result in a far less realistic assessment of Station resource requirements, it would allow projects sufficient time to develop fully their technical and programmatic discriminators before a selection was made. It would also allow more flexibility to be maintained in the program until the implementation plan was developed and would prevent a false impression being given to NASA management and the Administration of the true competition for Station opportunities.

Finally, for either option, sufficient flexibility should be maintained in the planning process to accommodate "rapid-response research".

6.3.2.2 Space Station Planning - Science Users

In the OSSA science planning discussed above, it has been assumed that each of the U.S. agencies sponsoring scientific research on the Station would conduct its own strategic planning process. The plans of each of these agencies (including NASA) would then be combined, together with the plans of the U.S. non-science Station users (e.g., the commercial and technology research programs), to produce an integrated U.S. Space Station user plan. Two management options have been identified for the development of the integrated U.S. Station science plan. These options are presented below:

OPTION 6.3.2.2 A:

The first option, based on the recommendations of the Space Station Operations Task Force, is illustrated in Figure 9a. The organization which the Task Force proposed to integrate all of the U.S. user requirements is the Space Station User Board (SSUB). As indicated in the diagram, the NASA Offices of Aeronautics and Space Technology (OAST), Commercial Programs (OCP), and Space Science and Applications (OSSA) and other participating U.S. government agencies (e.g., the National Bureau of Standards (NBS), the National Institutes of Health (NIH), the National Oceanic and Atmospheric Administration (NOAA), the National Science Foundation (NSF), the U.S. Department of Agriculture (USDA), and the U.S. Geological Survey (USGS)) would all have representatives on the Board. The chairmanship of the Board would be rotated among the participating organizations on an annual basis.

OPTION 6.3.2.2 B:

An alternate option which allows an integrated U.S. science plan to be developed before it is negotiated with the non-science users is shown in Figure 9b. In this case, a multi-agency Space Station Science User Board (SSSUB) would be formed, subordinate to the SSUB, to allow the participating agencies to integrate their Station science operations requirements, barter their resources, and plan their combined strategies prior to submitting their plans to the SSUB. OSSA would chair the SSSUB and would be responsible for integrating all U.S. science operations plans and requirements. OSSA would also act as the representative of all U.S. Station science users on the SSUB. This approach would have the advantage of providing a stronger and more cohesive scientific user voice on the SSUB. However, such inter-agency program integration and representation could only be undertaken upon formal agreement among the participating agencies. Further, an arbitration mechanism would be needed to ensure equity. A possible approach would be to have an independent body, such as the National Academy of Sciences Space Science Board (SSB) or the National Research Council (NRC), form a committee to oversee the activities of the SSSUB. Such a committee is also shown in Figure 9b. This option was the preferred approach of the study group participants.

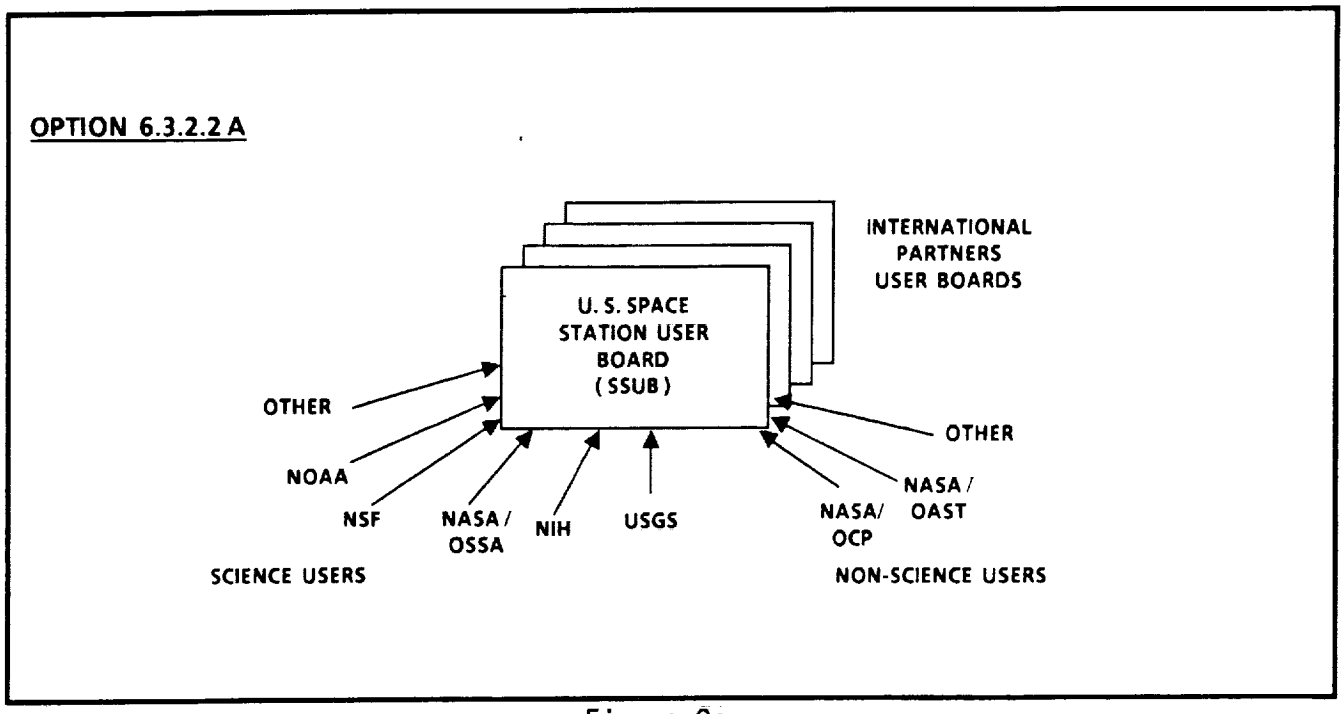

Figure 9a.

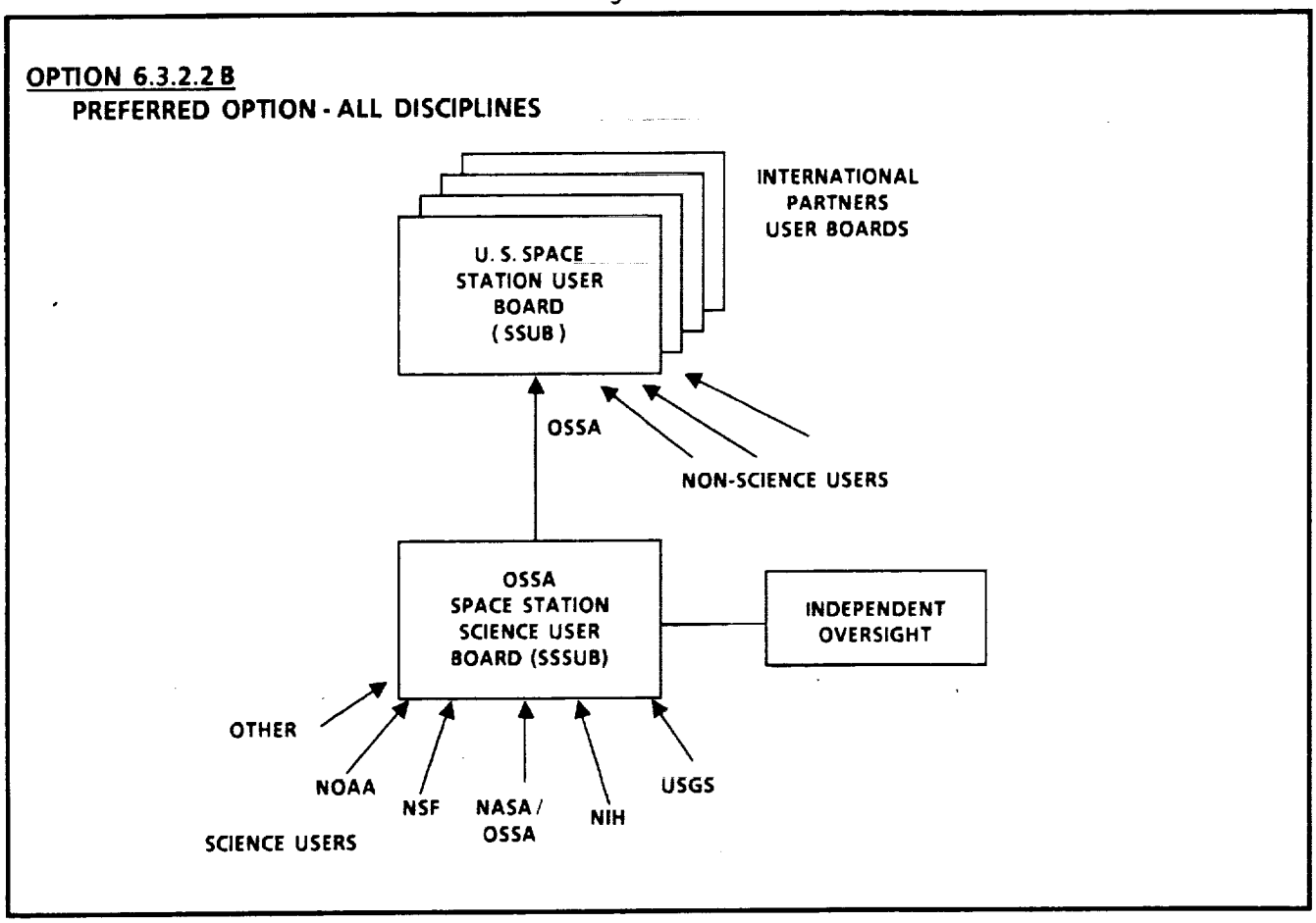

Figure 9b.

Figure 9. Space Station Planning Interface - Science Users

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6.3.2.3 Space Station Planning - User/Station Interface

Once the U.S. has developed its integrated Station science and non-science user plans and requirements, the chairman of the SSUB would submit the plans and requirements to the Space Station management. Similar plans would be submitted from the user boards of the other three international partners. The Station management would then develop integrated Station plans and resource allocations based on Station housekeeping requirements, international agreements, and the inputs from the Boards. Possible management options for this resource allocation process are shown below.

OPTION 6.3.2.3 A:

The procedure currently proposed for the allocation of Station resources by the Space Station Office is shown as Figure 10a. In this option, the user resources would first be allocated to the international partners and the Station based on guidelines specified in the Space Station Memoranda of Understanding (MOUs) with each of the international partners. This allocation would be made by the Space Station Multilateral Coordination Board (MCB), supported by the User Operations Panel (UOP). Both the MCB and the UOP would be four-person committees, with representatives from each of the international partners. The members of the UOP would probably be the Station Utilization Directors of the four international partners.

Following the preliminary allocation of resources, each partner would produce its own plan for the use of its allocated resources. Thus, in the case of the U.S., the SSUB chairman would develop the U.S. utilization plan for input to the UOP. The UOP would then integrate the utilization plans of each of the partners, identifying and resolving any technical or operational incompatibilities, would represent the user interests in the division of resources between Station and user, and would encourage bartering among the four partners. Any dispute between the Station, as represented by the international System Operations Panel (SOP), and the users would be resolved by the MCB.

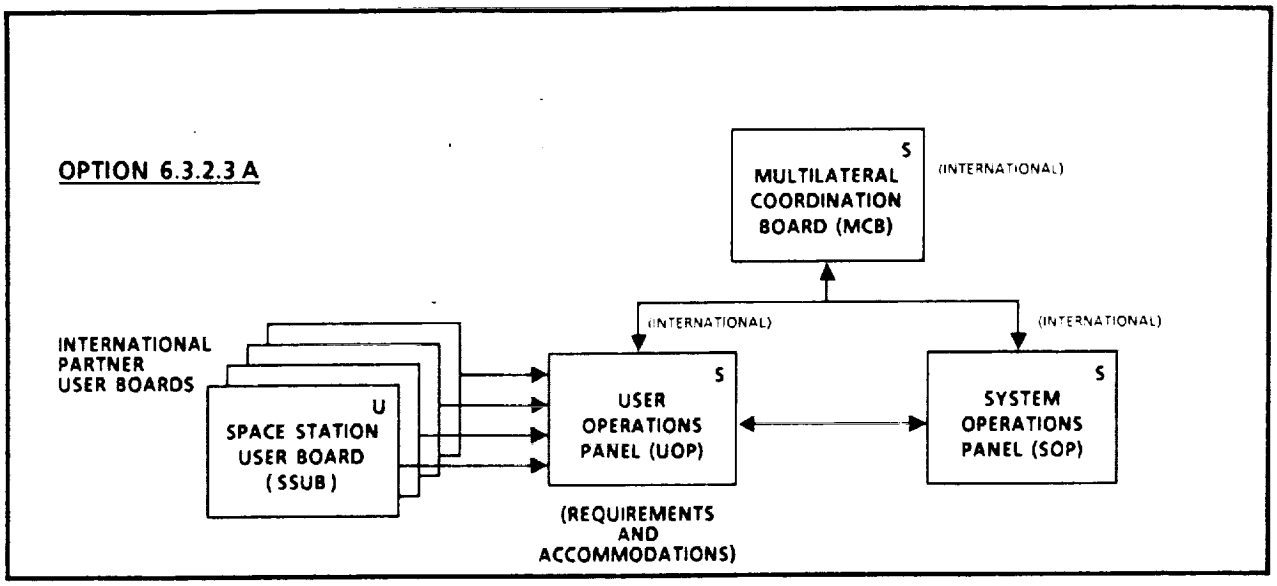

Figure 10a.

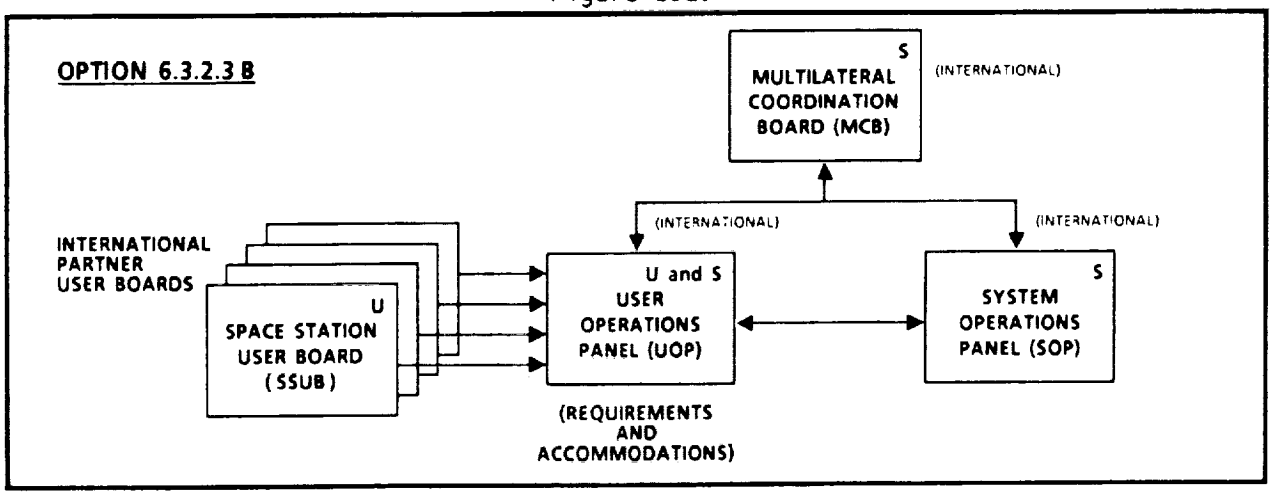

Figure 10b.

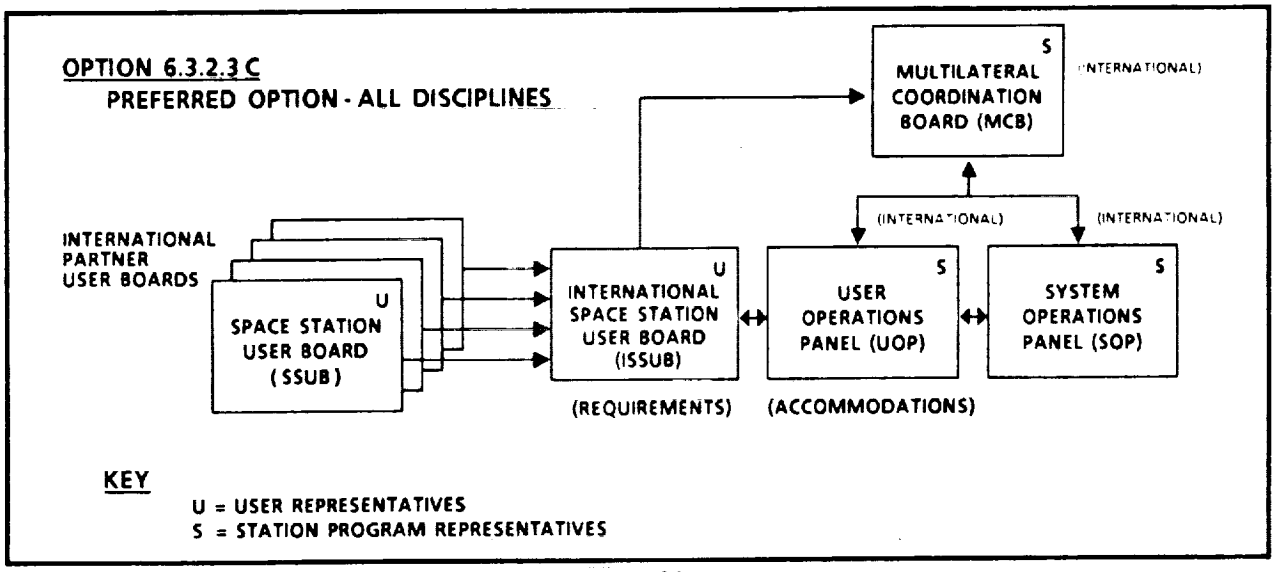

Figure 10c.

Figure 10. Space Station Planning Interface - Station

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The advantage of this option is that the task of negotiating resources for the users would be accomplished by Station program representatives who have an inside knowledge of the Station's operational requirements and plans. The disadvantage is that these representatives might not be fully conversant with the scientific rationales and flexibilities associated with their nations' user plans and requirements.

OPTION 6.3.2.3 B:

From the science user viewpoint, a strong user voice is required into the Space Station management organization to ensure optimum allocation of Station resources between the Station and the user. This could be achieved by making the chairman of the U.S. SSUB a member of the UOP by increasing the number of members on this panel from four to eight (see Figure 10b). Other international partners could follow suit and make their user board chairmen their second UOP representative or they could provide a second Station program representative to the panel as they saw fit.

The advantage of this option is that it provides a stronger user voice in the Station resource allocation process without changing the management structure.

OPTION 6.3.2.3 C:

The final option for Station resource allocation is illustrated in Figure 10c. In this case, the chairmen of the four international Space Station User Boards form an International Space Station User Board (ISSUB) which negotiates resource trades among international partners and produces an integrated user plan prior to its submission to the UOP. The UOP then negotiates this plan with the SOP. An appeal route is ensured for the international user representatives by making the ISSUB an equal voice in any interaction with the MCB. This option has two major advantages to the user community: it provides an international forum for users to discuss objectives and barter resources, and it provides the strongest user voice to the Space Station organization. This was the preferred option of the study group participants.

6.3.3 Investigator Selection

The following section discusses two topics:

(1) The selection of Principal Investigators (PIs) to develop PI-class and facility-class scientific instruments for inclusion in platform payloads, attached payloads, or pressurized laboratory facilities; and

(2) The selection of users of the PI-developed or government-developed facilities. Typically, a limited number of users are selected early in the design phase of a project, together with the PIs, to ensure that user interests are taken into consideration during flight hardware development. They form a Science Working Group (SWG) which guides the development of the instrument or facility. Subsequently, several solicitation and selection cycles may occur over a period of years to select additional users of the flight hardware. Although the latter activity could be considered an element of the operations phase, it is included here because of the commonality in management approaches for the two types of selection processes.

6.3.3.1 Payload Selection

The selection of PIs to participate in the development of major elements of NASA-sponsored flight hardware has traditionally been an OSSA Headquarters function. The generalized process was described in Section 4.2, and the current management approach to science payload selection is illustrated in Figure 11a.

