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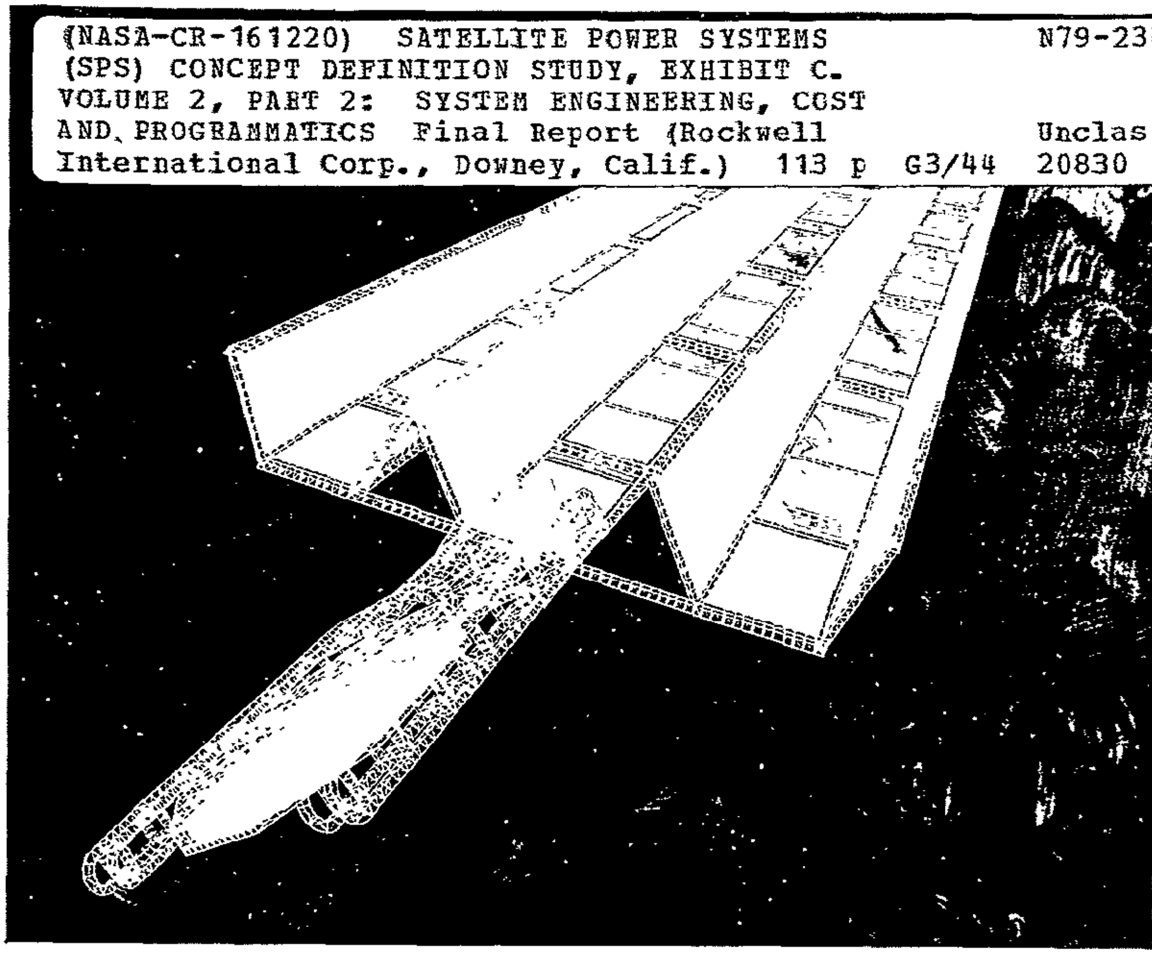

Satellite Power Systems (SPS) Concept Definition Study

FINAL REPORT (EXHIBIT C)
VOLUME II
SYSTEM ENGINEERING

PART 2
(COST AND PROGRAMMATICS)