The management options associated with this process relate to the management level within OSSA (and associated U.S. agencies) at which the Program Office, identified in Figure 11a, resides. These options are described below:

OPTION 6.3.3.1 A:

In this option, the current most-frequently used OSSA management approach would be applied to the selection of science payloads for the Station. Thus, the solicitation and selection of PIs to develop major scientific instruments would continue to be an OSSA sub-discipline

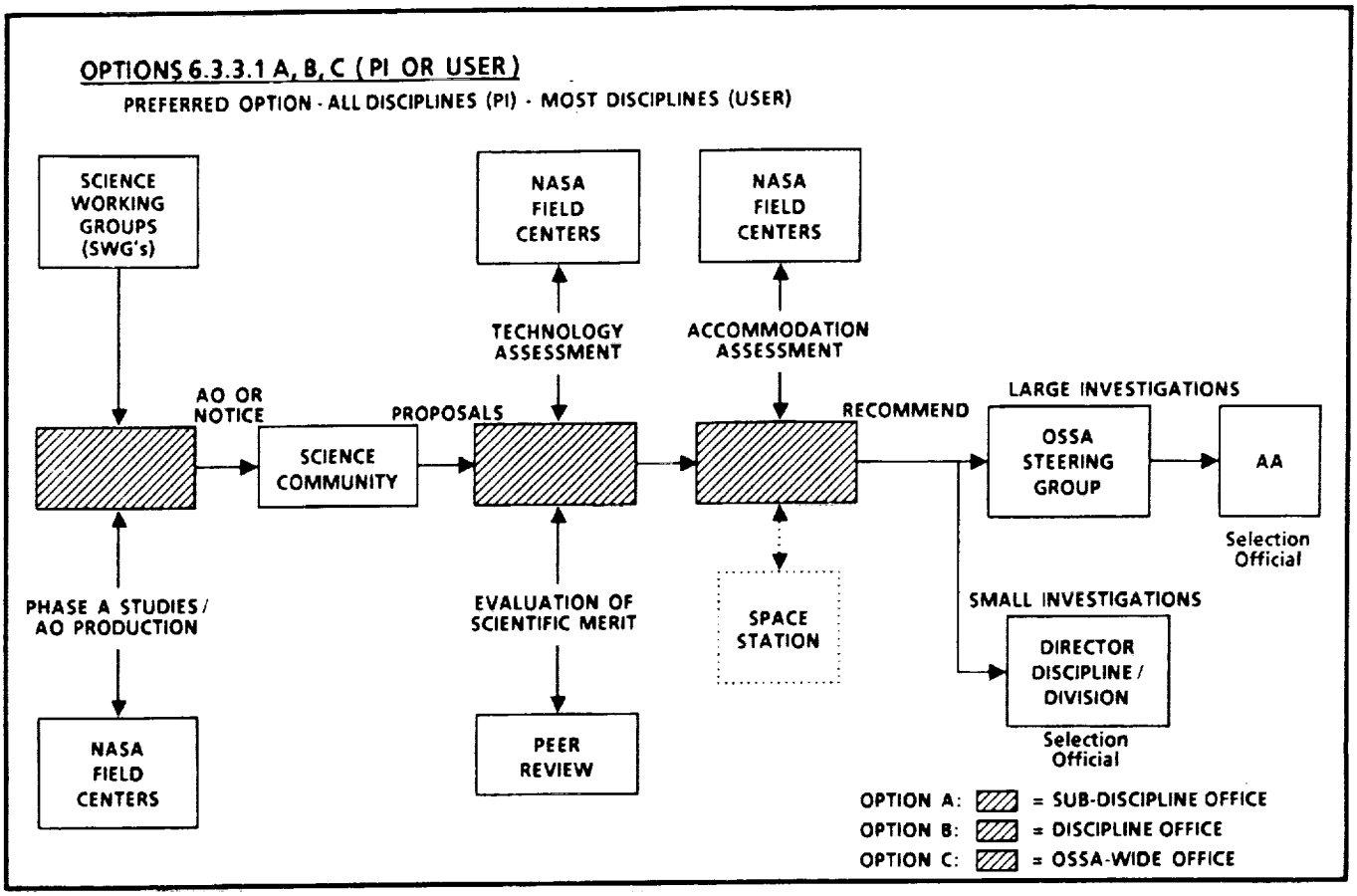

Figure 11a.

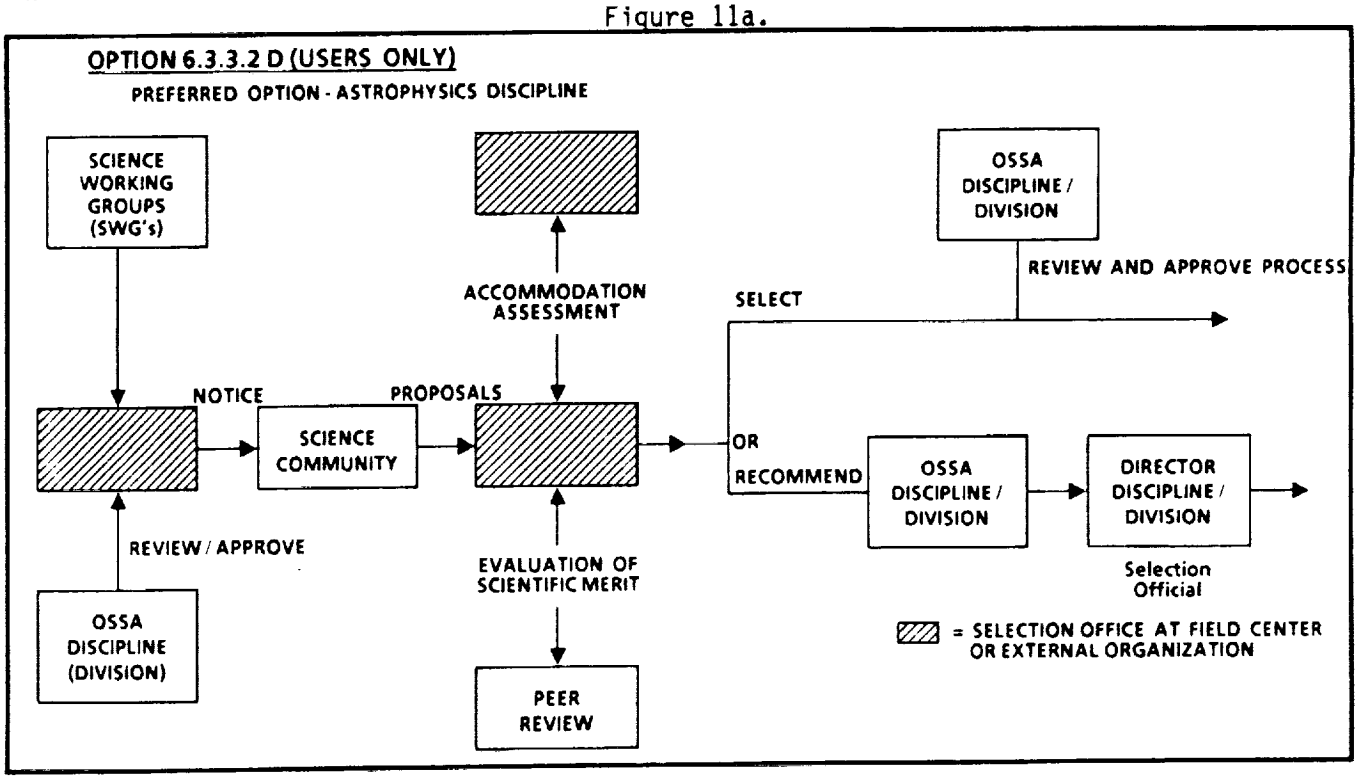

Figure 11b.

Figure 11. Investigator Selection Process

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responsibility, with Division Director approval and with the OSSA Associate Administrator (AA) acting as the selection official for OSSA-sponsored developments. Other participating agencies would make their own arrangements for PI selection or might enter into cooperative selections with OSSA.

For smaller, less-costly PI instruments (e.g., programs of the suborbital sounding rocket class) the selection officials would be the Directors of the Divisions to which the instruments belonged. In all cases, there would be heavy community involvement in the peer review process.

This option is the one preferred by the Observing Sciences disciplines of Astrophysics, Earth Sciences, and Solar Systems Research. The approach can be taken for these disciplines since the development of the Observing Sciences facilities and payloads can be treated as separate activities in the planning and early development stages, even though their use may be coordinated across the disciplines in the operational phases of the program. The limited scientific and technical scope of each review facilitates the formation of peer review committees which are qualified to judge the many flight-worthy proposals submitted by the highly competitive, technically mature Observing Sciences disciplines.

OPTION 6.3.3.1 B:

In the second option, the management level indicated in Figure 11a would be raised from the sub-discipline level to the discipline level. All other elements of the process would remain the same. This option would allow disciplines such as Life Sciences and Materials Sciences, which share equipment among sub-disciplines, to plan coordinated programs. It would also have the advantage of greater efficiency in the peer review and technical review processes and would allow Division Directors to make choices among competing sub-discipline instrument candidates if funds were constrained. It is the preferred option for the Microgravity Research disciplines.

OPTION 6.3.3.1 C:

A third possibility would be to have a separate division within OSSA assume responsibility for the planning and implementation of the OSSA-

wide Space Station science program. While such an organization is required to support integrated OSSA Space Station program planning, all users felt that the solicitation and selection of PIs should remain the responsibility of the discipline representatives who know their community and who understand their discipline requirements and priorities. Neither of the two classes of U.S. Station science users favored this option. Similarly, none of the OSSA Space Station user disciplines favored the delegation of responsibility for selecting NASA-sponsored Space Station science PIs to other organizations inside or outside NASA (i.e., to a field center or Science Institute) because of the very strong programmatic and financial implications of the selection process.

6.3.3.2 User Selection

The first three options for the management of the selection of users of the facilities and instruments to be flown on the Station are very similar to those specified above. The discipline preferences for the options are again based on the plans, needs, and traditions of the various communities. However, a factor which has yet to be evaluated is the workload associated with the user selection process. This consideration could influence the approach eventually adopted by the communities for user selection.

OPTIONS 6.3.3.2 A, B, and C:

These options are identical to those identified in Section 6.3.3.1 above with the exception that the Division Director would always act as the selection official because of the lower cost of the investigations being selected. The preferences were identical to the investigator selection, with the exception of Astrophysics.

OPTION 6.3.3.2 D:

An alternate approach, currently used only by the Space Astrophysics Division and its community, would be to have the facility or payload science operations center (which could be located at a NASA field center or external organization) conduct the peer review and preliminary selection of users (see Figure 11b). This center would still rely heavily on community support in the peer review and selection process. The OSSA

Division Director would then approve the process and, possibly, the selection. Models for this approach are the International Ultraviolet Explorer (IUE) guest-observer program (whose selection process is managed by NASA Goddard Space Flight Center) and the Hubble Space Telescope (HST) guest-investigator selection process (which is managed by the Space Telescope Science Institute (STScI), an external organization).

6.3.4 Summary

The management options which were considered for the Science Planning and Payload Selection phase are identified in Table 2. The activities for which options were identified are defined in the left-hand column, the options are described in the middle of the table, and the paragraph in which each option is identified is shown in the right-hand column.

The table assumes all of the Space Station science users to be divided into two major families of disciplines. These families are the Microgravity Disciplines (including Life Sciences and Materials Sciences) and the Observing Disciplines (including Astrophysics, Earth Sciences, and Solar System Research). The preferences of these families of disciplines, as represented by the study group participants, is indicated by asterisks. Completely unacceptable options are indicated by the word "REJECT". Options which are acceptable, but not preferred, are unmarked in the table.

TABLE 2. MANAGEMENT OPTIONS FOR SCIENCE PLANNING AND PAYLOAD SELECTION

ACTIVITY	MICROGRAVITY DISCIPLINES		OBSERVING DISCIPLINES	OPTION #
	PREFERENCE	OPTION DESCRIPTION	PREFERENCE	
INTEGRATED PROGRAM PLANNING	*	CONSTRAINED STRATEGIC PLAN OR UNCONSTRAINED STRATEGIC PLAN	*	6.3.2.1 A 6.3.2.1 B
SPACE STATION PLANNING INTERFACE A) USER	*	ALL U.S. SPONSORING ORGANIZATIONS ARE MEMBERS OF SSUB OR OSSA INTEGRATES U.S. SCIENCE USER REQUIREMENTS	*	6.3.2.2 A 6.3.2.2 B
B) STATION		SSUB INPUTS REQUIREMENTS TO STATION - MANAGED UOP OR SSUB CHAIRMAN IS MEMBER OF 8 - PERSON UOP OR		6.3.2.3 A 6.3.2.3 B
	*	NEW ORGANIZATION [ISSUB] IS FORMED TO REPRESENT USER REQUIREMENTS TO MCB	*	6.3.2.3 C
INVESTIGATOR SELECTION (NASA) A) PAYLOAD (PI)	*	MANAGED BY OSSA SUB - DISCIPLINE OFFICE WITH DIRECTOR OR AA SELECTION OR MANAGED BY OSSA DISCIPLINE (DIVISION) WITH DIRECTOR OR AA SELECTION OR	*	6.3.3.1 A 6.3.3.2 A 6.3.3.1 B 6.3.3.2 B
	REJECT	MANAGED BY OSSA SPACE STATION INTEGRATION OFFICE	REJECT	6.3.3.1 C 6.3.3.2 C
B) USER	*	AS FOR PAYLOAD OR	*	
	REJECT	MANAGED BY OPERATIONS CENTER (FIELD CENTER OR EXTERNAL ORGANIZATION - SEE 6.6.2.1)	* (ASTROPHYSICS ONLY)	6.3.3.2 D

KEY: * = Preferred Option
Blank = Acceptable Option
REJECT = Unacceptable Option

6.4 PAYLOAD DEVELOPMENT AND INTEGRATION

6.4.1 Introduction

Three different classes of science instrumentation are planned to be flown on the Space Station by OSSA. These include:

(1) Major research facilities which have been identified with science user community support and advice and are developed by the government for use by this community. Examples of such facilities are the SIRTF mirror and cryogenic cooling system and the microgravity research facilities;

(2) PI-developed instruments which transition to multi-user facilities, usually with a continuing PI support role or with a surrogate PI support role (e.g., the HST science instruments and the OSSA portion of the Earth Observing System (EOS) payload); and

(3) Small (low-cost) PI-developed instruments which may be used with a major facility or flown as independent elements but whose limited capabilities make them unsuitable for upgrade to facility status.

To a first approximation, the first class of instrumentation would be developed by the OSSA disciplines when the facility is a major technological challenge and acts as a "collector" or similar support system for an entire scientific payload (the SIRTF example) or when the facility serves multiple disciplines and multiple users and the user disciplines are relatively new and do not have a strong tradition of space instrument development (the microgravity research facility example).

The second and third classes of space instrumentation are generally preferred by the Observing Disciplines (Astrophysics, Earth Sciences, and Solar System Research) for their attached payloads, platform payloads, or small carrier (e.g., Spartan) payloads. These communities have been developing space instrumentation from the earliest days of the U.S. space program. They believe that the best sensors can only be built by scientists with a vested interest in the performance of the instrument

and are willing to risk bias in design in return for high quality performance.

The activities that are included in payload development and integration have been discussed in Section 4.3 and will not be reiterated here. The programs are managed hierarchically, starting with a Headquarters Program Office which manages the program's scientific content, technical progress, budgets, and schedules at a policy level. Next, a field center Project Office has primary responsibility for day-to-day management of the program's facility and/or payload developments. Within the Project, individual PI instruments and project-unique support systems are developed in-house or externally, and the project elements are tested individually and integrated with each other. Integration of the Project's flight-system and ground-system elements with the Space Station might be a Project responsibility or might be the responsibility of some other organization also managed by the Program Office.

Clearly in this hierarchical development and integration sequence, there exists a hierarchical set of management options which are, to some extent, interdependent. Thus, the selection of certain program management options will influence the set of project management options available, and so on down the management chain. This interdependence has been taken into account in the following discussions. Further, the two major classes of Space Station science users, the Microgravity Disciplines and the Observing Disciplines, frequently prefer different management options because of the traditions of their communities and because of the way in which their research is conducted on the Station. These community differences and their rationale are discussed below and the options and community preferences are summarized in Table 3 at the end of this Section.

6.4.2 Program and Project Management

The following discussion pertains to NASA science program and project management. It is assumed that other U.S. agencies planning to use the Station as a base for scientific research have similar options and must make similar decisions.

6.4.2.1 Integrated Program Management

Three options for the Program Management of the OSSA Space Station science programs are illustrated in Figure 12 and are discussed below.

OPTION 6.4.2.1 A:

In this first option (shown in Figure 12a), the Program Office for a sub-discipline's facility or payload development is located within the sub-discipline management organization within Headquarters. Several different Program Offices could, therefore, reside within a single division (discipline organization). A Space Station Integration Office (SSIO) would provide staff support to the OSSA Associate Administrator to assist in integrated OSSA Space Station program planning and to support the various Program Offices in their interactions with the Space Station program.

This is the management option preferred by most of the Observing Disciplines. It would allow each Program Office to be staffed by persons knowledgeable in the scientific requirements and technical approaches of its respective sub-disciplines since these requirements and approaches differ markedly from sub-discipline to sub-discipline. It would also allow the programs managed by these Program Offices to be of "manageable" size and would elevate conflict resolution between competing sub-discipline programs to the Director level where the scientific, programmatic, and financial aspects of the conflict could best be assessed.

The approach would be possible for the Observing Disciplines because of the loose coupling required among the flight hardware development activities undertaken by their sub-disciplines. More tightly integrated programs (e.g., OSSA-wide supporting infrastructure developments) could still be accommodated within this option by placing their management at a higher level in the OSSA management hierarchy (e.g., under the management of the SSIO). Finally, an OSSA-wide Station activity, which might require special Station knowledge and agreements (like the "rapid-response research" program), could be managed by the SSIO or by any of the other OSSA Divisions as a support service to the rest of the OSSA Station user communities.

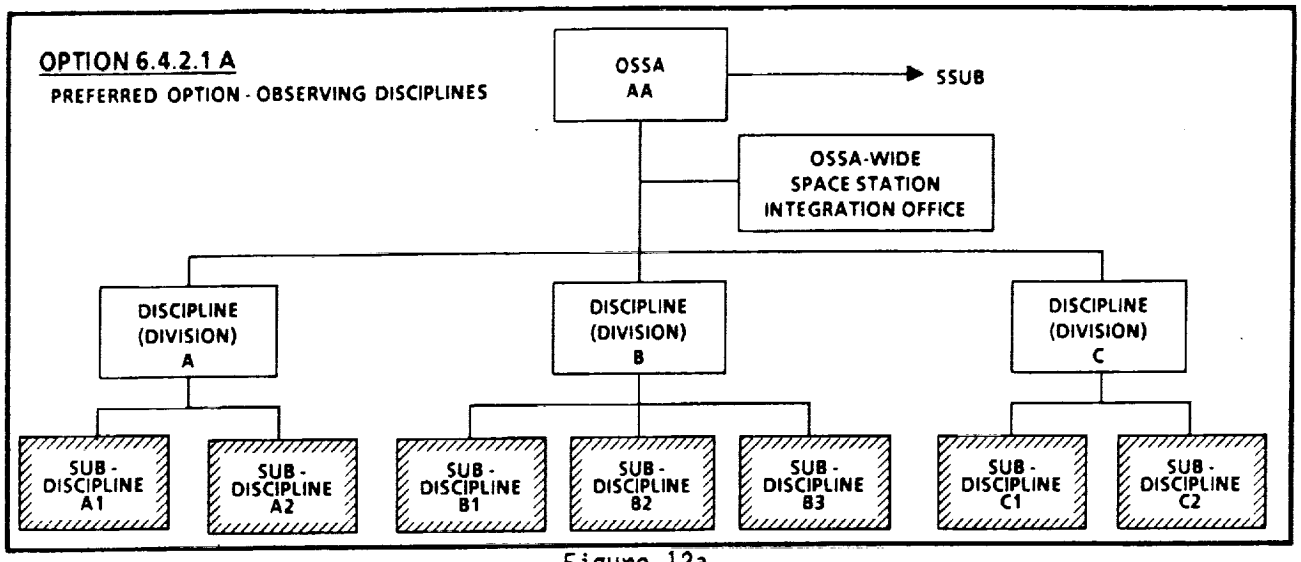

Figure 12a.

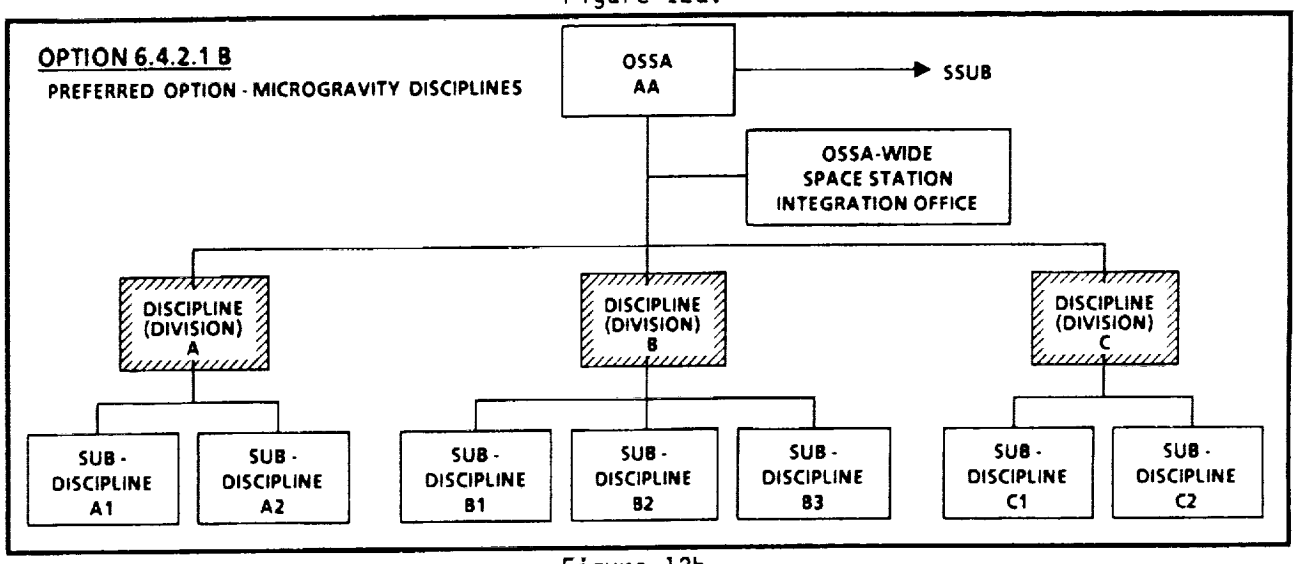

Figure 12b.

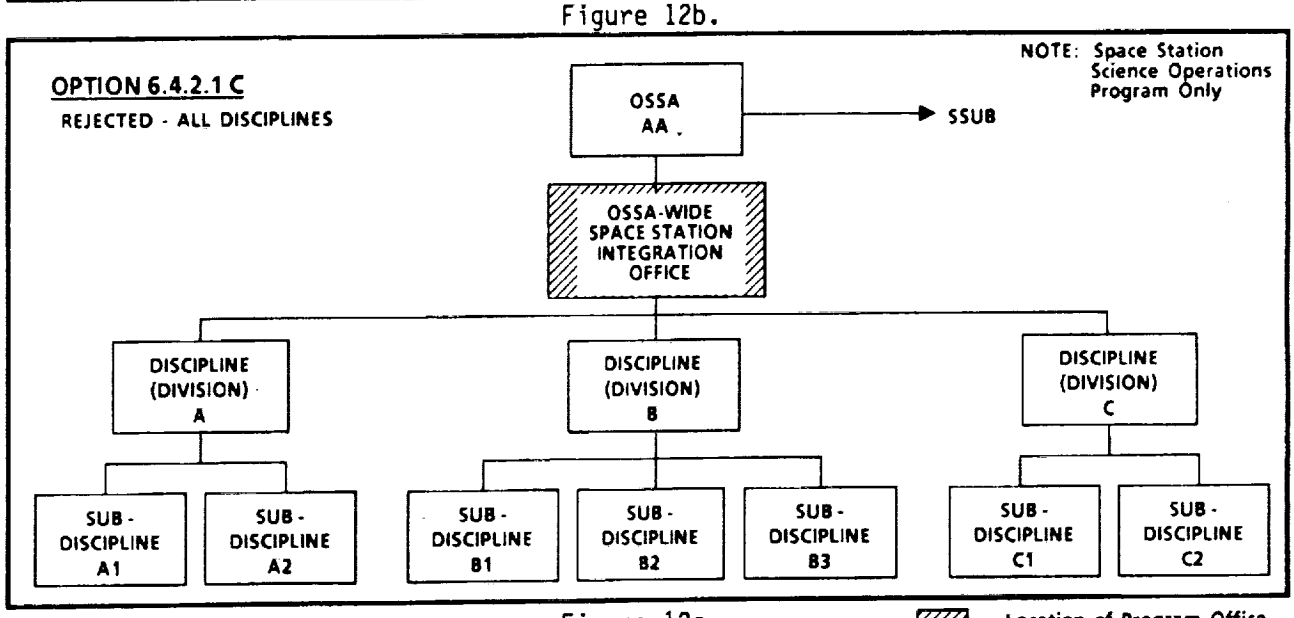

Figure 12c.

= Location of Program Office

Figure 12. Integrated Space Station Science Operations Program Management

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OPTION 6.4.2.1 B:

In this option (which is shown in Figure 12b), the management of the various sub-discipline development activities would be clustered at the discipline level. Such clustering would better accommodate the development of facility-class instrumentation which is shared by several sub-disciplines within a division. It would also reduce the number of Program Offices managed by each Director. The clustering would, however, increase the workload of each Program Office and possibly introduce conflicts in priorities within a Program Office.

This is the preferred option of the Microgravity Disciplines of Life Sciences and Materials Sciences, both of which would derive considerable programmatic advantage from an integrated planning and management approach because of their sub-discipline-shared research facilities. An added advantage of this option is that a strong Headquarters discipline level Program Office could resolve conflicts among the several different field center Project Offices responsible for the next level of program management.

OPTION 6.4.2.1 C:

In the final option (shown in Figure 12c), the management of the various OSSA discipline and subdiscipline Space Station development activities would be clustered into a Program Office (or group of Program Offices) located within the SSIO. This approach would offer the advantage of the strongest coupling with the Station but would suffer the disadvantages of scale (too large) and of a decoupling between hardware development and user representation. While some precedent for this approach exists within the OSSA Spacelab program, it is not favored by any of the user communities.

6.4.2.2 Integrated Project Management

The selection of an appropriate Project Management option should be dependent on the size and complexity of the program to be managed as well as on the content of the program and the character of the community. The three major management options are identified in Figure 13 and are discussed below.

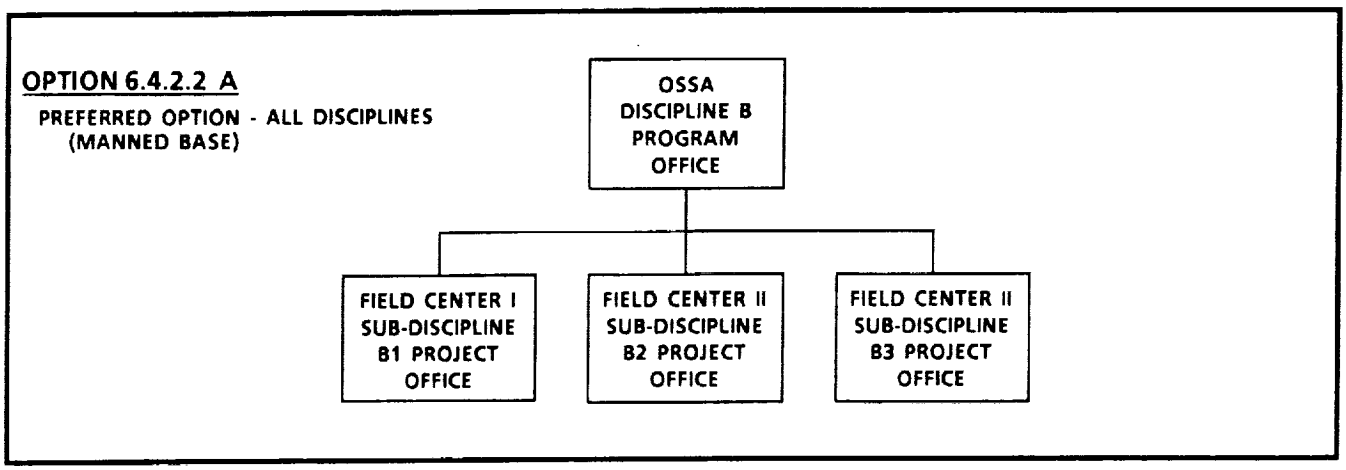

Figure 13a.

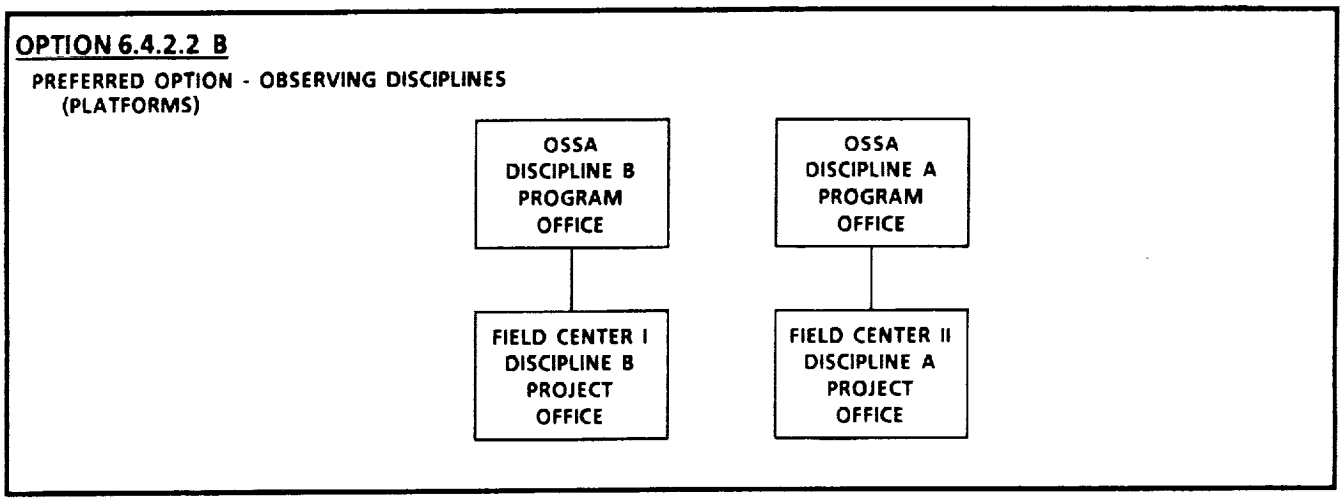

Figure 13b.

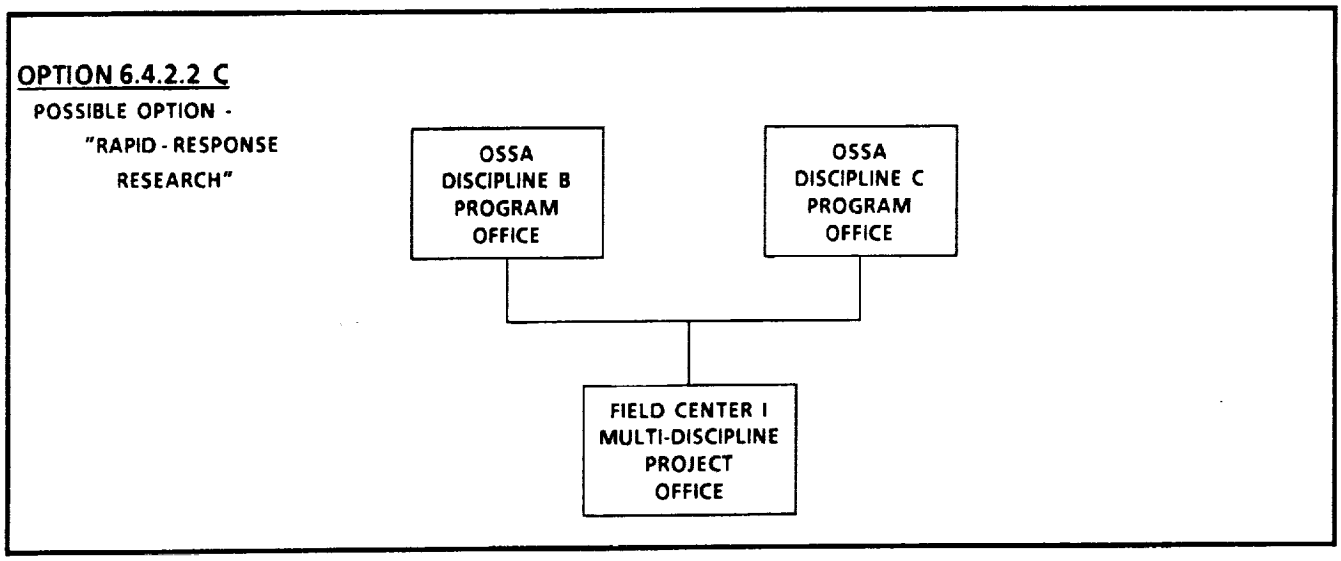

Figure 13c.

Figure 13. Integrated Space Station Science Operations Project Management

OPTION 6.4.2.2 A:

In this first option (shown in Figure 13a), the Program Office's development activities would be divided among several different Project Offices located at different NASA field centers. This option would allow the centers to continue to specialize in the management of discrete areas of science or technology while enabling the sub-discipline or discipline to plan and implement a coordinated program which involves several such areas. An example of such an approach is the planned Life Sciences program in which NASA's Ames Research Center (ARC) would have project management responsibility for plant- and animal-related Life Sciences research and NASA's Johnson Space Center (JSC) would have project management responsibility for human-related Life Sciences research.

OPTION 6.4.2.2 B:

An option more frequently encountered within current OSSA Programs is a one-to-one correlation between the headquarters Program Office and a field center Project Office (see Figure 13b). A candidate for this type of management approach might be the Astrophysics Division's planned SIRTF program and the Earth Sciences planned EOS program. Both of these activities are sufficiently large to warrant a focussed management effort at both the Program and Project levels.

OPTION 6.4.2.2 C:

In some rare circumstances (e.g., when sub-disciplines or disciplines share the same facility or when a specialized class of development is required), an option might be selected in which a single Project Office assumed responsibility for the management of a program involving two or more disciplines, each of which had its own Program Office. This arrangement is shown in Figure 13c. Neither of the Microgravity Disciplines favors such a management structure because of its obvious programmatic problems, even though they share some facilities and have similar management approaches. Also it would imply project management of a highly diversified, multi-center development activity by a single NASA field center. However, it is possible that the "rapid-response research" program could be managed in this way (i.e., that "rapid-response research"

Program Offices in several of the OSSA divisions could manage their programs through a single "rapid-response research" Project Office).

Each of the three options discussed above may offer some advantages for different elements of the OSSA Space Station Program. It is important, therefore, to retain flexibility in the selection of the program and project management structure for different elements of the program to allow the best approach to be chosen for each element.

6.4.3 Flight Hardware Development

All of the management options so far identified have assumed that the management responsibility for the development in question should remain within the government. At a certain stage, for programs that are sufficiently well-defined and whose costs are moderate or low, the responsibility for managing the development of flight hardware could be delegated to organizations outside the government. The two hardware development options presented in this section deal with this choice of in-house versus external management of small-to-moderate hardware developments. The options are illustrated in Figure 14.

OPTION 6.4.3 A:

The management structure for a traditional NASA development program is shown in Figure 14 a. It is typical of the approach proposed by the Materials Sciences community for the development of its integrated set of Space Station facilities. The option assumes the development of several facility elements for which both Principal Investigators and users have been selected. The PIs and users together form a series of science working groups (SWGs) which guide the development of each facility element. In the case of the Life Sciences facilities, the SWG is an ad-hoc group, formed from researchers working in the appropriate areas of the Life Sciences program.

In this option, management responsibility for all major hardware and infrastructure elements would be retained within the government. Only the PI-instrument developments would be allowed to be managed external to the agency. Even then, the management responsibility delegated to the PI

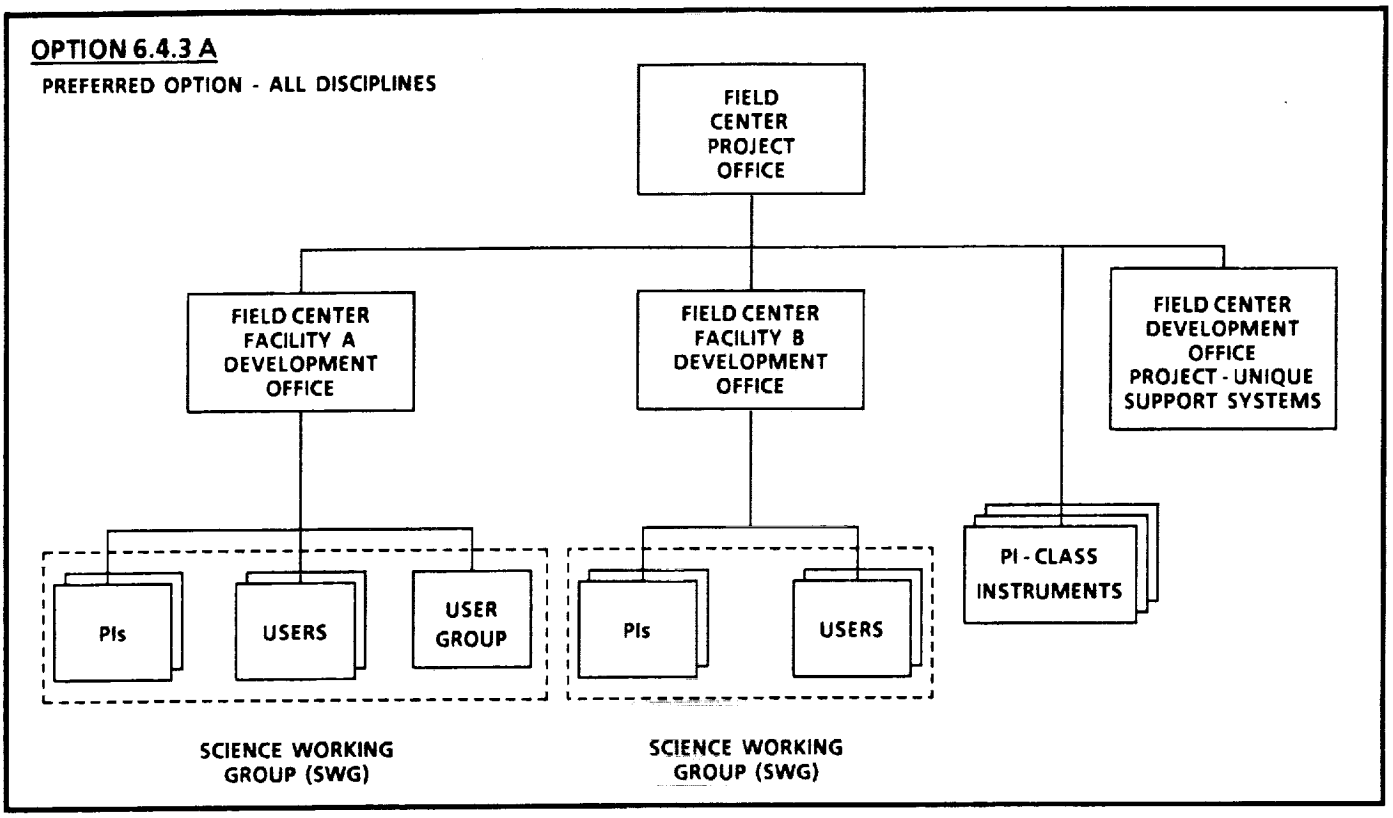

Figure 14a.

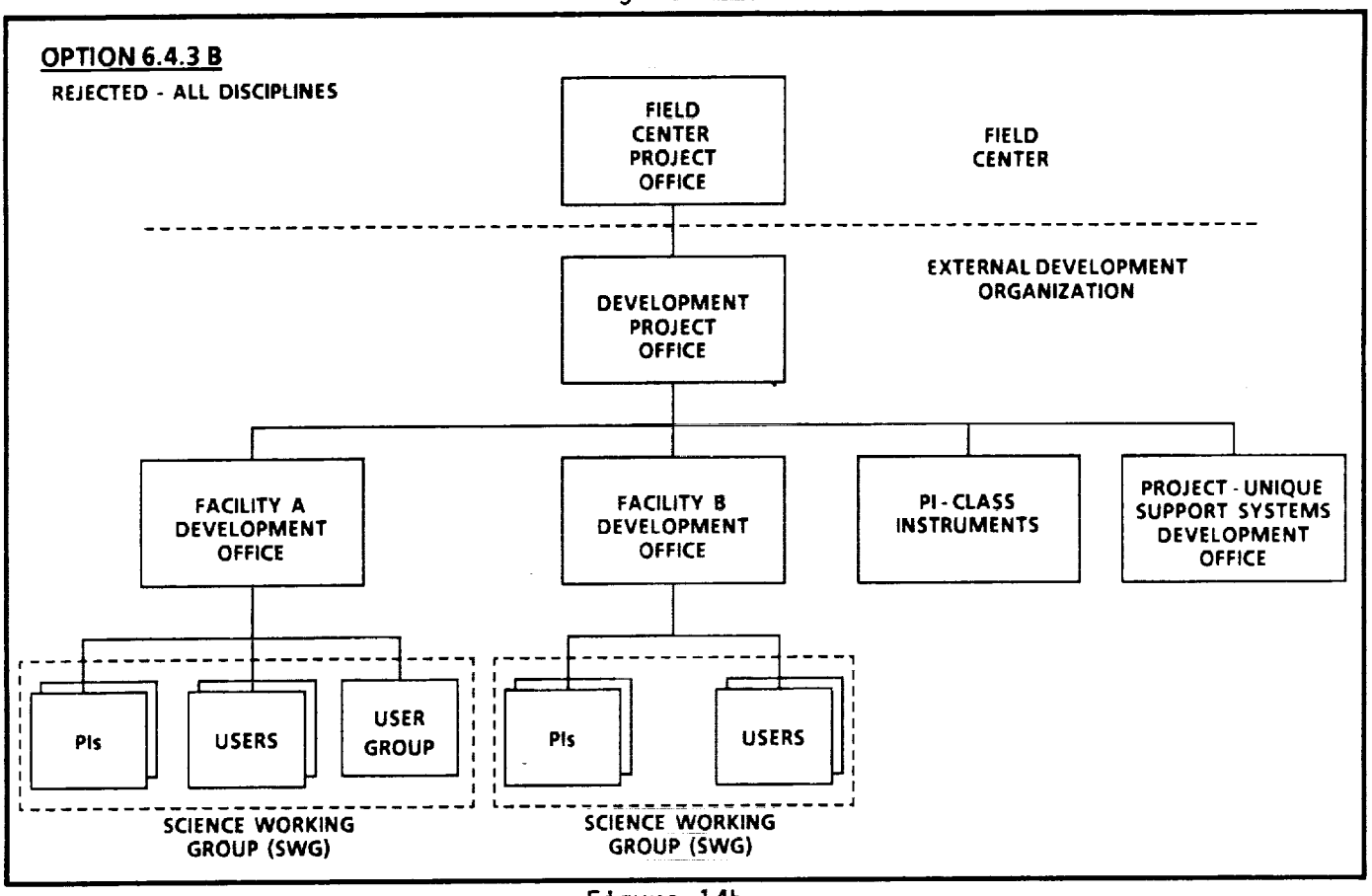

Figure 14b.

Figure 14. Flight Hardware Development

would be similar to that delegated to a prime contractor (i.e., the product being developed would be well-defined, the costs and schedules well-understood, and sufficient NASA-managed technical and programmatic reviews would be scheduled to ensure successful development of the PI-instrument). This approach is considered necessary by most of the users involved in this study because the cost of some of the more sophisticated current PI-class instruments can reach 50 to 100 million dollars.

OPTION 6.4.3 B:

In the second option (shown in Figure 14b), the management responsibility for developing a major facility (together with its associated science payload) would be delegated to an outside organization, for example a Science Institute. Although the use of the SWG is still indicated, such an option would give the external management organization the freedom to use whatever advisory approach it desired to guide the development of the facility. It would also remove much of the day-to-day control of science and technical tradeoffs and cost and schedule performance from the NASA Project Office.

None of the science user representatives participating in this study, regardless of affiliation, felt comfortable with this approach because of the high level of technical and management skill required of the facility development management organization and because of the risk involved to NASA and the community. Further, some members of the Materials Sciences community have indicated a preference for dealing with government managers rather than with their peers because of possible conflicts of interest resulting from the highly competitive environment.

6.4.4 Flight Hardware Integration and Test

A final development program management decision, to be made by NASA and other participating U.S. Space Station science users, is the management approach to be adopted for flight hardware integration and test. As in the previous choices discussed, the best solution to the management of flight hardware integration and test may differ from discipline to discipline and from program to program. The three major management options identified for this activity are shown in Figure 15.