Rockwell International

Satellite Systems Division
Space Systems Group

12214 Lakewood Boulevard
Downey, CA 90241

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SYSTEM ENGINEERING

PART 2
(COST AND PROGRAMMATICS)
CONTRACT NAS8-32475
DPD 558 MA-04

March 1979

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FOREWORD

Volume II, System Engineering, is presented in two parts. Part 1 encompasses SPS system engineering aspects. Part 2 consists of a volume on SPS cost and programmatics; an appendix is included in Part 2 to cover the SPS WBS and cost estimates. Volume II of the SPS Concept Definition Study final report is submitted by Rockwell International through the Satellite Systems Division. All work was completed in response to NASA/MSFC Contract NAS8-32475, Exhibit C, dated March 28, 1978.

The SPS final report will provide the NASA with additional information on the selection of a viable SPS concept, and will furnish a basis for subsequent technology advancement and verification activities. Other volumes of the final report are listed as follows:

Volume	Title
I	Executive Summary
III	Experimentation/Verification Element Definition
IV	Transportation Analyses
V	Special-Emphasis Studies
VI	In-Depth Element Investigations
VII	Systems/Subsystems Requirements Data Book

The SPS Program Manager, G. M. Hanley, may be contacted on any of the technical or management aspects of this report. He can be reached at 213/594-3911, Seal Beach, California.

ACKNOWLEDGEMENTS

Since the publication of earlier Rockwell SPS cost, economic, and programmatic documentation—dating back to 1976—a continuing effort has been maintained to incorporate the latest program developments, expand the Rockwell SPS cost model; conduct comparative cost/economic analyses; prepare integrated schedules or networks; and define SPS program plans and resource requirements. The results of this work represent a professional contribution on the part of many individuals, where most of them have been with the SPS contract activity and supplementing company-sponsored efforts since the start of our effort. It is this contribution that requires acknowledgement.

The overall study activity was also supported by other business/industrial organizations and technical members of the SPS program team and their management, making it possible to reach the desired conclusions with the minimum of effort.

The Rockwell SPS program development team that contributed to the search, analyses, and results of this study are:

• Dr. L. R. Blue	Cost/Risk Programming
• W. Cooper	Cost Analysis
• D. E. Lundin	SPS Schedules/Networks
• A. D. Kazanowski	Resource Analysis

The overall SPS program development activity on SPS costs, schedules, program planning, resource analysis, and computer programming was completed under the direction of F. W. Von Flue.

The help and support of personnel from NASA/MSFC and the SPS Program Planning Office is also acknowledged.

- Engineering Cost Group
  - W. S. Rutledge
  - J. W. Hamaker
  - D. T. Taylor

- Program Plans and Requirements Group
  - W. A. Ferguson
  - H. K. Turner

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1.0 SPS COST AND PROGRAMMATICS

1.0 SPS COST AND PROGRAMMATICS

1.1 INTRODUCTION

U.S. energy demands continue to increase dramatically and the availability of traditional energy resources have become the focal point of national/international concern and economic balance. It is therefore important that alternate sources of energy be identified and evaluated as potential solutions to the law of supply and demand. In this regard, the possibility of generating large quantities of electrical power in space and transmitting it to earth offers a conceivable solution. However, economic and technological requirements of such a program needs to be established with confidence. This volume considers the cost and programmatic requirements for a recommended satellite power system reference concept evolving from a series of contracts[1] and company-sponsored work completed by the Rockwell International Satellite Systems Division of the Space Systems Group.