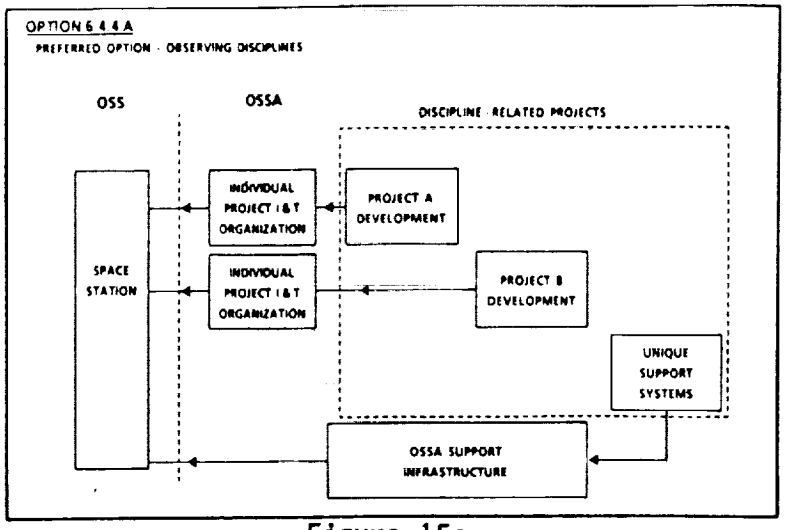

Figure 15a.

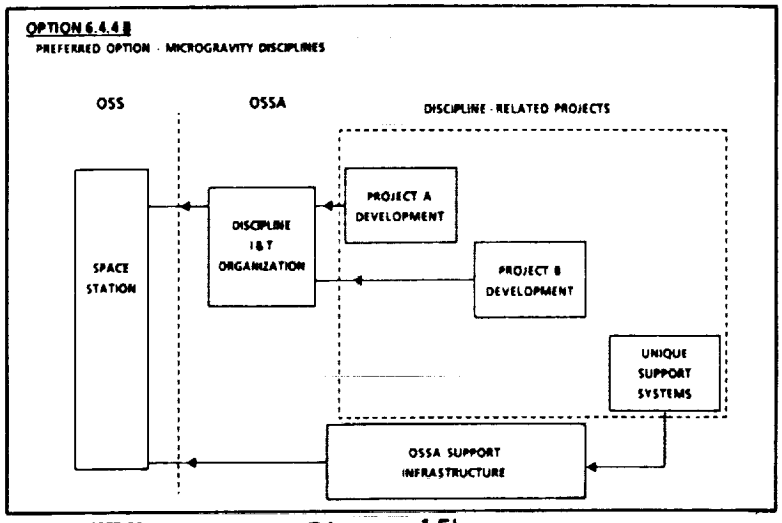

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Figure 15b.

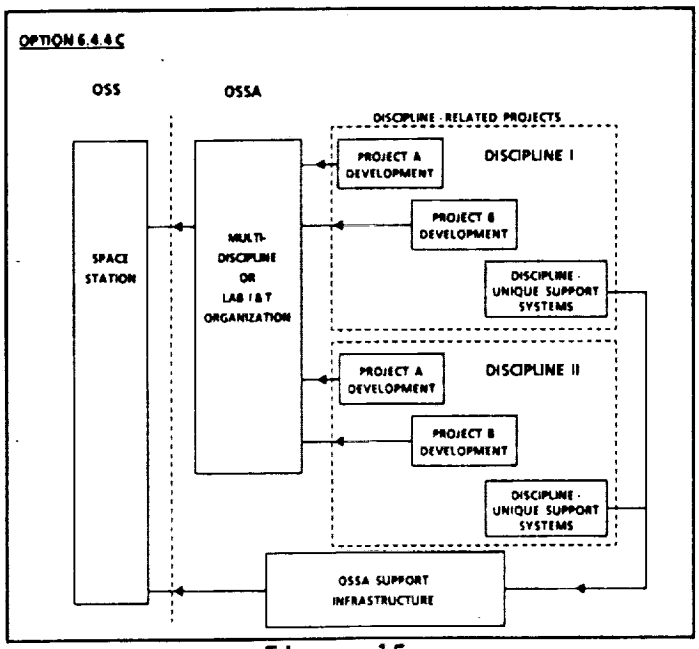

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Figure 15c.

Figure 15. Flight Hardware Integration and Test (I&T)

OPTION 6.4.4 A:

In the first option (shown in Figure 15a), each separate facility development or integrated program development would have its own unique integration and test organization. This organization would interface directly with the Space Station. The project-unique support systems (e.g., operations and data systems) would interface with an OSSA (science user-wide) infra-structure which would, in turn, interface with the Station's support systems. The advantage of such an approach would be the management control that each facility development office or integrated program development office would have over the integration and test process. The disadvantage would be the proliferation of such organizations, the duplication of effort, the large demand for Station interface simulators, and the drain on Station user support services.

This is the preferred option of the Observing Disciplines, particularly for their platform programs and larger, facility-class attached payloads.

OPTION 6.4.4 B:

In the second option (shown in Figure 15b), the integration and test activities for a number of discipline-related developments would be clustered within a single organization at the discipline level to maximize use of Station expertise and discipline-unique support equipment and facilities and to minimize the drain on the Station's support services and interface simulator requirements. This is the approach currently preferred by the Microgravity Disciplines. It is also still being evaluated by the Observing Disciplines who still consider it a viable option for some of their programs.

OPTION 6.4.4 C:

In the third option, several different disciplines share a common integration and test organization (see Figure 15c). Such an approach might be advantageous for the Microgravity Disciplines of Life Sciences and Materials Sciences which share some common laboratory facilities. It would provide a center where the complementary instrumentation developed by the various disciplines could be assembled as an integrated unit. The approach

would also enable larger and more realistic Space Station interface simulators to be developed since fewer simulators would be required. It would, however, offer the normal disadvantages of shared management responsibilities and size of organization. The option is still being evaluated by the Microgravity Disciplines. An indication of how the Life Sciences community might approach the integrated activity is shown in Figure 16.

6.4.5 Summary

A summary of the management options considered for payload development and integration is shown in Table 3 together with an indication of the preferences of the various user communities. As indicated throughout this discussion, it has been assumed that the other U.S. agencies participating in the Space Station science program will be faced with similar management decisions and options. In the case of the OSSA Life Sciences and Materials Sciences programs, the NASA scientists and their communities are prepared to share with their non-NASA colleagues the facilities and expertise that NASA has developed. Thus, while the other U.S. government agencies may develop their own flight hardware, it is anticipated that this hardware will be integrated into the U.S. Life Sciences and Materials Sciences research facilities by the respective division's Payload Integration Offices or by the combined laboratory level (dual-discipline) integration office.

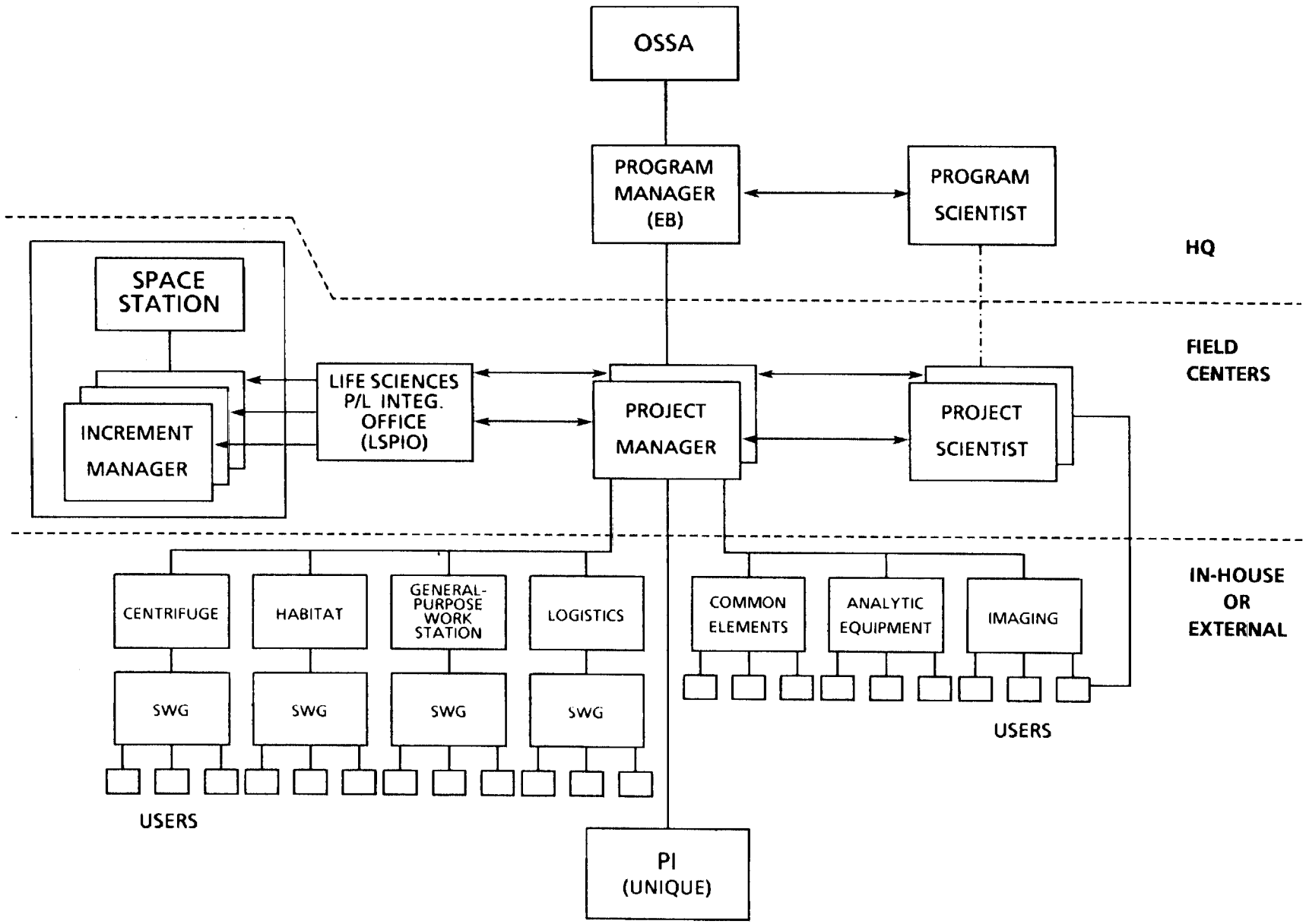

Figure 16. Management Structure for Life Sciences Space Station Payload Development

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TABLE 3. MANAGEMENT OPTIONS FOR PAYLOAD DEVELOPMENT AND INTEGRATION (NASA PAYLOADS)

ACTIVITY	MICROGRAVITY DISCIPLINES		OBSERVING DISCIPLINES	OPTION #
	PREFERENCE	OPTION DESCRIPTION	PREFERENCE	
INTEGRATED PROGRAM MANAGEMENT		MANAGED AT OSSA AT:		
		- SUB - DISCIPLINE LEVEL	*	6.4.2.1 A
		OR		
	*	- DISCIPLINE LEVEL		6.4.2.1 B
		OR		
	REJECT	- OSSA - WIDE LEVEL	REJECT	6.4.2.1 C
INTEGRATED PROJECT MANAGEMENT	*	PROGRAM OFFICE MANAGES SEVERAL PROJECTS AT DIFFERENT CENTERS		6.4.2.2 A
		OR		
		PROGRAM OFFICE MANAGES A SINGLE PROJECT	*	6.4.2.2 B
		OR		
		SEVERAL RELATED PROGRAMS SHARE SAME PROJECT ORGANIZATION	* (RAPID-RESPONSE RESEARCH)	6.4.2.2 C
FLIGHT HARDWARE DEVELOPMENT	*	FIELD CENTER MANAGEMENT OF DEVELOPMENTS WITH IN - HOUSE OR EXTERNAL PI s	*	6.4.3 A
		OR		
	REJECT	EXTERNAL MANAGEMENT OF TOTAL DEVELOPMENT	REJECT	6.4.3 B
FLIGHT HARDWARE INTEGRATION AND TEST		EACH DEVELOPMENT PROJECT WITHIN DISCIPLINE MANAGES ITS OWN INTEGRATION & TEST ORGANIZATION	*	6.4.4 A
		OR		
	*	EACH DISCIPLINE MANAGES ITS OWN MULTI - PROJECT INTEGRATION & TEST ORGANIZATION		6.4.4 B
		OR		
		RELATED DISCIPLINES SHARE A MULTI-DISCIPLINE - OR LAB - LEVEL INTEGRATION & TEST ORGANIZATION		6.4.4 C

KEY: * = Preferred Option
Blank = Acceptable Option
REJECT = Unacceptable Option

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6.5 TACTICAL AND INCREMENT PLANNING FOR SCIENCE OPERATIONS

6.5.1 Introduction

The activities which comprise science tactical and increment planning were summarized in Section 4.4. They represent the most intensive analytical interface between the science hardware development and the Space Station planning function. The timescale over which these activities extend overlaps with both the development and the operations activities (see Figure 7). For this reason, they can be the responsibility of a development organization, an integration organization, or an operations organization. Further, these activities can be sub-divided into three basic areas for which different management decisions must be made. These are:

(1) The development of policy-level priorities and program trades which are needed for the development of the Space Station manifest (i.e., the decisions which determine which instrument or investigation is flown on each Space Station increment) (see Section 3.5);

(2) The development of detailed flight activity plans, crew support plans, crew training support, integrated science operations analyses, coordinated science timelines, flight simulations, and logistics plans; and

(3) The management interface with the Station for the development of increment plans, timelines, support, and procedures.

The management options for these three areas are discussed in the following sections.

6.5.2 Science Payload Manifesting Priorities and Trades

Only one possible management option is acceptable for the determination of which instrument or investigation is included on each increment. This option is presented below.

OPTION 6.5.2 A:

In this option, which was preferred by most of the U.S. science user communities involved in this study, the final determination of the complement of science investigations or instruments to be flown on a given

increment would be a Headquarters decision. While recommendations would be made by the Station managers and by the managers of the individual science instrument and facility development, integration, and operations organizations, the integration of these recommendations with science discipline priorities and programmatic considerations would only occur at the OSSA level.

6.5.3 Science Operations Tactical and Increment Planning and Crew Training

Since the activities associated with the tactical planning, increment planning, and crew training for science user instruments and facilities are so interrelated, they should be closely coordinated. Such coordination implies a single organization responsible for the management of these activities, even though they may be supported by several different organizations. To support this process, an Investigator Working Group (IWG) comprising representatives of each payload or investigation "manifested" in an increment would also be formed (see discussion in Section 6.6).

Three options are identified for this single management organization. These options are illustrated in Figure 17 and are presented below.

OPTION 6.5.3 A:

In this option (see Figure 17a), the development organization (whose selection was discussed in Section 6.4.3) would assume the responsibility for tactical planning, increment planning, and crew training. The advantage of this approach is that this organization would have the best insight into the instrument or facility physical interfaces with the Shuttle and Space Station. It might not, however, have the best insight into the operational requirements of the system which it was developing.

OPTION 6.5.3 B:

For disciplines like Life Sciences and Materials Sciences, each of which may use a Payload Integration Office (PIO) to integrate payloads developed by different project organizations, considerable benefit may be gained from having the PIO assume responsibility for tactical and increment

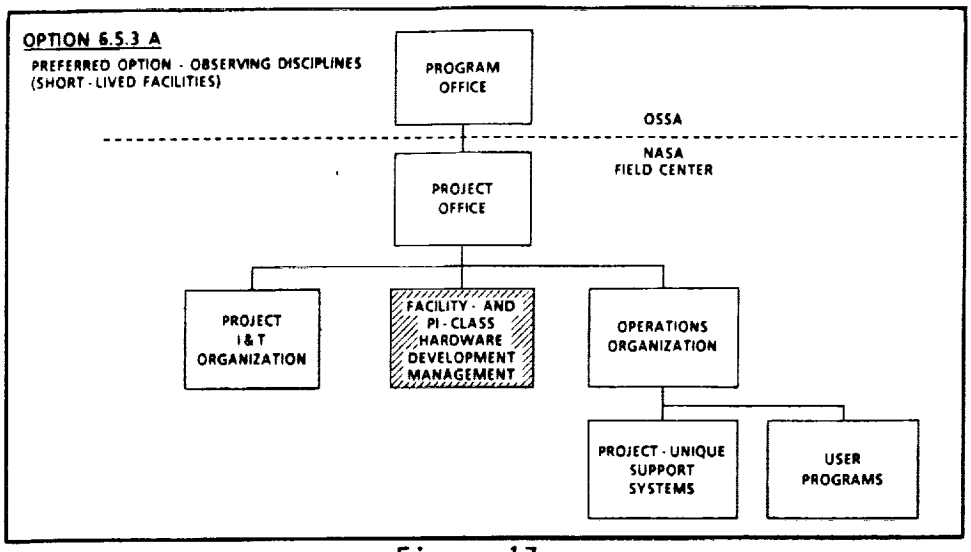

Figure 17a.

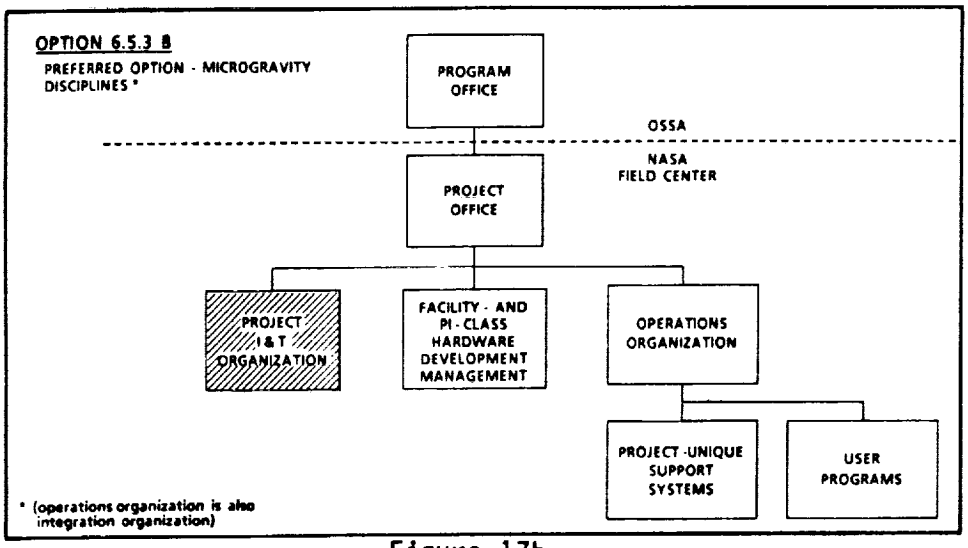

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Figure 17b.

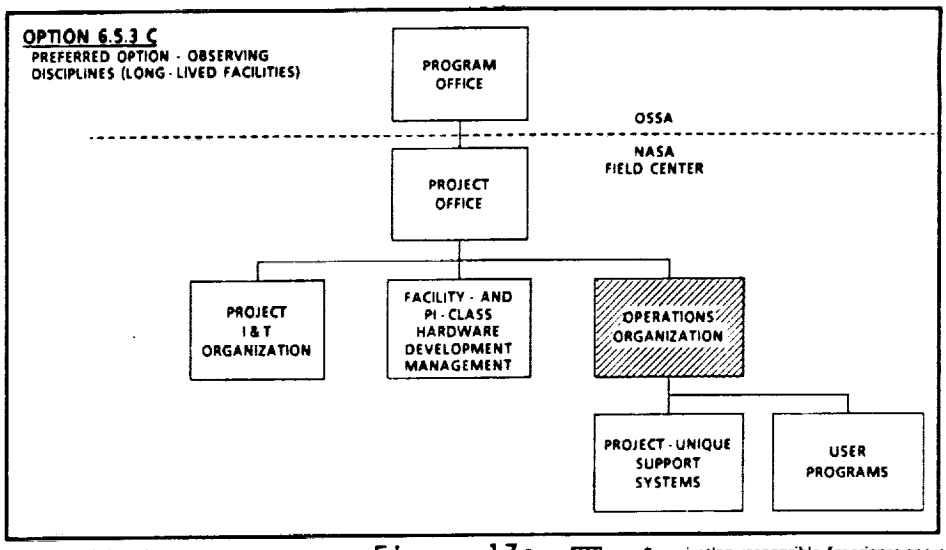

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Figure 17c. ▨ = Organization responsible for science operations tactical and increment planning

Figure 17. Science Operations Tactical and Increment Planning Options

planning and crew training (see Figure 17b). While such an organization would not have the same depth of knowledge of the flight hardware that would be available through the development center, it would have a broader perspective when it came to the operation of that hardware. Also, since the organization would be the site of the Station interface simulators, it would offer the crew an opportunity to train to use and operate the instrumentation in an environment which was relatively representative of the on-orbit conditions.

OPTION 6.5.3 C:

Finally, for long-lived facilities, responsibility for the long-term operations and sustaining engineering support of the facility might be transitioned from the development center to an operation center (see Figure 17c and Section 6.6.3). Thus for this class of Station programs, the initial development center would no longer be the appropriate organization to handle the tactical and increment planning for later flights of the facility. Rather, the operations center would assume management responsibility for the tactical planning and increment planning of the facility from the earliest phases of the program but would rely heavily on the development center inputs for the definition of Station mechanical and electrical interfaces, transport requirements and constraints, service support requirements, etc.

It is clear that none of the above options provides the "best" solution for all science investigations on the Station. Instead, it is clear that each discipline or program should select the approach which best suites the development and operations approach selected for its instrument or facility. Further, it should be noted that all of the approaches should be equally acceptable to the Station, provided that a single planning interface is defined between the Station and the Program and that this interface works (i.e., the program organization representing the instrument or facility can access the information necessary for Station planning in a timely and accurate way).

6.5.4 Increment Management

Once formal increment assignments are made, the orientation of the science operations process will change from individual payload developments to an assemblage of many payloads into a single operations entity. This assemblage of payloads, involving the sponsorship of many national and international organizations, is likely to include clusters of complementary instruments and equipment and other completely independent instruments and equipment. The most-analogous experience to this situation is the Shuttle-based Spacelab missions. In these missions, sets of diverse, international, multi-disciplinary instruments were grouped together and formed unified operational units. The instruments co-existed and were concurrently operated, synergistically in some cases, within a common overall Shuttle resource envelope. Resources of power, data, communications, thermal control, Shuttle attitude, and crew support were shared and distributed to the instruments in a scheduled and controlled manner by means of a formal timeline.

The science management practices developed and evolved by the Spacelab Programs have proved to be quite effective in satisfying and balancing the science needs of a large collection of instruments within a common resource envelope. The Spacelab management process (which is quite intricate) has the following principal elements:

(1) A MISSION MANAGER: who has overall responsibility for physical and analytic integration of the science payload, mission planning, and mission execution. He or she is an employee of a NASA field center and reports to OSSA;

(2) A PAYLOAD OPERATIONS DIRECTOR: who has responsibility for the control and execution of realtime mission payload operations. He or she is an employee of a NASA field center and reports directly to the Mission Manager;

(3) A MISSION SCIENTIST: who is responsible for representing and coordinating the science interests of the overall integrated payload. He or she is an employee of a NASA field center and reports to OSSA; and

(4) An INVESTIGATOR WORKING GROUP (IWG): consisting of all Principal Investigators and other science users (as appropriate) who participate in the mission. The IWG provides the forum in which unified science positions on all matters pertaining to the mission are developed. The IWG is chaired by the Mission Scientist.

Certain aspects (or possibly the entire set) of Spacelab management practices might be appropriately applied to Space Station science operations. Specifically, many of the study participants believed that a Mission Increment Scientist should be used for Space Station science operations. In addition, it could be beneficial to assign a Science Increment Manager (SIM) and a Payloads Operations Director from a payload organization to work with (or in place of) their Space Station counterparts.

The SSSOMC study participants discussed the applicability of these aspects of the Spacelab process to Space Station but did not develop recommendations. It was concluded that detailed consideration of the matter should be included in the follow-up study of the SSOTF report, thereby allowing adequate time for an in-depth treatment of the subject and a thorough analysis of the Space Station plans.

6.5.5 Summary

The options identified for Tactical and Increment Planning for Science Operations are shown in Table 4. Also shown are the preferences of the two families of Space Station science communities.

TABLE 4. MANAGEMENT OPTIONS FOR TACTICAL AND INCREMENT PLANNING FOR SCIENCE OPERATIONS (NASA PAYLOADS)

ACTIVITY	MICROGRAVITY DISCIPLINES		OBSERVING DISCIPLINES	OPTION #
	PREFERENCE	OPTION DESCRIPTION	PREFERENCE	
SCIENCE PAYLOAD MANIFESTING PRIORITIES AND TRADES	*	MANAGED AT OSSA - LEVEL WITH SUB - DISCIPLINE / DISCIPLINE INPUTS	*	6.5.2 A
SCIENCE OPERATIONS TACTICAL AND INCREMENT PLANNING AND CREW TRAINING	*	MANAGED BY: - THE DEVELOPMENT ORGANIZATIONS (SEE 6.4.3) OR - THE INTEGRATION ORGANIZATIONS (SEE 6.4.4) OR - THE OPERATIONS ORGANIZATIONS (SEE 6.6.2)	* (SHORT-LIVED INSTRUMENTS AND FACILITIES) * (LONG-LIVED FACILITIES)	6.5.3 A 6.5.3 B 6.5.3 C
INCREMENT PLANNING MANAGEMENT		TBD (SEE 6.5.4)		

KEY: * = Preferred Option
Blank = Acceptable Option
REJECT = Unacceptable Option

6.6 SCIENCE OPERATIONS AND DATA MANAGEMENT

6.6.1 Introduction

The numerous activities which are associated with science operations and data management are identified in Section 4.5. They can be clustered into the following groups of activities for which management options may be defined:

(1) Operations support of investigations undertaken in the Station's pressurized laboratories or attached payloads;

(2) Operations support of Platform payloads;

(3) Sustaining engineering and servicing support;

(4) Initial Data Processing, Data Distribution, and Sample Return; and

(5) Science Data Analysis and Archival Storage.

These five groups of activities are discussed below, and the management options identified for them are summarized in Table 5 at the end of this section. Also included in the discussion and table is an indication of the preferences of the various user communities, as represented by the participants in this study.

6.6.2 Operations Support

As indicated in Section 3.5, the Space Station program plans to form an Investigator Working Group (IWG) to help plan each increment of the Station's operations. This IWG would be the primary user voice in the day-to-day tradeoffs and decisions which would be made in the Station user operations plans. Further, the Space Station Operations Task Force has proposed a Payload Operations and Integration Center (POIC) whose responsibility would be the planning and implementation of all user operations on the manned base, and a Platform Support Center (PSC) which would manage the operations of the Station's polar and co-orbiting platforms.

On the user side, the Task Force assumed that an operations organization would be set up to:

(1) Support the discipline's or sub-discipline's PIs and users in planning and executing their on-orbit activities;

(2) Integrate the operations of the PIs and users within a sub-discipline or discipline into a coherent program;

(3) Assist the PIs and users in the use of telescience capabilities;

(4) Act as an initial data processing facility and data distribution node for users served by the organization;

(5) Develop centers of Space Station operations expertise within the user communities; and

(6) Limit the number of independent operations interfaces with the Station (POIC) and with the Space Station Information System (SSIS).

The management options for the user support organization are discussed in Sections 6.6.2.1 and 6.6.2.2 below, and diagrams illustrating these options are provided as Figures 18 and 19 later in this document.

An issue of particular interest and importance to the Station's science user communities is that of autonomous payload operations. There are considerable scientific and programmatic advantages to be derived from autonomous (or semi-autonomous) operations of science payloads where such operations are feasible. For example, the ability to make fast changes in observing programs on the basis of preliminary results or in response to some transient event (like a hurricane or solar flare) may be an important factor in an investigation.

The users accept that the operational plans of the Station's laboratory payloads and of some of the Plasma Physics and potential Materials Sciences attached payloads should be integrated with the Station's operations at a detailed level because of their heavy and variable demands for Station resources (particularly crew time). However, such detailed integration of operations should not be required for many of the other Earth Sciences, Astrophysics, and Solar System Research attached payloads and platforms.

The criteria for semi-autonomous versus integrated operations are:

(1) The amounts of Station resources that are required by a given attached payload or platform for normal operations;

(2) The planned variability in these resource requirements; and

(3) The potential for unplanned changes due to either internal or external factors.

Thus, attached payloads which could operate within fairly constant envelopes of power and communications with little or no crew support during normal operations should be allowed to operate relatively autonomously (within a given resource envelope) until problems necessitate a change in the resource allocation.

The concept of providing semi-autonomous operations for undemanding Station payload elements is an important one from the science user standpoint. It is also consistent with the recommendations of the Space Station Operations Task Force and with the operational plans of the Space Station Program. All of the options identified in Section 6.6.2.2 for user science operations at the manned base would accommodate such operations.

In the case of the platforms, a far-greater degree of operational autonomy should be allowed (if the user of the platform is a single sub-discipline or discipline) since the platform would operate completely independent of the manned base. This would be the case for both the EOS and the SIRTF programs. This consideration drives the options illustrated later in Figure 20 and discussed in Section 6.6.2.3 below.

6.6.2.1 Internal or External Operations Organization

A simplified representation of a typical science investigation management organization showing the relationship of the operations organization to the development organization is shown in Figure 18. For all of the planned Space Station science programs (including platforms, attached payloads, and pressurized laboratory payloads), an important consideration is whether the operations management organization should be an in-house- or externally-managed activity. The pros and cons of these two approaches are discussed below.

OPTION 6.6.2.1 A:

The first option defined (see Figure 18a) would have an in-house (NASA field center) organization assume responsibility for payload

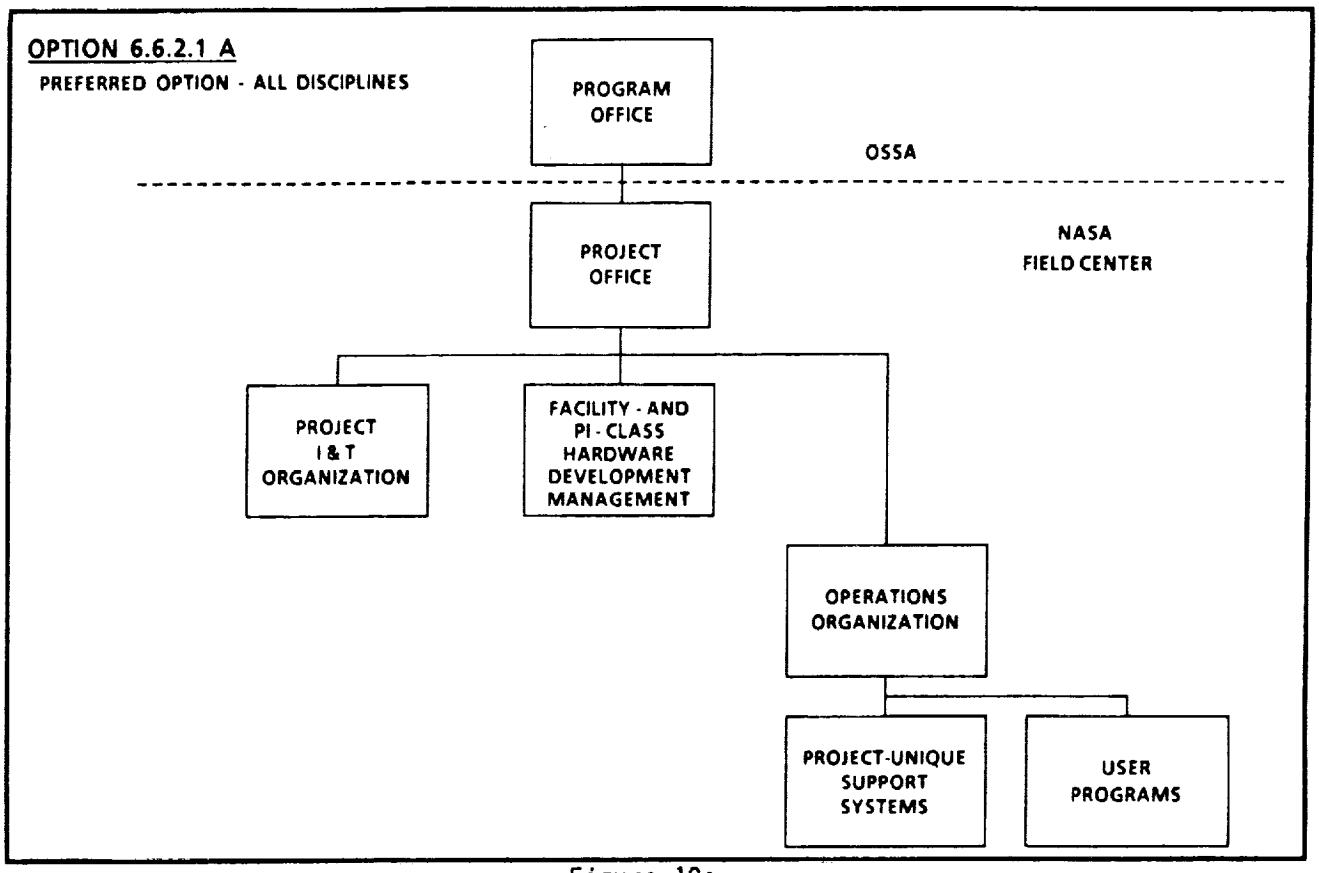

Figure 18a.

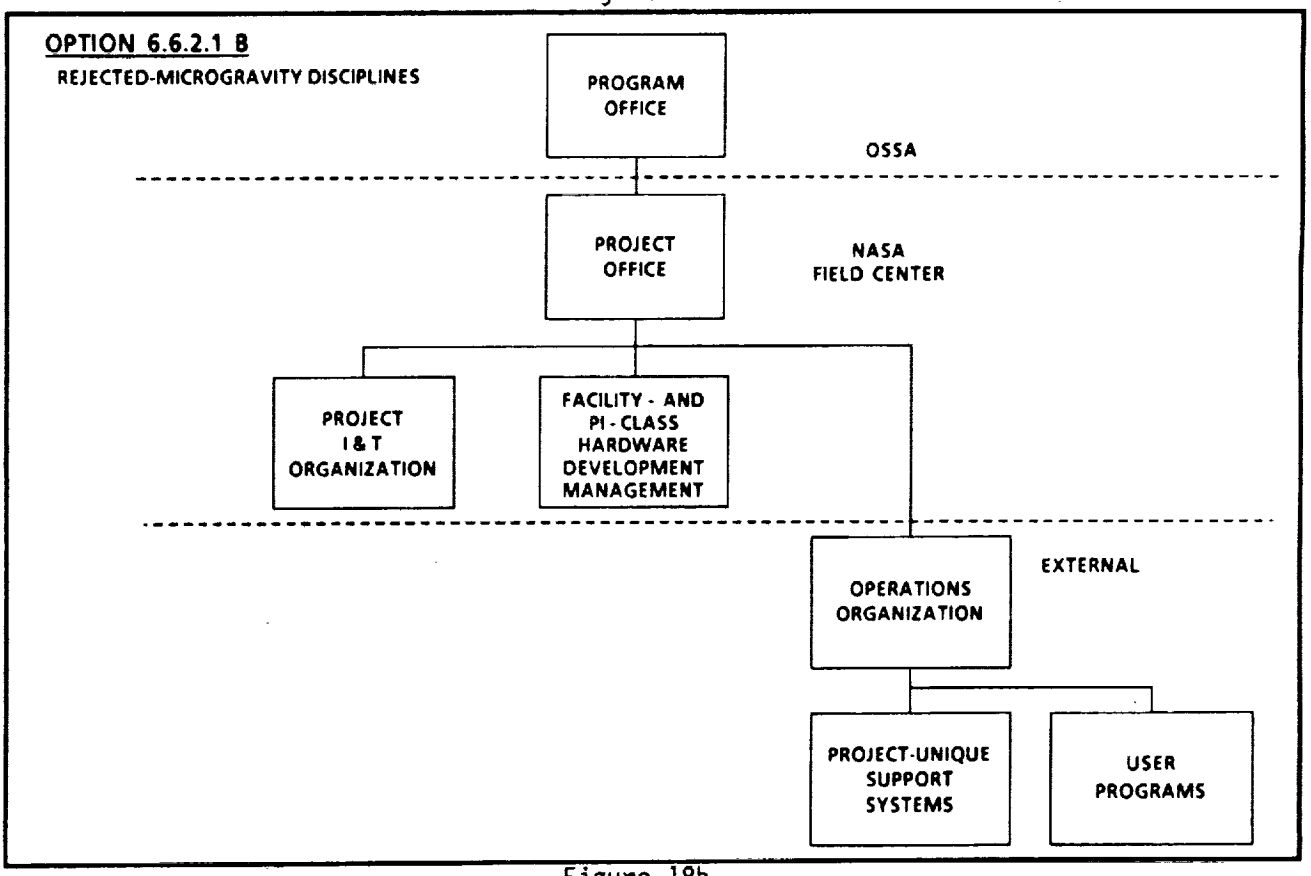

Figure 18b.

Figure 18. Operations Center Options (Typical Project Structure)

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operations. This is the option preferred by most of the users participating in the study, particularly those also favoring discipline-level or multi-discipline level operations organizations. The primary arguments favoring an in-house organization are:

(1) The multiplicity of different users that would need to be supported by the organization;

(2) The level of Station and user expertise needed by the organization to define and support science user operational requirements effectively;

(3) Freedom from conflict of interest (competition with the users);

(4) The level of expertise needed to use the Space Station Information System (SSIS) and OSSA Science and Applications Information System (SAIS) to support user operational and data requirements effectively; and

(5) The additional overhead costs for which funds might have to be found out of the users operational budgets to support the external organization.

OPTION 6.6.2.1 B:

The second option (see Figure 18b) would allow the operations management organization to be located at an external (non-NASA) center. A model for this approach is the Space Telescope Science Institute. Such an option could benefit facilities (like the HST) for which a relatively small community of PIs and users exists and for which relatively independent operations are possible. While not particularly favored by most of the user communities involved in this study (for the reasons outlined in Option 6.6.2.1 A above), it should remain an option for HST-like Station payloads.

6.6.2.2 Attached Payloads and Pressurized Laboratory Payloads

Three management options have been identified for the science user operations management organization. These are presented in Figure 19 and are discussed below.

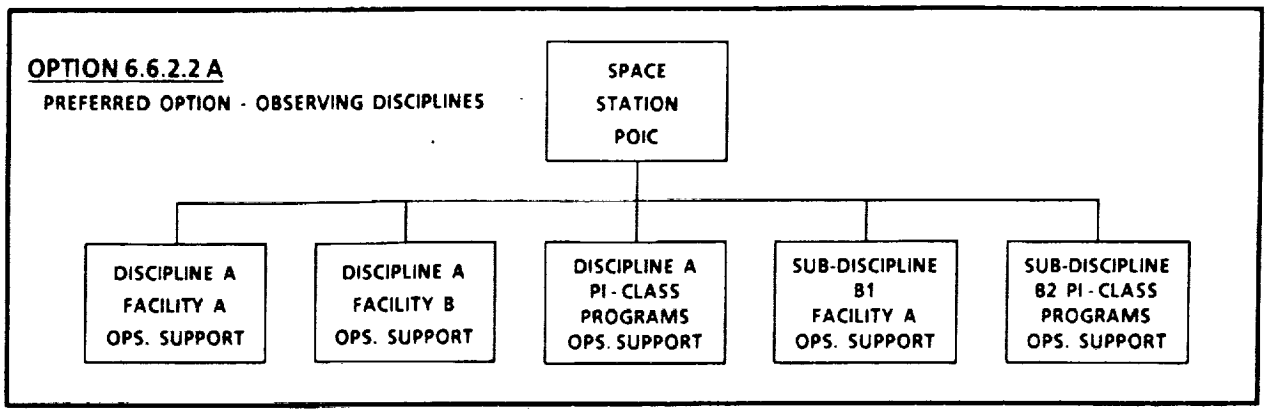

Figure 19a.

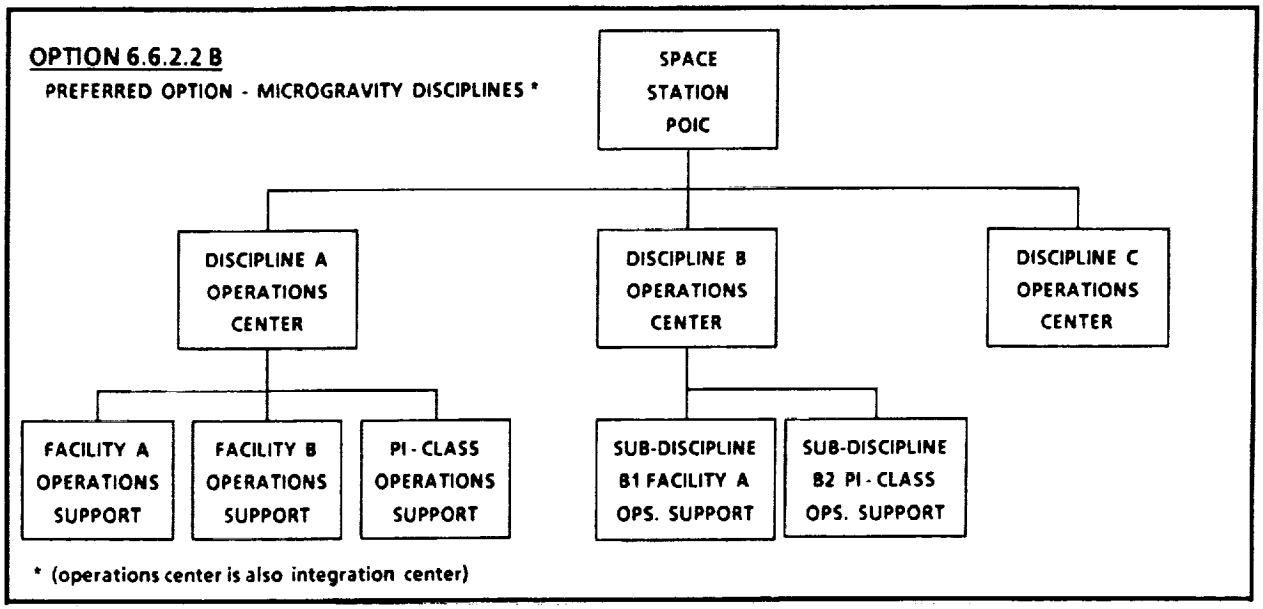

Figure 19b.