The Rockwell SPS reference satellite and rectenna concept are illustrated in Figure 1.1-1. These configurations were used in the definition of costs and programmatics described in this volume. Typically, a single SPS provides 5 GW of electric power to the utility interface on the ground. The satellite is located in geosynchronous orbit and converts solar energy to dc electrical energy using large GaAlAs solar arrays at a concentration ratio of two suns. The dc electrical energy is conducted from the solar arrays to the microwave antenna where the energy is transformed to microwave RF energy. A large, 1-km-diameter, antenna beams the energy to a receiving antenna (rectenna) on the ground. The rectenna converts the RF energy, at very high efficiency, to dc electrical energy where it is collected and routed to conversion centers for subsequent input to the utility grid.

The overall scenario for SPS space transportation involvement is shown in Figure 1.1-2. Eight major elements comprise the transportation system:

- Shuttle
- SPS heavy-lift launch vehicle (HLLV)
- Electrical orbit transver vehicle (EOTV)
- Intraorbit transfer vehicle (IOTV)
- Personnel orbit transfer vehicle (POTV)
- Crew module (CM)
- Leo propellant depot
- GEO propellant depot

The SPS HLLV is used to bring construction payload, crew expendables, and propellants for the EOTV and POTV. The IOTV is used to carry payloads over short

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[1] *Satellite Power Systems (SPS) Concept Definition Study* (NAS8-32475)—*Exhibit C*, March 1978; *Exhibit A/B*, March 1977; and the *SPS Feasibility Study* (NAS8-32161), August 1976.