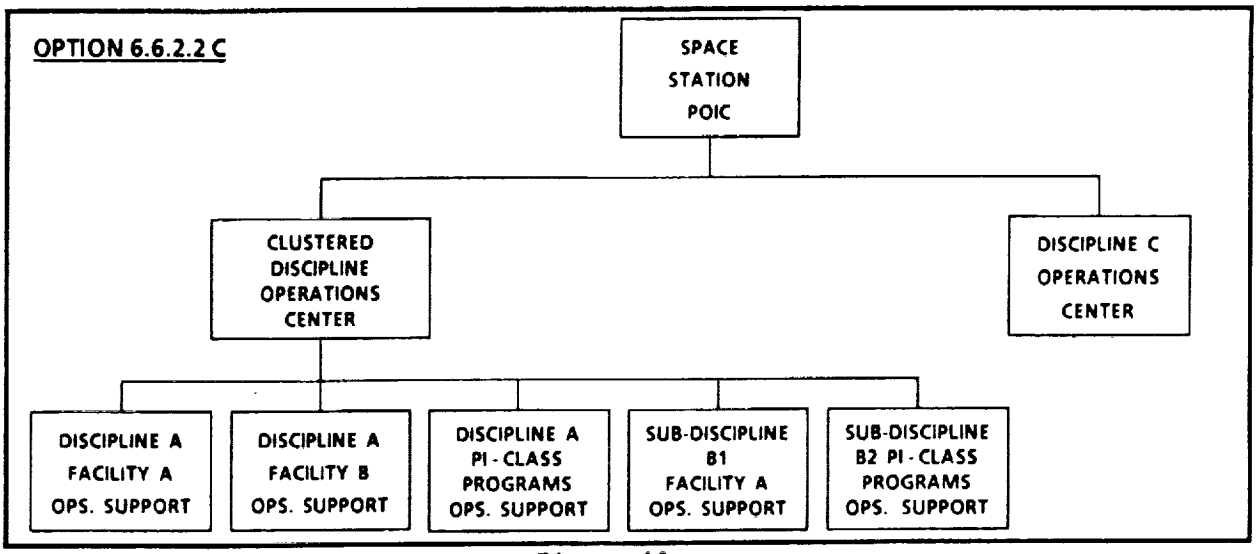

Figure 19c.

Figure 19. Manned-Base Science Operations

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OPTION 6.6.2.2 A:

In this first option (see Figure 19a), each major program element for each sub-discipline and discipline would establish its own independent operations management organization which would interface to the Station via the POIC. The advantages of such an approach would be the degree of special support and tailoring possible for each of the program elements, the manageable size of the operations organizations, and the degree of control over this support that could be exercised by each of the Program Offices over their operational support organizations. The disadvantages would be the duplication of effort and systems resulting from such an approach, the large number of operational interfaces which would have to be supported by the Station, the difficulty of defining and implementing uniform user interfaces and standards among operations organizations, and the complexity of the system for users wishing to use several different facilities or instruments, each having its own independent operations organization.

The option particularly suits the Observing Disciplines whose attached payloads and platforms would operate relatively independently of each other. The trend towards relatively large, capable facilities (each with a large community of diverse users) would also be accommodated well by this option. The communities would achieve their desired level of uniformity in user interface and data and archival standards across disciplines and across OSSA through OSSA (headquarters) management and inter-project coordination.

OPTION 6.6.2.2 B:

In the second option, the management of science user operations at the manned base would be clustered by discipline. This is the option that was most-favored by the Space Station Operations Task Force since it reduced the operational interfaces between the users and the Station to a manageable number.

This option is also the one which is most-favored by the Microgravity Disciplines (pending further study) because:

(1) The option would facilitate the development of common user interfaces, procedures, support systems, data infra-

structures, and data and archival standards across disciplines;

(2) It would facilitate the sharing of facilities and equipment among sub-disciplines;

(3) It would offer each discipline an efficiency of operations which would still accommodate their special operational and data preferences; and

(4) The option would allow a Station operations expertise to be developed within each discipline.

A possible disadvantage is the potential large size of each center.

Because of the emphasis of both of the Microgravity Disciplines on laboratory experiments, there is a great advantage to be gained from extending the responsibilities of the integration organization to include operations. Users would thus be able to visit the integration and operations organization and could work with the simulators to develop detailed operational procedures which they could then monitor and control remotely during execution.

OPTION 6.6.2.2 C:

A final possibility might be to have like-disciplines (e.g., the two Microgravity Disciplines of Life Sciences and Materials Sciences) join together to plan and execute their on-orbit operations. This option is shown in Figure 19c. The rationale for such a consolidation of operations organizations would be the need to share facilities among the disciplines and the need to share Station resources (particularly power, communications, and crew time) within each of the laboratory elements. While such an approach would offer improved coordination for operations planning, the operational needs and desires of the Life Sciences and Materials Sciences communities are quite different and might be difficult to accommodate within a single organization. Even if such an accommodation were possible, the resulting organization would be large. This option is, therefore, considered less-desirable than the previous discipline-level approach.

6.6.2.3 Platform Operations

The key issue in the platform operations management options discussed below and illustrated in Figure 20 is that of operational autonomy.

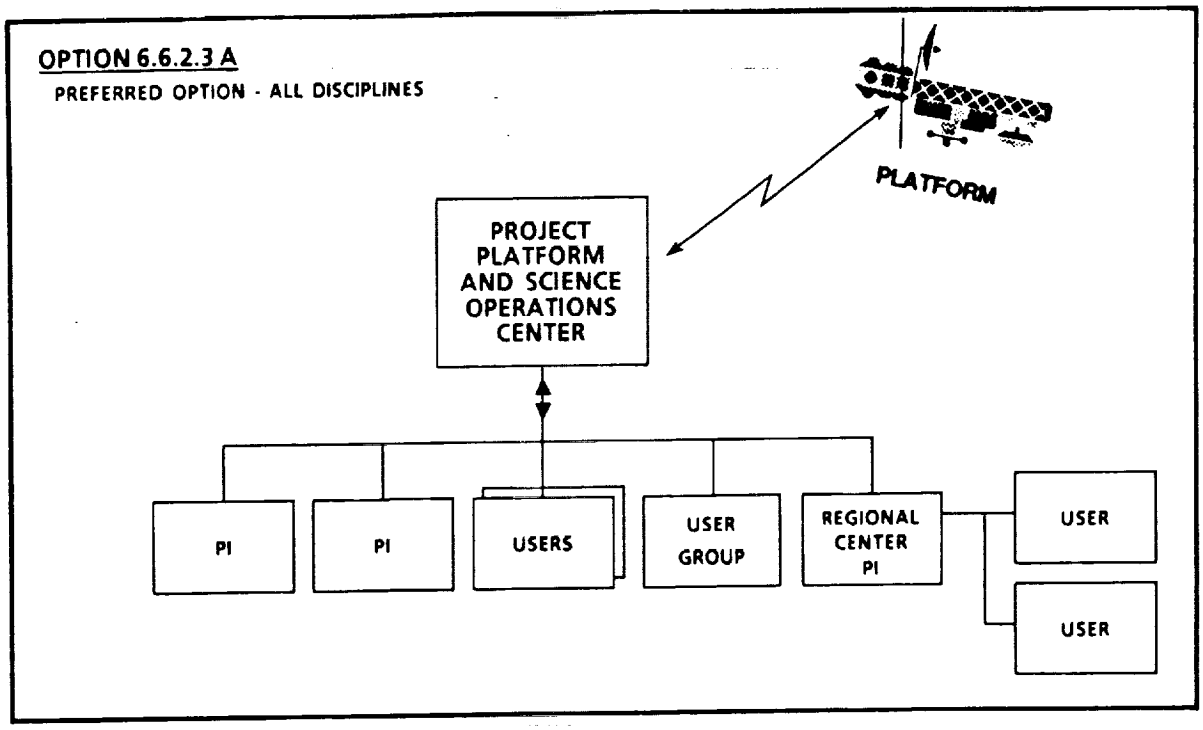

Figure 20a.

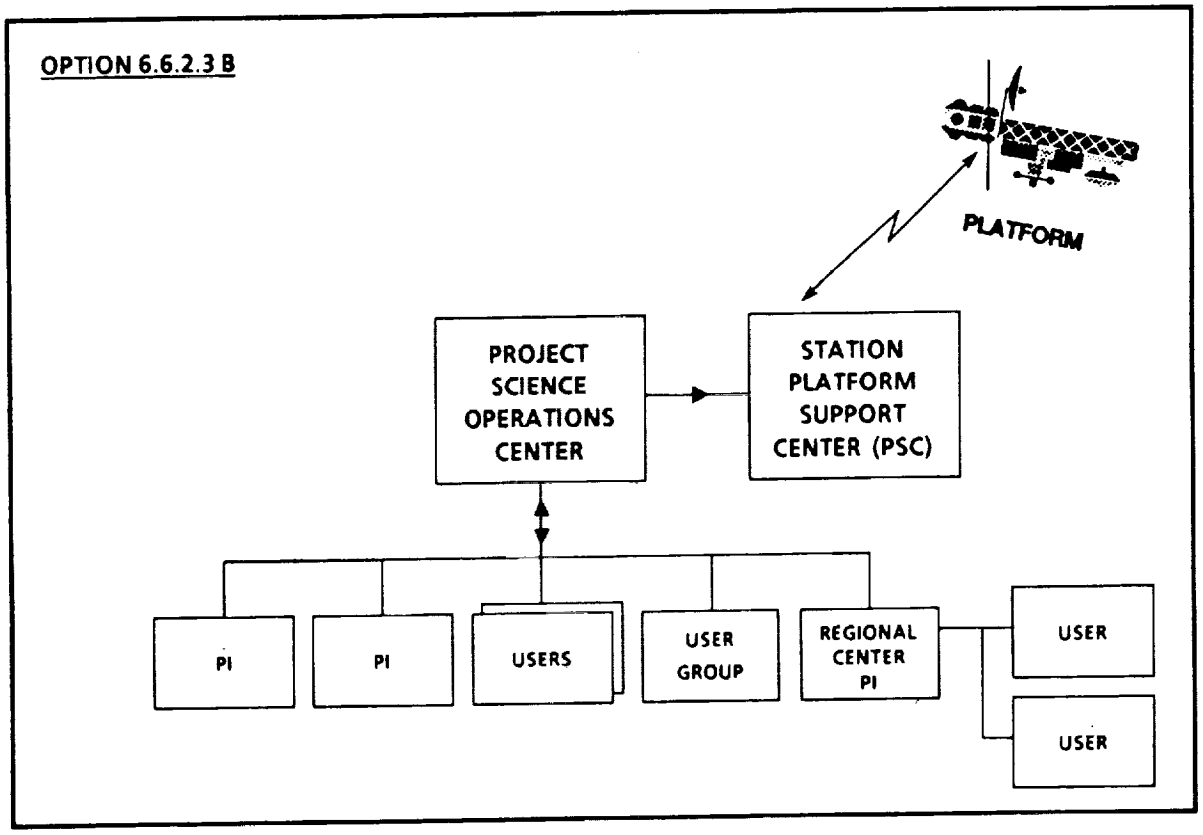

Figure 20b.

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Figure 20. Platform Science Operations

OPTION 6.6.2.3 A:

In the first option, it is assumed that the user of the platform is restricted to a single sub-discipline or discipline. This is the case for both the EOS (polar-platform) and the SIRTF (co-orbiting platform) .

The preferred approach of the users to managing the operations of such platforms is illustrated in Figure 20a. In this option, the user operations management organization would be responsible for planning and executing on-orbit operations of both the payload and the platform. Such operations would take into account PI and user observing requirements (as approved by the selection process), platform housekeeping requirements (e.g., battery charging and engineering diagnostics), communication link availability, day-night cycle, ground track, etc. Headquarters oversight of these operations would be maintained (particularly in the case of the EOS) where the complex, multi-agency, multi-national management agreements demand a high degree of Headquarters involvement.

The advantage of this option would be the complete operational autonomy of the platforms during normal operations. Only at times of servicing would the platform operations need to be coordinated with Station or Shuttle operations. The disadvantages would be the need for the platform developers (the Space Station organization) to hand-off the operations of their spacecraft to the users, the higher staffing demands on the users, and the difficultly of factoring in users from other disciplines in the case of mixed-discipline payloads.

OPTION 6.6.2.3 B:

The second option for the management of the platforms is shown in Figure 20b. This is the option proposed by the Space Station Operations Task Force. In this case, the Station operations organization would retain responsibility for operating the platform, and the user organization would manage a subsidiary payload planning and execution program.

The disadvantage of the latter approach would be that the users would not have complete control over platform operations, even though platform operations should be fully supportive of the user's operational needs. The advantage would be that the organization with long-term

responsibility for the platform would continue to operate it and that the management approach would lend itself more easily to multi-discipline use of platforms. (Note: such multi-discipline use of platforms may not make sense operationally since the pointing and control requirements and contamination potential and sensitivity of different user payloads are likely to result in operationally incompatible payload complements.)

6.6.3 Sustaining Engineering and Servicing

Since the Space Station plans to offer the capability of on-orbit servicing of science payloads and since such payloads can also be returned to Earth for refurbishment and repair, many science user disciplines plan to use servicing to achieve an extended operational lifetime for their instruments and facilities. In order to do this, the users would have to establish an organization to monitor the operational health of the equipment on-board the Station, trouble-shoot failures, devise work-arounds, and maintain a suitable complement of spares, tools, and support equipment. The organization would also have to develop and support servicing activities and procedures, train crews for on-orbit servicing, and manage repairs or refurbishment of returned equipment, when necessary.

The management decisions which must be made to ensure such support are the same as those presented in Section 6.5.3 for tactical and increment planning and crew training support. They are discussed below and are illustrated in Figure 21.

OPTION 6.6.3 A:

In the first option (shown in Figure 21a), sustaining engineering and servicing would remain the responsibility of the development center. This would have the advantage of sensitizing the developers to the need for developing easily serviceable systems and to the advantages of using standard systems, spares, and tools, where possible. It would also ensure that the sustaining engineering support would be provided by engineers who had a detailed understanding of the design and function of the instrument. The approach would work best if the development organization were large enough to sustain a continued development activity while having sufficient schedule flexibility to accommodate sustaining engineering and servicing

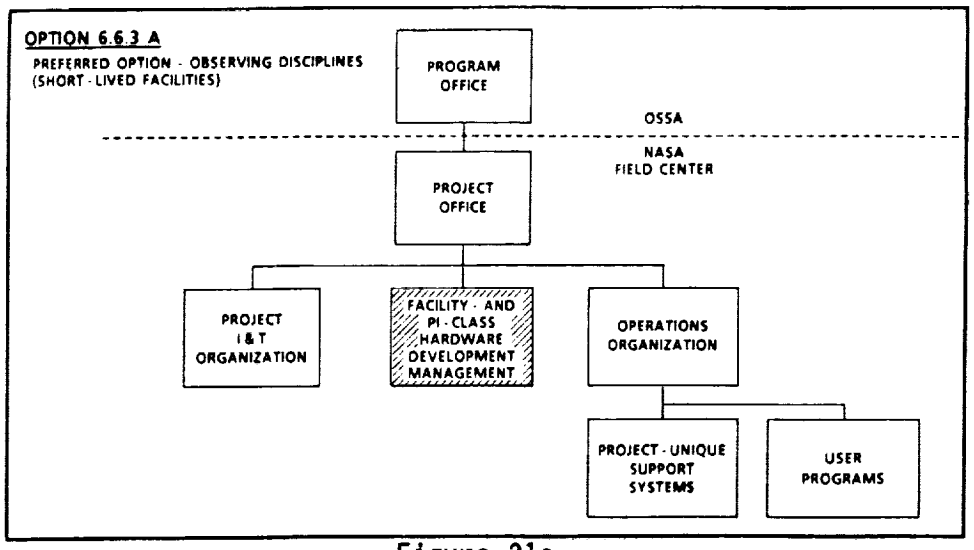

Figure 21a.

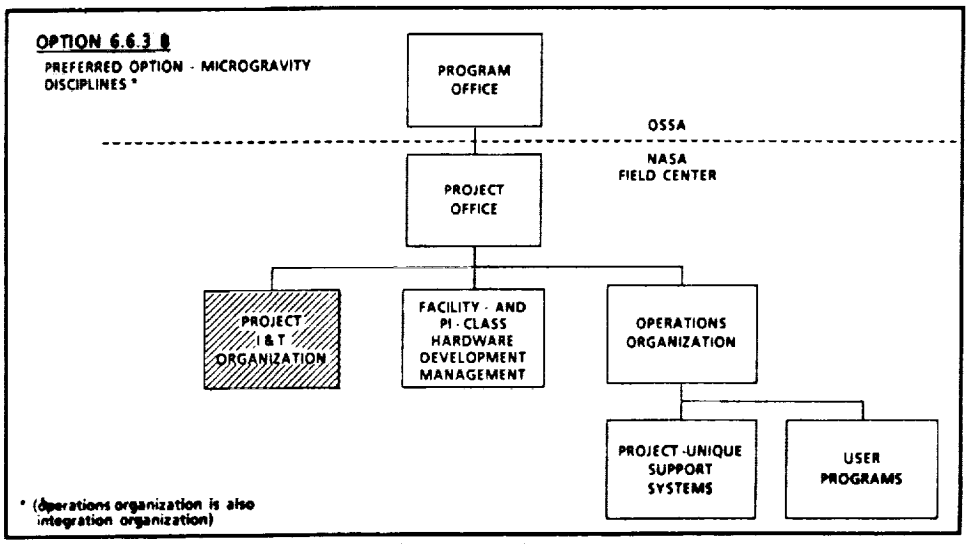

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Figure 21b.

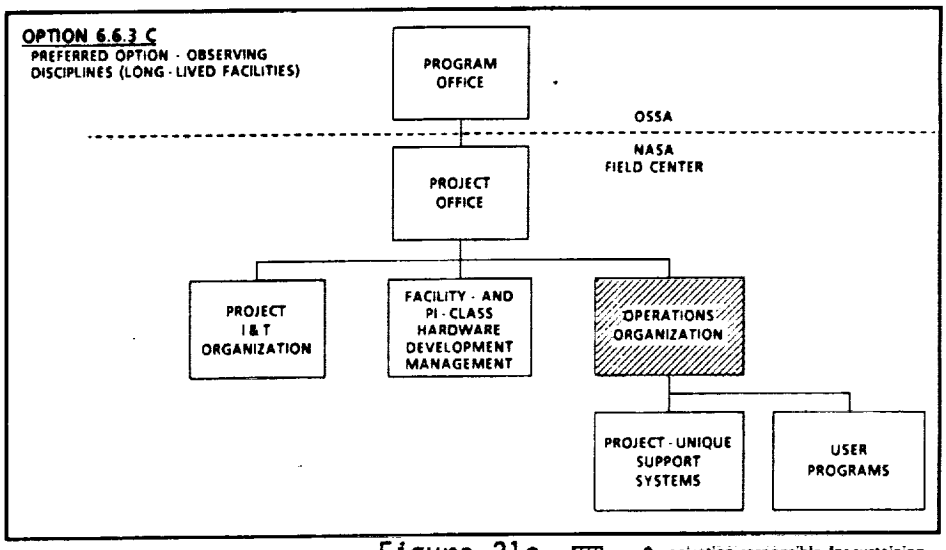

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Figure 21c. ▨ = Organization responsible for sustaining engineering and servicing

Figure 21. Sustaining Engineering and Servicing (Typical Project Structure)

activities when needed. It would be particularly suitable for relatively short-lived instruments and facilities developed by the Observing Disciplines.

A disadvantage of the option might be the difficulty of ensuring commonality of spares and interfaces across related developments undertaken by several different organizations (e.g., the Life Sciences facility developments illustrated in Figure 16).

OPTION 6.6.3 B:

The second option for managing the sustaining engineering and servicing of Station science instruments and facilities is to have the activity managed by the integration centers. For disciplines such as Life Sciences and Materials Sciences, this approach would offer the advantages of coordinated sparing and crew aides, tools, and training. It would, however, either require the participation of the development centers in a support role to provide the sustaining engineering and servicing support or would require that engineers at the integration center develop this capability. Since the latter would result in a considerable duplication of effort, the former is the more likely approach that would be adopted for this option.

OPTION 6.6.3 C:

The final option is that the operations center would assume the long-term sustaining engineering support and servicing of the Space Station science facilities. In this case, it is assumed that a decreasing level of development organization expertise and an increasing level of operations organization expertise in facility design and operations might occur during the extended operational lifetime of the facility. A transition of sustaining engineering responsibilities from the development office to the operations office would, thus, be highly desirable. It is this consideration which resulted in the planned handoff of the HST maintenance and refurbishment program management responsibility from the NASA Marshall Space Flight Center (HST development organization) to the NASA Goddard Space Flight Center (HST operations organization). This option should, therefore, continue to be carried, pending further study.

6.6.4 Initial Data Processing, Data Distribution, and Sample Return

Current Station program plans have commands to science user payloads on the Station's manned base formulated and generated via the POIC. The data generated by these payloads would then be sent from the Station via the Tracking and Data Relay Satellite (TDRS) to the White Sands Ground Terminal. Here, the Station operations organization would divide the Station user data stream into appropriate blocks which would be sent to the appropriate user operations organizations. A schematic representation of this planned data flow between the Station and a hierarchy of science users is provided in Figure 22.

OPTION 6.6.4 A:

In the first option (shown in Figure 22a), the Space Station operations organization would strip out the user data from the Station user data stream for an entire spectrum of user organizations, from discipline operations center to individual PI-class organization. Space Station would, then, send the resulting data packages from White Sands to the multiplicity of user organizations using the Space Station Information System (SSIS). Each user organization would deal directly with the Station for the definition of its own specific user data requirements. It would also establish its own user networks and initial and advanced data processing systems. No SAIS would need to be developed in this option, although the existence of such a system would aid the establishment of user interface and data standards and would reduce the cost of development of the subsidiary user networks.

For those Microgravity Discipline users requiring samples from their Station experiments, the Station organization would deal directly with these users to arrange the delivery of these samples.

While this approach could, in theory, be accommodated by the Station operations organization, the demands that it would place on the Station's information system, support staff, and Shuttle landing site facilities are likely to be excessive. Further, it would result in significant duplication of effort among organizations and would inhibit the development of standard user interfaces, data formats, and archival data standards.

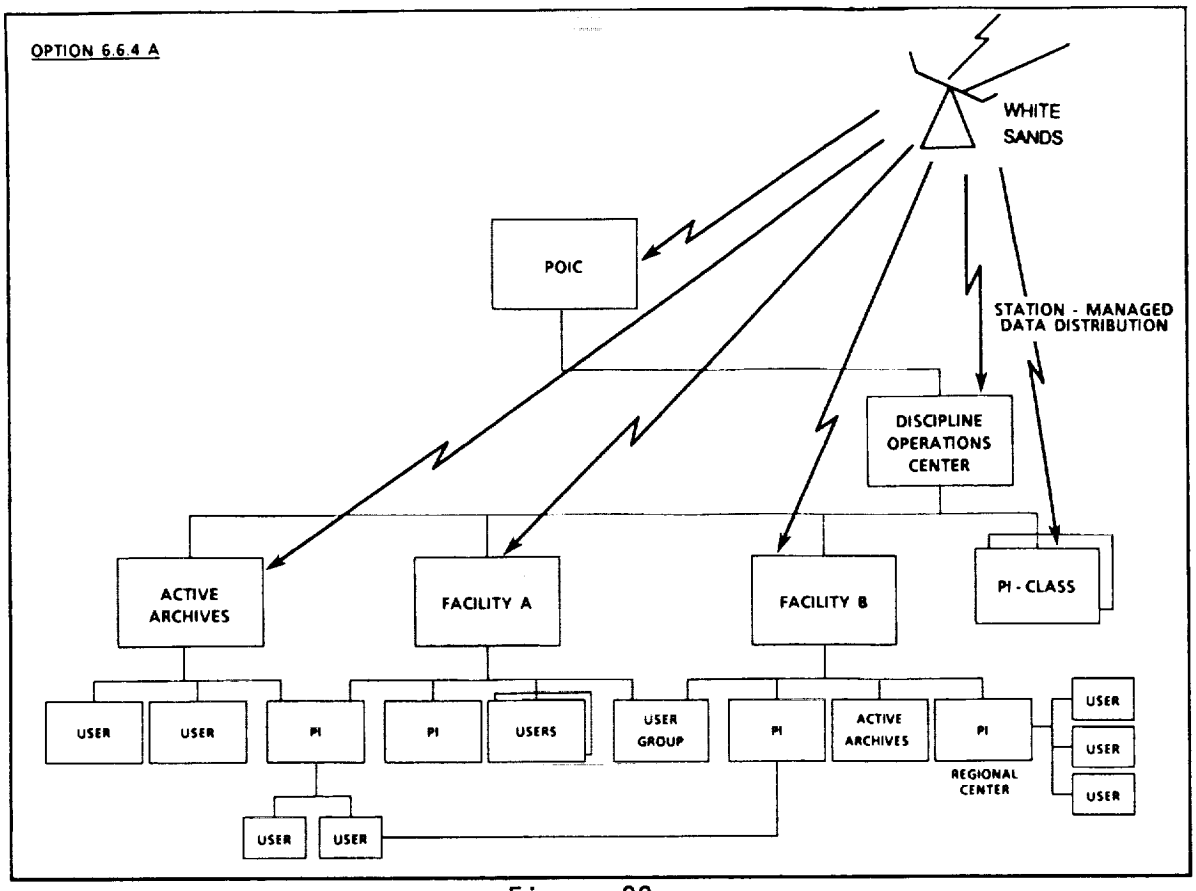

Figure 22a.

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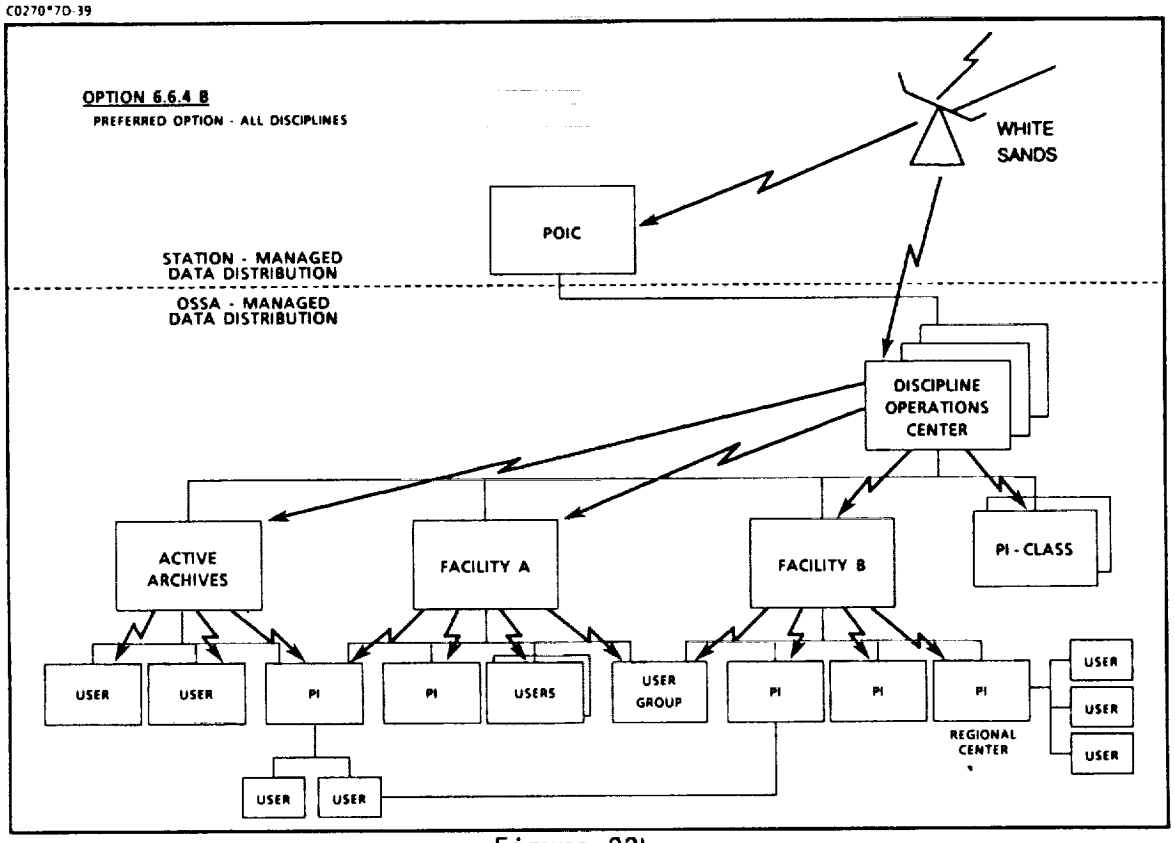

Figure 22b.

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Figure 22. Data Distribution and Analysis

OPTION 6.6.4 B:

In the second option (shown in Figure 22b), the Space Station organization at White Sands would divide the Station user data stream into a limited number of packages which would be sent, via SSIS, to a few discreet user operations organizations. It would be the responsibility of each of these organizations to further subdivide the data it received to support its various user groups. The organization would also apply any initial processing that was appropriate and would send the resulting, partially processed data streams to the appropriate next levels in the data distribution hierarchy. These next-level organizations might then process the data further, as appropriate, before further subdividing the stream for transmission to the next level of users.

The system which would be used primarily to support all of the user-level processing and dissemination would be the SAIS. At the lower levels in the data hierarchy, special user-unique data software and systems might also be used. The option would fully support the concept of telescience which could be implemented such that the command and data nodes between the PI or facility users and their Station instruments are transparent during the realtime telescience operations. It would also allow very flexible organization of data distribution and analysis nodes, depending on the needs of the users. This capability would reduce the need to establish fixed ("bricks and mortar") Science Institute-type organizations and would favor the establishment of relatively short-lived regional centers which might be established to satisfy a set of discipline or subdiscipline science objectives and might be disbanded when the planned research was complete.

In the case of sample return (which pertains primarily to the Microgravity Disciplines), the Payload Integration Office would arrange for the timely dispersal of samples to the users and would provide, where necessary, some modest laboratory facilities at the Shuttle landing site to facilitate initial data processing, inspection, and packaging of the samples.

This option (in which the SAIS is the primary tool for science user data dissemination and the user data are processed through a hierarchy

of organizations) is the preferred approach of all Station science user disciplines participating in this study.

6.6.5 Science Data Analysis and Archival Storage

The analysis of data and samples returned from the Station's science payloads should be undertaken by the PIs and the selected users of the facilities and instruments. In most cases, a significant level of scientific expertise is required to transform the initial data or sample into meaningful scientific results.

The location of the analysis effort for any instrument or experiment may vary, depending on the degree of sophistication of the PI or user and on the tools that have already been developed by the government and other PIs and users for processing such data. There is considerable user support for the establishment of PI analysis facilities, regional data centers, or science centers or institutes (inside or outside NASA) to which other users could come to learn how to process their data and to obtain (and possibly use) the algorithms and procedures needed to conduct their analyses. In addition, such science user analysis "nodes" would also have to be able to support the remote processing of data by users by making use of the SAIS and any facility- or instrument-unique support systems developed by the community for the purpose.

In order to succeed in their role, the various science user analysis nodes would also have to be the site of temporary active data (or sample) archives. More permanent archives would have to be established at selected sites, including the National Space Science Data Center. Standards for archiving data should be established across OSSA and by discipline, as appropriate, and should be managed by the organization with management responsibility for the science data analysis and archival storage program.

While a multiplicity of options clearly exists for the flexible establishment of the science user analysis nodes, these options do not represent real management alternatives. The capability should exist in the system to cluster flexibly the scientific analysis activities about the PIs (or surrogate PIs) or about groups of archival data users and to make local

and remote analyses of the data possible. The management options identified in this section thus pertain to which organizations would decide where the analysis nodes and data archives will exist and would select the community of users to use them. These options are discussed below.

OPTION 6.6.5 A:

In the first option, the overall management of the data analysis would be the responsibility of the OSSA (or other government agency) Headquarters organization that was also responsible for planning the sub-discipline or discipline Station science program and for selecting the science investigators and users for that program. This is the preference both of the Microgravity Disciplines and the Observing Disciplines. The advantage of this approach would be that this organization could determine the support needs of its communities based on the results of the competitions and on the recommendations of the community advisory bodies. It could also determine the requirements that should be satisfied by the SAIS and those that should be provided as part of the discipline-unique Station support systems. The Headquarters organization could also work with its counterparts for other user disciplines and with some unifying organization (e.g., the OSSA Space Station Integration Office) (see Section 6.4.2.1) in the establishment of OSSA-wide and discipline-wide data standards. Appropriate steps could then be taken to ensure that the appropriate systems were developed and standards were applied.

Some of these decisions would be necessary early in the planning cycle to allow development of new capabilities. Focussing these tradeoffs at the Headquarters level supports consideration of the data system development requirements as part of the initial implementation process.

OPTION 6.6.5 B:

An alternate approach would be to use the operations organization (in-house or external) as the management center for the analysis and archival activities. This approach might have the advantage of closer ties between the managers and the PIs and users but would have the disadvantage of a more difficult coordination route for the development of infrastructure elements and standards.

6.6.6 Summary

The management options identified for Science Operations and Data Management are shown in Table 5 together with the preferences of the Microgravity Disciplines and Observing Disciplines. A complete summary of all the preferred options which were identified for all four functional phases of the program is provided in Table 6 in the next chapter of this report.

TABLE 5. MANAGEMENT OPTIONS FOR SCIENCE OPERATIONS AND DATA MANAGEMENT (NASA PAYLOADS)

ACTIVITY	MICROGRAVITY DISCIPLINES		OBSERVING DISCIPLINES	OPTION #
	PREFERENCE	OPTION DESCRIPTION	PREFERENCE	
OPERATIONS SUPPORT	*	MANAGED: - IN - HOUSE (FIELD CENTER)	*	6.6.2.1 A
		OR		
	REJECT	- BY EXTERNAL ORGANIZATION		6.6.2.1 B
MANNED BASE		MANAGED AT: - SUB - DISCIPLINE LEVEL	*	6.6.2.2 A
		OR		
	*	- DISCIPLINE LEVEL		6.6.2.2 B
		OR		
		- MULTIDISCIPLINE LEVEL		6.6.2.2 C
PLATFORM OPERATIONS		MANAGED BY: - STATION		6.6.2.3 A
		OR		
		- PROJECT	*	6.6.2.3 B
SUSTAINING ENGINEERING AND SERVICING		MANAGED BY: - THE DEVELOPMENT ORGANIZATIONS (SEE 6.4.3.1)	* (SHORT-LIVED INSTRUMENTS/ FACILITIES)	6.6.3.1 A
		OR		
	*	- THE INTEGRATION ORGANIZATIONS (SEE 6.4.4.1)		6.6.3.1 B
		OR		
		- THE OPERATIONS ORGANIZATIONS (SEE 6.6.2.1)	* (LONG-LIVED FACILITIES)	6.6.3.1 C
INITIAL DATA PROCESSING / SAMPLE RETURN / DATA DISTRIBUTION	REJECT	MANAGED BY: - SPACE STATION ORGANIZATION	REJECT	6.6.4 A
		OR		
	*	- OSSA/OPERATIONS ORGANIZATION	*	6.6.4 B
SCIENCE DATA ANALYSIS AND ARCHIVAL STORAGE	*	MANAGED BY: OSSA	*	6.6.5 A
		OR		
		- THE OPERATIONS ORGANIZATIONS (SEE 6.6.2.1)		6.6.5 B

KEY: * = Preferred Option
Blank = Acceptable Option
REJECT = Unacceptable Option

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CHAPTER VII

SSSOMC STUDY CONCLUSIONS AND RECOMMENDATIONS

7.1 INTRODUCTION AND GENERAL CONCLUSIONS

The insight gained from this study makes it clear that the ultimate success of the Space Station as a multi-purpose scientific research laboratory will be dependent upon the effective management of the overall science operations process. A management system which is responsive to the needs of the science user and which provides the necessary flexibility to accommodate a broad range of discipline peculiarities should be established in the early stages of Space Station development. To do otherwise would result in the research laboratory driving the design of science, an inversion of the fundamental principle that form should follow function.

It was not the intent of this study to develop the optimal science operations management system for Space Station but rather to reduce the range of possible management options to a workable number, thereby laying the groundwork for the in-depth planning and analysis which must follow. Table 6 collects and summarizes the preferred management options developed and discussed in Chapter VI. Discrete management options for the entire end-to-end science operations process are not presented. Instead, preferred management options for individual science operations activities are presented. Discrete end-to-end management options can be formulated from Table 6 by making option selections for each activity of the science operations process. This report does not formulate finalized discrete end-to-end management options since it was felt that to do so would be premature at this time.

Table 6 is organized into two sets of options, one set reflecting the management preferences of the Microgravity Disciplines and another set reflecting the preferences of the Observing Disciplines. This organization of options is used as a result of the commonality in management preferences between Life Sciences and Materials Sciences and the commonality of management preferences among Astrophysics, Earth Sciences, and Solar System Research.

TABLE 6. SUMMARY OF PREFERRED SCIENCE OPERATIONS MANAGEMENT OPTIONS (NASA PAYLOADS)

	ACTIVITY	MICROGRAVITY DISCIPLINES	OBSERVING DISCIPLINES	OPTION #
		OPTION DESCRIPTION		
SCIENCE PLANNING & PAYLOAD SELECTION	INTEGRATED PROGRAM PLANNING	CONSTRAINED STRATEGIC PLAN		6.3.2.1 A
	SS USER PLANNING INTERFACE	OSSA INTEGRATES U. S. SCIENCE USER REQUIREMENTS		6.3.2.2 B
	SS USER - STATION INTERFACE	NEW ORGANIZATION [ISSUB] IS FORMED TO REPRESENT USER REQUIREMENTS TO MCB		6.3.2.3 C
	INVESTIGATOR SELECTION PI / USER SELECTION	MANAGED BY OSSA DISICIPLINE WITH DIRECTOR OR AA APPROVAL (6.3.3.1 B AND 6.3.3.2 B)	MANAGED BY OSSA SUB-DISCIPLINE WITH DIRECTOR OR AA APPROVAL (6.3.3.1 A AND 6.3.3.2 A)	
PAYLOAD DEVELOPMENT & INTEGRATION	INTEGRATED PROGRAM MANAGEMENT	MANAGED BY OSSA AT DISCIPLINE LEVEL (6.4.2.1 B)	MANAGED BY OSSA AT SUB- DISCIPLINE LEVEL (6.4.2.1 A)	
	INTEGRATED PROJECT MANAGEMENT	PROGRAM OFFICE MANAGES SEVERAL PROJECTS AT DIFFERENT CENTERS (6.4.2.2 A)	ONE-TO-ONE RELATIONSHIP BETWEEN PROGRAM AND PROJECT (6.4.2.2 B) AND SEVERAL RELATED PROGRAMS SHARE SAME PROJECT (RAPID - RESPONSE RESEARCH) (6.4.2.2 C)	
	FLIGHT HARDWARE DEVELOPMENT	FIELD CENTER MANAGEMENT OF DEVELOPMENTS WITH IN- HOUSE OR EXTERNAL PIs		6.4.3.1 A
	FLIGHT HARDWARE INTEGRATION AND TEST	EACH DISCIPLINE MANAGES ITS OWN MULTI-PROJECT INTEGRATION ORGANIZATION (6.4.4.1 B)	EACH DEVELOPMENT PROJECT WITHIN DISCIPLINE MANAGES ITS OWN INTEGRATION ORGANIZATION (6.4.4.1 A)	

TABLE 6. SUMMARY OF PREFERRED SCIENCE OPERATIONS MANAGEMENT OPTIONS (NASA PAYLOADS) (CONTINUED)

	ACTIVITY	MICROGRAVITY DISCIPLINES	OBSERVING DISCIPLINES	OPTION #
		OPTION DESCRIPTION		
SCIENCE TACTICAL & INCREMENT PLANNING	SCIENCE PAYLOAD MANIFESTING PRIORITIES AND TRADES	MANAGED AT OSSA LEVEL WITH SUB-DISCIPLINE / DISCIPLINE INPUTS		6.5.2 A
	SCIENCE OPERATIONS TACTICAL AND INCREMENT PLANNING AND CREW TRAINING	MANAGED BY: THE INTEGRATION ORGANIZATIONS (6.5.3 B)	MANAGED BY: -THE DEVELOPMENT ORGANIZATIONS (SHORT - LIVED INSTRUMENTS AND FACILITIES) (6.5.3 A) -THE OPERATIONS ORGANIZATIONS (LONG - LIVED FACILITIES) (6.5.3 C)	
SCIENCE OPERATIONS & DATA MANAGEMENT	OPERATIONS SUPPORT	MANAGED IN-HOUSE (FIELD CENTER)		6.6.2.1 A
	MANNED BASE	MANAGED AT DISCIPLINE LEVEL (6.6.2.2 B)	MANAGED AT SUB - DISCIPLINE LEVEL (6.6.2.2 A)	
	PLATFORM OPERATIONS	MANAGED BY PROJECT		6.6.2.3 B
	SUSTAINING ENGINEERING AND SERVICING	MANAGED BY: THE INTEGRATION ORGANIZATIONS (6.6.3. B)	MANAGED BY: -THE DEVELOPMENT ORGANIZATIONS .(SHORT-LIVED INSTRUMENTS & FACILITIES) (6.6.3 A) AND -THE OPERATIONS ORGANIZATIONS (LONG-LIVED FACILITIES) (6.6.3 C)	
	INITIAL DATA PROCESSING / SAMPLE RETURN/ DATA DISTRIBUTION	MANAGED BY OSSA / OPERATIONS ORGANIZATIONS		6.6.4 B
	DATA ANALYSIS AND ARCHIVAL STORAGE	MANAGED BY OSSA		6.6.5 A

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The format of Table 6 is also intended to show where there is "global" commonality between the preferences of the Microgravity Disciplines and the preferences of the Observing Disciplines, as well as where there are differences. In general, there is commonality at the very beginning of the science operations process (i.e., initial science planning) and at the very end of the process (i.e., data management). For the intervening activities (which constitute the major portion of the science operations process) there is, for the most part, divergence between the management preferences of the Microgravity Disciplines and the Observing Disciplines. This divergence typically takes the form of the Observing Disciplines preferring to delegate management responsibility to a lower level within the organizational hierarchy than do the Microgravity Disciplines. This difference is a reflection of the disparity in the spaceflight experiences between the two groups and the much more established and distributed practices of the Observing Disciplines. In general, the Observing Disciplines prefer management at the sub-discipline or project level, whereas the Microgravity Disciplines prefer management at the discipline level.

As a point of reference, the reader is once again referred to Table 1. The preferences of the Observing Disciplines essentially equate to Option 1 of Table 1. The full range of viable options for the Observing Disciplines are captured by the combination of Option 1 and a portion of Option 2. This is depicted pictorially in Table 7 in which the range of viable management options for the Observing Disciplines is mapped against the entire spectrum of options originally considered.

The preferences of the Microgravity Disciplines essentially equate to Option 2 of Table 1. The full range of viable options for the Microgravity Disciplines is captured by the combination of Option 2 and a portion of Option 3 of those options originally considered, as depicted in Table 8.