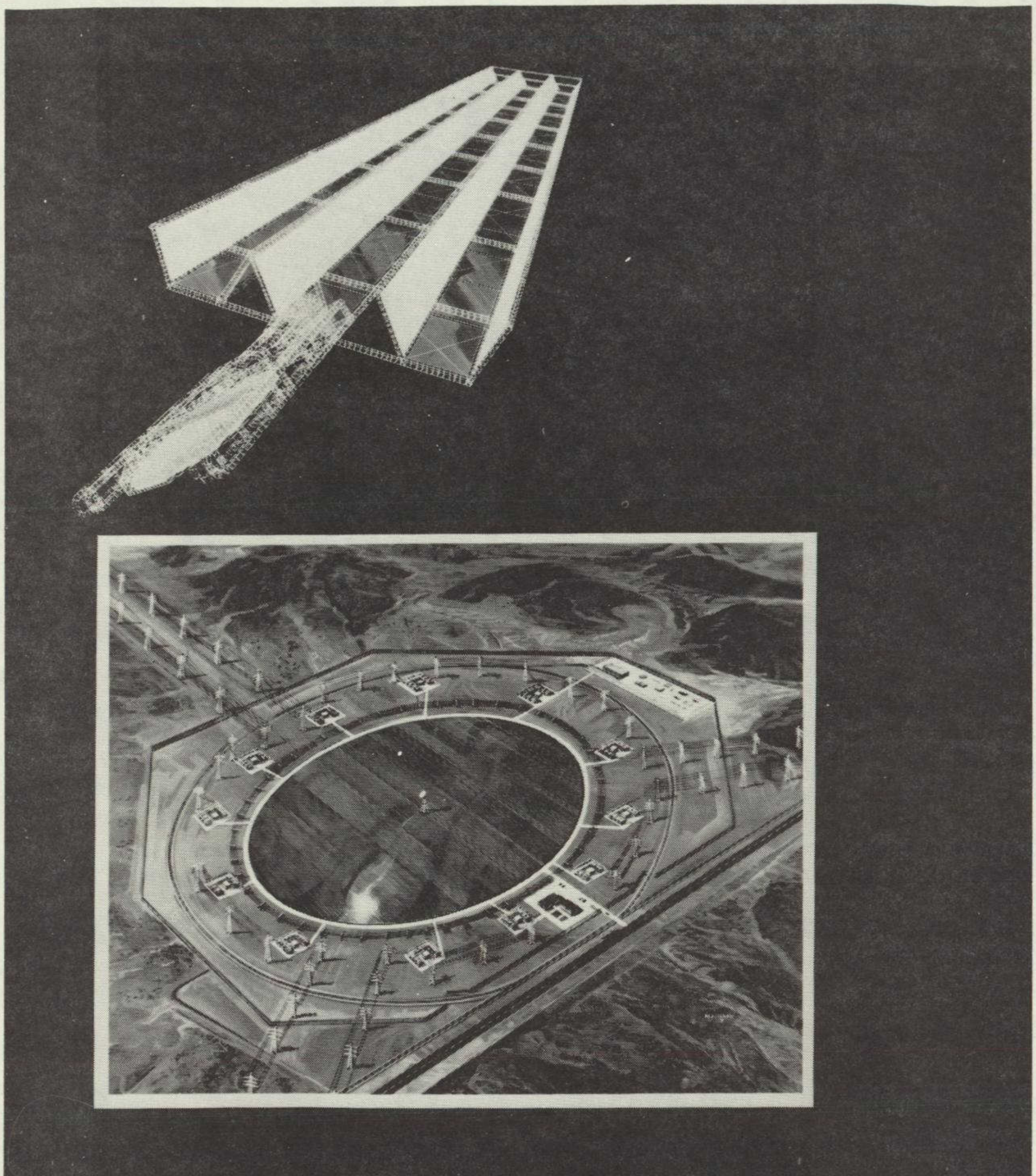

Figure 1.1-1. SPS Reference Satellite and Rectenna Concept

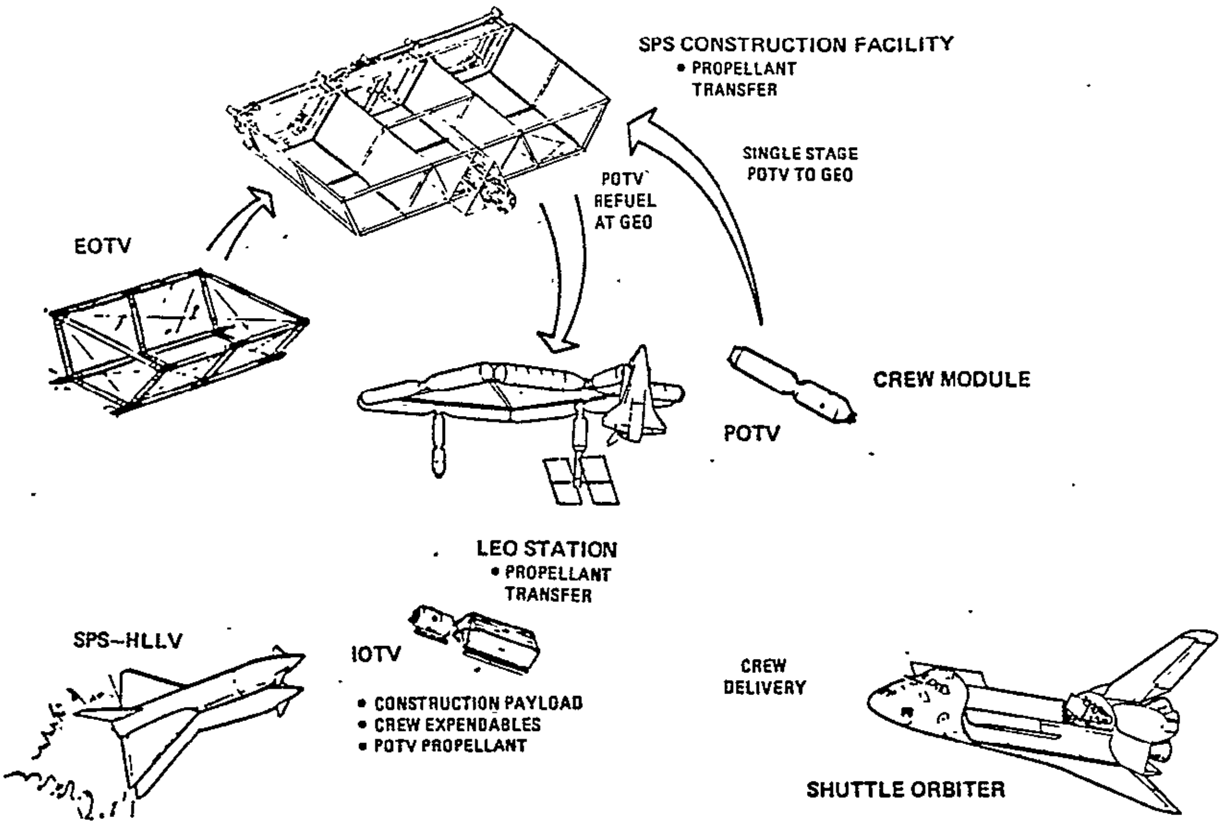

Figure 1.1-2. Transportation Operations Scenario

distances, e.g., between the SPS HLLV and the LEO station or EOTV, between the EOTV and space construction base (SCB), and between the Shuttle orbiter and the POTV. The EOTV carries payloads brought up in the HLLV between LEO and GEO. Because of the long flight duration of the EOTV, another vehicle (the POTV) is used to rapidly carry crew members between LEO and GEO. A crew module, capable of carrying 60 crew members, is needed to provide life support during crew transfer. The Space Shuttle provides transportation of crew, in its crew module, between earth and LEO.

The initial step in satellite precursor operations is to establish the LEO base as shown in the lower left of Figure 1.1-3. Crew and power modules are transported to LEO by Shuttle derivatives and assembled. When the base is fully operational, Shuttle external tanks are delivered and mated to form construction fixtures for SCB construction. Since the more economical HLLV will not be available, and since overall plans specify an EOTV test vehicle, it is probable that only the center trough of the SCB would be constructed initially. This trough would be used to fabricate the pilot plant EOTV with antenna. After proof of concept and SPS go-ahead, the remainder of the SCB would be completed, an initial fleet of EOTV's constructed, and the SCB transferred to GEO, using one or more EOTV's for propulsion and attitude control. Upon reaching GEO, satellite construction would commence, with the logistics support as shown at the right of the figure.