It should be clear from Tables 7 and 8 that none of the science disciplines support the concept of an external science center responsible for both payload development and operations either at a sub-discipline,

TABLE 7. VIABLE MANAGEMENT OPTIONS FOR OBSERVING DISCIPLINES (COMPARED TO OPTIONS INITIALLY CONSIDERED)

	OPTION 1	OPTION 2	OPTION 3	OPTION 4	OPTION 5	OPTION 6
DISCIPLINE TYPES	SUB-DISCIPLINE	SINGLE DISCIPLINE	CLUSTERED DISCIPLINES	SUB-DISCIPLINE	SINGLE DISCIPLINE	CLUSTERED DISCIPLINES
PLANNING AND SELECTION	PLANNING - OSSA DIVISIONS AND AA PI SELECTION - OSSA DIVISIONS AND AA USER SELECTION - OSSA DIVISIONS OR SCIENCE (OPERATIONS) CENTER					
DEVELOPMENT	DEVELOPMENT CENTER (NASA FIELD CENTER)			SCIENCE CENTER (NASA FIELD CENTER OR EXTERNAL ORGANIZATION)		
SCIENCE TACTICAL / INCREMENT PLANNING	DEVELOPMENT OR SCIENCE OPERATIONS CENTER (NASA FIELD CENTER)					
OPERATIONS AND DATA MANAGEMENT	SCIENCE OPERATIONS CENTER (NASA FIELD CENTER OR EXTERNAL ORGANIZATION)					

= RANGE OF VIABLE OPTIONS

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TABLE 8. VIABLE MANAGEMENT OPTIONS FOR MICROGRAVITY DISCIPLINES (COMPARED TO OPTIONS INITIALLY CONSIDERED)

	OPTION 1	OPTION 2	OPTION 3	OPTION 4	OPTION 5	OPTION 6
DISCIPLINE TYPES	SUB-DISCIPLINE	SINGLE DISCIPLINE	CLUSTERED DISCIPLINES	SUB-DISCIPLINE	SINGLE DISCIPLINE	CLUSTERED DISCIPLINES
PLANNING AND SELECTION	PLANNING - OSSA DIVISIONS AND AA PI SELECTION - OSSA DIVISIONS AND AA USER SELECTION - OSSA DIVISIONS OR SCIENCE (OPERATIONS) CENTER					
DEVELOPMENT	DEVELOPMENT CENTER (NASA FIELD CENTER)					
SCIENCE TACTICAL / INCREMENT PLANNING	DEVELOPMENT OR SCIENCE OPERATIONS CENTER (NASA FIELD CENTER)			SCIENCE CENTER (NASA FIELD CENTER OR EXTERNAL ORGANIZATION)		
OPERATIONS AND DATA MANAGEMENT	SCIENCE OPERATIONS CENTER (NASA FIELD CENTER OR EXTERNAL ORGANIZATION)					

= **RANGE OF VIABLE OPTIONS**

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discipline, or clustered discipline level. However, the Observing Disciplines' options do include the possibility of an external science operations center (like the STScI) for the operations and data management phase only.

Specific conclusions and recommendations concerning science operations management, management interfaces with Space Station, and follow-on activities are presented in subsequent sections of this Chapter.

7.2 SCIENCE OPERATIONS MANAGEMENT: CONCLUSIONS AND RECOMMENDATIONS

(1) Conclusion: The nature of the research to be performed on the Space Station varies significantly from discipline to discipline, and the characters of the associated science communities differ greatly. Consequently, there is no single management system best-suited for all science disciplines. The Station does not need all users to follow a single management approach as long as the number of management interfaces is limited. The concept of a universal science center responsible for all or part of the science operations process for all science disciplines on Space Station is not desirable. (For supporting rationale, see Sections 6.1 and 6.2.)

RECOMMENDATION: Each individual science discipline should establish the science operations management structures best-suited to its research activities and community needs and traditions.

(2) Conclusion: There are efficiencies associated with clustering science operations activities in instances of functional similarity. (For supporting rationale, see Sections 6.2 through 6.6.)

RECOMMENDATION: Each individual science discipline should assess the advisability of clustering into a single organization the management responsibility for activities (e.g., payload development) which are common among the programs within that discipline.

(3) Conclusion: The types of planned Space Station science utilization generally segregate into two categories:

(a) Experimentation by the Microgravity Disciplines of Life Sciences and Materials Sciences which will be primarily conducted inside the pressurized laboratories; and

(b) Experimentation by the Observing Disciplines of Astrophysics, Earth Science, and Solar System Research which will primarily utilize attached payloads and platforms.

Within the Microgravity Disciplines, there is a particularly high degree of interaction and interdependence between the science operations associated with Life Sciences experimentation and Materials Sciences experimentation. (For supporting rationale, see Sections 6.2 through 6.6.)

RECOMMENDATION: The science operations management activities proposed by the Life Sciences and Materials Sciences communities should be closely coordinated. Appropriate management interfaces with Space Station should be made common, where practical.

(4) Conclusion: NASA responsibility for the management of science payload development is appropriate for Space Station science operations. (For supporting rationale, see Section 6.4.3.)

RECOMMENDATION: Management responsibility for NASA payload development should be maintained within NASA and should not be delegated to an outside organization.

(5) Conclusion: NASA's traditional approach to developing a science support infrastructure (e.g., information systems, integration and training capabilities, payload carriers) on an individual-project basis would be inefficient for the support of the diverse, distributed user community of the Space Station era. (For supporting rationale, see Sections 6.2 through 6.6.)

RECOMMENDATION: OSSA should develop strategic and tactical plans for defining requirements for, and the long-term development of, the science infrastructure systems and capabilities needed to support the planned utilization of the Space Station.

7.3 MANAGEMENT INTERFACES WITH SPACE STATION: CONCLUSIONS AND RECOMMENDATIONS

(1) Conclusion: The proposals of the Space Station Operations Task Force (SSOTF) are extensive. They are presently being incorporated into appropriate Space Station control documents. However, the implications of these proposals to the management of science operations are not yet fully understood. (For supporting rationale, see Sections 3.5, 5.1, and 6.5.4.)

RECOMMENDATION: OSSA should immediately initiate a detailed review and analysis of the SSOTF proposals, with participation from the science community. Particular attention should be paid to the possible application of Spacelab management practices to Space Station science operations (e.g., the roles of Increment Scientist and IWG). The results of this review should be incorporated into future science operations planning by OSSA and OSS.

(2) Conclusion: It is crucial that science obtain an appropriate share of the U.S. allocation of Space Station resources. Coordination of all U.S. science organizations is needed in the allocation process. (For supporting rationale, see Section 6.3.2.2.)

RECOMMENDATION: If possible, OSSA should have responsibility for coordinating and focusing all U.S. science uses of the Space Station. The OSSA Associate Administrator should serve as the single science member of

the U.S. Space Station User Board (SSUB). Exploratory discussions with other Agencies on these matters should be initiated.

(3) Conclusion: Effective utilization of the Space Station can best be served if the Space Station strategic planning process facilitates the coordination and bartering of user resources among the four International Partners and if users have direct input and access to the Multilateral Coordination Board. (For supporting rationale, see Section 6.3.2.3.)

RECOMMENDATION: An International Space Station User Board (ISSUB) should be established for the purpose of coordinating the user resource requests of the four International Partners and communicating these requests to the User Operations Panel. This board should have direct and formal access to the Multilateral Coordination Board.

(4) Conclusion: The User Operations Panel is expected to produce a 5-year Composite Utilization Plan (CUP) based on inputs from the Space Station User Boards. The first Space Station science payloads are projected to be on-orbit and operating in Fiscal Year 1994. Thus, the first CUP should be produced in Fiscal Year 1989. (For supporting rationale, see Section 3.5.2.)

RECOMMENDATION: The U.S. SSUB and the UOP and their supporting science functions should be chartered, staffed, and in full operation early enough in Fiscal Year 1988 to meet the present Space Station timetable.

7.4 SSSOMC STUDY FOLLOW-UP RECOMMENDATIONS

It is important that this study be followed up with an aggressive set of actions to determine, in a substantive manner, the specifics of how Space Station science operations are to be implemented. OSSA, with support

from OSS, should proceed expeditiously with this next step and be provided with the personnel and funding resources that the situation warrants.

THE FOLLOWING SET OF ACTIONS, OR A SUITABLE REPLACEMENT SET, SHOULD BECOME AN IMMEDIATE OSSA PRIORITY.

(1) RECOMMENDATION: A Space Station science users' advisory group, comparable to the Task Force on Scientific Uses of Space Station (TFSUSS), should be established and report directly to the OSSA Associate Administrator. This group should be broadly based and provide guidance on scientific utilization and Station evolution.

(2) RECOMMENDATION: Formal working arrangements should be established between OSSA and other science agencies (e.g., NBS, NIH, NOAA, NSF, USDA, and USGS). Informal working arrangements between OSSA and user organizations of the International Partners should be explored.

(3) RECOMMENDATION: OSSA should establish a strong centralized office to act as a focal point for coordination of all OSSA Space Station activities and to provide support services to the science disciplines within OSSA.

(4) RECOMMENDATION: In response to the recommendations contained herein, OSSA should develop, within 12 months, a comprehensive Space Station Science Utilization Plan which builds upon current Space Station science planning and management activities within OSSA. The utilization plan should include:

(a) A Science Program Plan with:

(i) Strategy for the identification and/or acquisition of scientific investigations, including use of existing payloads and solicitation of additional payloads

- -Objectives and operational characteristics
- -Development status and plans
- -Funding requirements
- -Transportation needs
- -Station resource requirements
- -Space network and ground support resource requirements

-Solicitation processes
-Targeted flight opportunity dates
-Schedule overview
-Budget requirements

(ii) Rapid-response research
-What is it
-Types of opportunities
-Recommendations

(iii) Strategy for science collaboration
-Opportunities for collaboration
-Principles of collaboration
-Draft MOUs for international partners and agencies

(iv) Science outreach initiatives
-Workshops
-Symposia
-Publications

(b) A Management Plan with:

(i) Detailed approaches, by discipline, for the management of the overall science operations process
-Institutional roles and responsibilities
-Management interfaces with Space Station
-Staffing and budget requirements
-Implementation plans

(ii) Science support infrastructure (e.g., information system) strategies
-Requirements
-Alternatives and recommendations
-Interfaces with Station and external systems
-Developments and major acquisitions required
-Staffing and budget requirements
-Implementation plans

CHAPTER VIII
RELATED ISSUES AND RECOMMENDATIONS

During the course of the SSSOMC study, a number of issues were identified which do not directly impact science management structures but which are relevant to the implementation of Space Station science operations. Due to the significant knowledge and experience base of the study participants, it was felt that these issues and associated recommendations should be conveyed to OSSA and OSS.

(1) Issue: A predictable set of Space Station interfaces, practices, and procedures is needed by the Station user from the earliest stages of payload development. However, payloads selected for Space Station could be assigned, very late in the development phase, to any one of several Space Station elements developed by different countries.
RECOMMENDATION: Payload mechanical and electrical interfaces, operational protocols (including software command and control), and user procedural requirements should be made common for all like elements of the Space Station.

(2) Issue: Unlike previous NASA programs, payload installation into the host system will take place on-orbit rather than on the ground. Therefore, verification of interface compatibility is more important than ever before.
RECOMMENDATION: One or more high-fidelity Space Station interface verification facilities, maintained under configuration control, should be provided by OSS.

(3) Issue: The loss-of-signal due to the void in full-orbit coverage by the TDRSS complicates significantly the already difficult task of planning and scheduling user and Station flight activities.

RECOMMENDATION: NASA should conduct a trade-off study comparing the cost of providing continuous command and data coverage to the additional development and operations costs caused by the lack of the continuous coverage. OSSA should also analyze and quantify the impact of this lack of continuous coverage on science operations.

(4) Issue: Management and control of Station on-orbit operations will be an involved process with many layers of protocol.

RECOMMENDATION: All payloads should be allowed to operate as autonomously as possible during normal operations.

(5) Issue: Given the relatively short duration of Spacelab missions (i.e., 7 to 10 days), payload activities were fully scheduled with no reserve time allocated for dealing with anomalous conditions. This approach invariably led to frequent timeline deviations and almost constant replanning. A different philosophy is needed for Space Station operations.

RECOMMENDATION: A policy of holding in reserve a significant fraction of all Space Station resources needs to be established to provide the necessary margins to deal with anomalous conditions in an orderly manner.

(6) Issue: With the multiplicity of concurrent Station activities, available crew support could become a major limiting resource.

RECOMMENDATION: Payload design and operations should optimize crew interaction, automation, and telescience. Science quality should not be sacrificed in order to reduce crew time, but designs should maximize crew efficiency.

RECOMMENDATION: Crew inputs should be solicited in the design of major payload facilities and instruments.

RECOMMENDATION: Crew selections should emphasize broad science capabilities and knowledge appropriate to the increment's science objectives.

(7) Issue: Station planners desire that science payloads maintain dual-compatibility with the Shuttle and ELVs for manifesting flexibility. Dual-compatibility can represent a significant burden for certain types of payloads.
RECOMMENDATION: Criteria for maintaining dual-compatibility should be developed as a function of payload type and phase of development.

(8) Issue: The character of Space Station payloads will vary greatly in technical complexity, with development times ranging from many years to a few months, in some cases. The Space Station operations control concept proposed by the SSOTF (i.e., 2-year tactical planning cycle) may not efficiently accommodate the development schedules of all payload types.
RECOMMENDATION: The Space Station operations control process should have sufficient flexibility to adjust to differing degrees of payload complexity. For complex payload developments, greater detailed engineering interaction and commitments between user organizations and the Space Station may be required much earlier than indicated in the standard operations control process. Correspondingly, payload developers should consider the trade-offs between payload complexity and ease of entry into the Space Station operations control and integration processes.

(9) Issue: Successful scientific research requires the flexibility to react to new ideas and discoveries on a timely basis. However, late changes in plans can disrupt Space Station operations.

RECOMMENDATION: OSSA with OSS support should implement a plan allocating a limited segment of each planning increment as an OSSA reserve to accommodate a small number of investigations with minumum resource requirements introduced late in the planning cycle. These "rapid-response research" investigations should be treated as a special class of experiment or payload and be selected by a multi-disciplinary committee.

(10) Issue: The Space Station Information System activity is currently moving into the C/D phase of development. Unless OSSA data and information systems activities keep pace, the distribution of data from various Space Station sources could represent a major bottleneck in the science operations process.

RECOMMENDATION: OSSA must recognize the necessity for and begin to work to ensure that science data and information systems activities are properly coordinated and managed so that efficient and effective science use of the Space Station is realized. This work should include activities designed to define policies, standards, and techniques for the national and international acquisition and distribution of Space Station data.

(11) Issue: The Space Station represents a major international investment to create research opportunities. These opportunities will be limited and should be used in a manner which maximizes the overall utility of the Space Station.

RECOMMENDATION: Payload risk should be consciously and deliberately managed. The establishment of formal reliability categories for Space Station payloads should be considered. Reliability categories might span the range from high reliability (with full redundancy for major payloads of national importance) to minimal reliability requirements (except for safety) for payloads selected for simple, low-cost investigations.

APPENDIX A

SPACE STATION SCIENCE OPERATIONS MANAGEMENT CONCEPTS STUDY

STEERING COMMITTEE

Warren Keller (Chairman)	GSFC
John Bartoe (Vice-Chairman)	NRL/NASA HQ (OSS)
Joe Alexander	NASA HQ (Office of Chief Scientist)
Philip Cressy	GSFC
Mike Devirian	NASA HQ (OSSA)
Ken Frost	GSFC
Dick Halpern	NASA HQ (OSS)
Dick Keefe	NASA HQ (OSSA)
Ron Kinsley	The BDM Corporation
Granville Paules	NASA HQ (OSS)
Adrienne Pedersen	The BDM Corporation

WORKSHOP #1 (July 13-17, 1987)
PARTICIPANTS

Steering Committee Members and

George Anikis	NASA HQ (OSF)
Rodney Ballard	Ames Research Center
Richard Chappell	MSFC
Donna Dawson	NASA HQ (OSS)
Ted DeLaca	National Science Foundation
Rodger Doxsey	Space Telescope Science Institute
Bonnie Dunbar	JSC
Jack Estes	University of California, Santa Barbara
Gordon Garmire	Pennsylvania State University
Dick Hahn	Rensselaer Polytechnic Institute
Dick Johnson	NASA HQ (OSSA)
Rolf Jonsson*	European Space Agency
Fred Leslie	MSFC
Jaylee Mead	GSFC
Jay Moskowitz	National Institutes of Health
Gary Musgrave	The Bionetics Corporation
Joe Nuth	GSFC
Bill Oran	NASA HQ (Commercial Programs)
Tucker Pierce	Booz-Allen & Hamilton
Rhea Seddon	JSC
Carl Shelley	JSC
Mike Stevens	NASA HQ (Space Tracking)
Peter Thiringer	Booz-Allen & Hamilton
Bob Thirsk*	National Research Council of Canada
Richard Tyson	NASA HQ (OAST)
Gene Urban	MSFC
Koji Yanagawa*	National Space Development Agency of Japan

* International Partner Observers

WORKSHOP #2 (August 12-14, 1987)

PARTICIPANTS

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Darrell Cole	Department of Agriculture
Louis J. Demas	NASA HQ (OSSA)
Al Diaz	NASA HQ (OSS)
Bonnie Dunbar	JSC
Jack Estes	University of Calfornia, Santa Barbara
Dick Hahn	Rensselaer Polytechnic Institute
Elaine Hansen	University of Colorado
Jeff Hoffman	JSC
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Hugh Hudson	University of California, San Diego
Dick Johnson	NASA HQ (OSSA)
David Koch	Smithsonian Astrophysical Observatory
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Bruce McDonald	National Science Foundation
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WORKSHOP #2 (Continued)

Walter Planet	National Oceanic and Atmospheric Administration
Rudolf G. Richler	Grumman S.S. Prog. Support Divison
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Kathryn Schmoll	NASA HQ (OSSA)
Rhea Seddon	JSC
David Soderblom	Space Telescope Science Institute
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Gene Urban	MSFC
Dave Van Pelt	The BDM Corporation
Koji Yanagawa*	National Space Development Agency of Japan

* International Partner Observer

APPENDIX B

PRESENTATIONS TO SSSOMC STEERING COMMITTEE

DATE	SUBJECT	PRESENTER	ORGANIZATION
June 25, 1987	Space Station International Agreements	Peggy Finarelli	NASA HQ (OSS)
June 25, 1987	Space Station Operations Task Force (SSOTF)	Granville Paules	NASA HQ (OSS)
June 26, 1987	Telescience	Randy Davis	Univ. of Colorado
June 26, 1987	UARS Data Processing System	Robert Taylor	GSFC
June 26, 1987	Science and Applications Information System	Jim Weiss	NASA HQ (OSSA)
June 26, 1987	Space Telescope Science Institute (STScI)	Bob Milkey	STScI
June 26, 1987	NSF Antarctica Program	Peter Wilkniss	NSF
June 26, 1987	Management of National Laboratories	Jack Waite	Pace & Waite
July 7, 1987	OSSA Planning and AO Process	Jeff Rosendhal	NASA HQ (OSSA)
July 7, 1987	SSOTF Strategic Planning	Granville Paules	NASA HQ (OSS)

APPENDIX C
LIST OF ACRONYMS

AA	Associate Administrator (NASA)
AO	Announcement of Opportunity
ARC	Ames Research Center
AXAF	Advanced X-Ray Astrophysics Facility
COUP	Consolidated Operations and Utilization Plan
CUP	Composite Utilization Plan
DOC	Discipline Operations Center
DoD	Department of Defense
ELV	Expendable Launch Vehicle
EMI	Electromagnetic Interference
EOS	Earth Observing System
ESA	European Space Agency
FMPT	First Materials Processing Test
GRO	Gamma Ray Observatory
GSE	Ground Support Equipment
GSFC	Goddard Space Flight Center
HST	Hubble Space Telescope
ICD	Interface Control Document
IPS	Instrument Pointing System (Spacelab)
ISAS	Institute for Space and Astronautical Studies (Japan)
ISSUB	International Space Station User Board
I & T	Integration and Test
IUE	International Ultraviolet Explorer
IWG	Investigator Working Group
JEM	Japanese Experiment Module
JPL	Jet Propulsion Laboratory
JSC	Johnson Space Center
JSUP	Japan Space Utilization and Promotion
LAMAR	Large Area Multiple Array of Reflectors
LDR	Large Deployable Reflector

LSAC	Life Sciences Advisory Committee (NASA)
LSPIO	Life Sciences Payload Integration Office
MCB	Multilateral Coordination Board
MOA	Memorandum(a) of Agreement
MOU	Memorandum(a) of Understanding
MSFC	Marshall Space Flight Center
NAS	National Academy of Sciences
NASA	National Aeronautics and Space Administration
NASDA	National Space Development Agency (Japan)
NBS	National Bureau of Standards
NIH	National Institutes of Health
NOAA	National Oceanic and Atmospheric Administration
NRC	National Research Council (Canada)
NRL	Naval Research Laboratory
NSF	National Science Foundation
NSSDC	National Space Science Data Center
OAST	Office of Aeronautics and Space Technology
OCP	Office of Commercial Programs
OMV	Orbital Maneuvering Vehicle
OSS	Office of Space Station
OSSA	Office of Space Science and Applications
PAM	Payload Accommodation Manager
PSC	Platform Support Center
PI	Principal Investigator
PIMS	Plasma Interaction Monitoring System
PIO	Payload Integration Office
P/L	Payload
PLIO	Pressurized Laboratory Integration Office
POIC	Payload Operations Integration Center (Space Station)
SAAC	Space Applications Advisory Committee
SAB	Space Applications Board
SAC	Space Activities Commission (Japan)
SAIS	Science and Applications Information System (OSSA)

SESAC	Space and Earth Sciences Advisory Committee (NASA)
SIM	Science Increment Manager
SIRTF	Space Infra-Red Telescope Facility
SMM	Solar Maximum Mission
SMWG	Science Management Working Group
SOP	System Operations Panel
SSB	Space Science Board (NAS)
SSIO	Space Station Integration Office
SSIS	Space Station Information System
SSOTF	Space Station Operations Task Force
SSSC	Space Station Support Center
SSSOMC	Space Station Science Operations Management Concepts
SSSUB	Space Station Science User Board
SSUB	Space Station User Board
STA	Science and Technology Agency (Japan)
STScI	Space Telescope Science Institute
SWG	Science Working Group
TDRS	Tracking and Data Relay Satellite
TDRSS	Tracking and Data Relay Satellite System
TFSUSS	Task Force on Scientific Uses of Space Station
TOP	Tactical Operations Plan
TRMM	Tropical Rainfall Measurement Mission
UARS	Upper Atmospheric Research Satellite
UOP	User Operations Panel
USDA	U.S. Department of Agriculture
USGS	U.S. Geological Survey