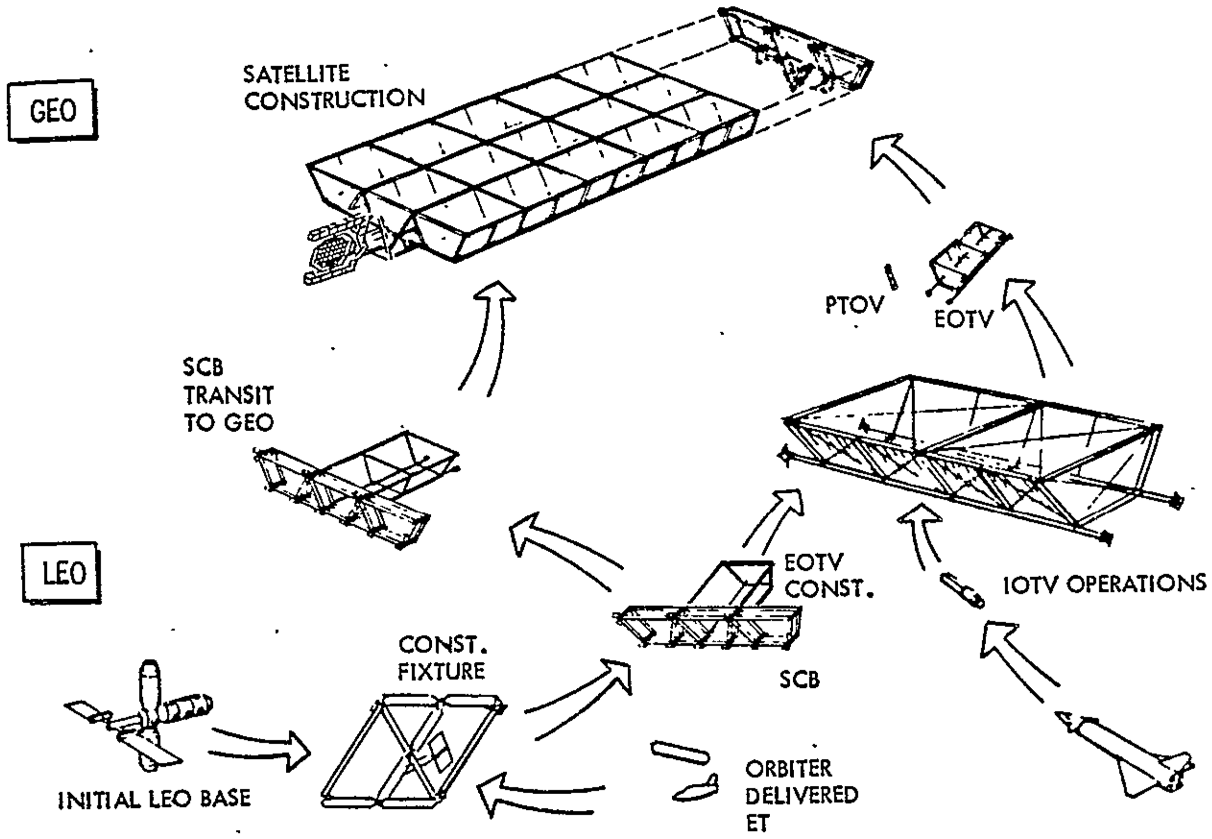

Figure 1.1-3. Overall Satellite Construction Scenario

This volume is divided into three sections that describe the program, study approach, and ground rules/guidelines (Section 1.0). Section 2.0 covers cost analysis definitions and summarizes SPS costs for each of the main elements—satellite, space construction and support, transportation/facilities, ground receiving station, and management/integration. Comparative assessments are presented along with a description of cost trades. SPS programmatic elements are presented in Section 3.0 to provide detail schedule/network information on the flow and sequence of design, development, construction, and operational activity. Included are some 13 program plans identifying operational requirements and considerations of the SPS program.

1.2 SPS GROUND RULES AND GUIDELINES

A series of ground rules and guidelines were used during the study to provide a common reference point for the uniform development of cost and programmatic elements of the SPS program. These considerations are itemized as follows.

1. The SPS WBS of Appendix A was used as the structure of program hardware, activities, and accounts.

2. Key dates of program planning:
   - 1980-1985 Ground-Based Exploratory Research Activities
   - 1981-1987 Key Technology Program Activities
   - 1990 Decision Point for SPS Commercialization (Phase C/D)
   - 2000 IOC of First SPS

3. Costs are reported at WBS level in terms of:

   (a) Development cost and TFU (theoretical first unit)

   (b) Initial capital investment average cost per satellite (Satellites TFU and No. 2 through No. 60)

   (c) Replacement capital investment (RCI) cost and operations and maintenance (O&M) cost per satellite per year

4. Cost estimates are projected in 1977 dollars and maximum use was made of past SPS studies and other associated data as appropriate.

5. SPS build rate will be two nominal 5-GW SPS systems per year for 30 years to provide a total capacity of 300 GW by 2030.

6. Overall SPS lifetime will be 30 years with minimum maintenance and no salvage value or disposition costs.

7. Complete construction and assembly will occur at geosynchronous orbit.

8. Calculations are based on 0% launch losses.

9. Program management and SE&I (management and integration) are costed at 5% of all other Level 2 costs.

10. 25% mass contingency is costed as a 15% cost contingency on SPS WBS items of the satellite (1.1), space construction and support (1.2), and transportation (1.3).

In order to promote a complete and understandable comparison of SPS concepts, and to maintain compatible economic and programmatic references, the SPS Work Breakdown Structure (WBS) Dictionary[1] was used as the baseline document for the definition and organization of program elements. This structure subdivided the program into lower-level elements within each major system grouping and associated the dictionary definition with special accounts and phases unique to the program. Accounts and phases were designated for the DDT&E; initial capital investment (covering initial procurement and placement of each SPS); replacement capital investment (capital asset replacement over the SPS operating life); and operations/maintenance (expendables and minor maintenance). This structural interface (Figure 1.2-1) provides the capability to view and analyze the SPS program from a number of programmatic, economic/cost, and management aspects. The WBS dictionary (Appendix A) was carefully maintained and updated throughout the study as the programmatic baseline.

[1] *SPS Work Breakdown Structure Dictionary*, National Aeronautics and Space Administration, November 1978.

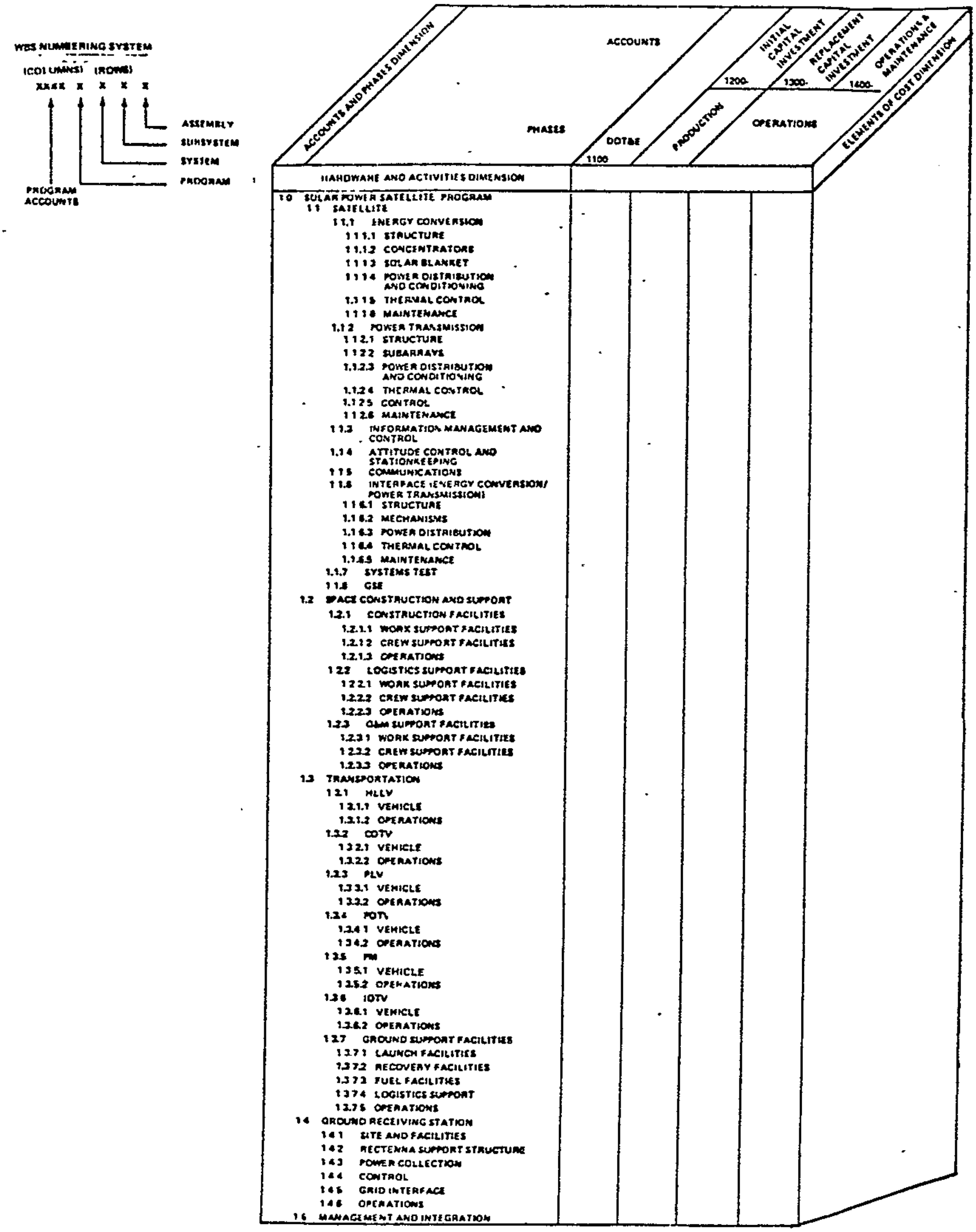

Figure 1.2-1. Satellite Power System Work Breakdown Structure

1.3 STUDY TEAM AND INTERFACES

The SPS program development group functioned as an integral part of the overall SPS studv team and participated in the progress and results of each task as it evolved. In addition to the daily interface with members of the Rockwell staff, discussions were held with representatives of the NASA/DOE. Supporting business/industrial representatives, such as those listed in Table 1.3-1, were contacted during the analysis and grass roots development of cost and programmatic estimates.

Table 1.3-1. Industry Contacts

ORGANIZATION	PURPOSE
• SME (SOCIETY OF MANUFACTURING) ENGINEERS)	OBTAIN TECHNICAL DATA ON ROBOTICALS AND TECHNOLOGY STATUS
• RIVERSIDE CEMENT CO.	RECTENNA CEMENT/CONCRETE REQUIREMENTS AND PROCESSES
• MODERN ALLOYS, INC.	METHODS & EQUIPMENT FOR CONTINUOUS PLACEMENT OF RECTENNA PANEL CONCRETE FOOTINGS
• SANDIA-SOLAR THERMAL	COMPARISON OF STTF CONSTRUCTION/HANDLING APPROACH WITH SPS RECTENNA REQ'TS
• TOWNSEND & BOTTUM, CONST. MGRS, 10 MW SOLAR PLANT IN BARSTOW, CA	SITE PREPARATION AND CONSTRUCTION OPERATIONS
• AMERICAN BRIDGE - A DIVISION OF UNITED STATES STEEL	STEEL REQ'TS & CONSTRUCTION APPROACH FOR INSTALLATION OF RECTENNA PANELS
• ALPHA-BETA DISTRIBUTION CENTER	ANALYSIS OF MATERIALS HANDLING SYSTEMS
• CATAPILLAR	EARTH MOVING & GRADING EQUIPMENT
• INTERNATIONAL HARVESTER	EARTH MOVING & GRADING EQUIPMENT
• SOUTHERN CALIFORNIA EDISON	DC/AC POWER DISTRIBUTION LINES/TOWERS

1.4 STUDY APPROACH

The objective of the study was to provide NASA with additional, accurate, and sufficient data and information to enable the selection of preferred viable SPS concepts by CY 1980 as a basis for subsequent technology advancement and verification activities in the CY 1980-1987 time frame. In this regard, the cost and programmatics contribution is documented in this final report. The results of each task evolved from two major activities: (1) a review and update of contract Exhibits A and B costs as reported in April 1978; and (2) the extensive analysis, selection, and determination of cost estimates, along with program plans/schedules applicable to the newly selected Rockwell SPS reference configuration of Exhibit C—especially the expansion of transportation and ground-receiving station data bases. All results of this work were consistent with SPS ground rules/guidelines and contract requirements covering four areas as detailed in the study plan:

- Cost Analysis
- Schedules/Networks
- Planning Packages
- Program Plans

Figure 1.4-1 identifies the close interrelationship of these tasks, the source of data, and the flow of cost and programmatic information into applicable final report volume such as this Part 2 of Volume II—Systems Engineering that summarizes the activity in all areas.

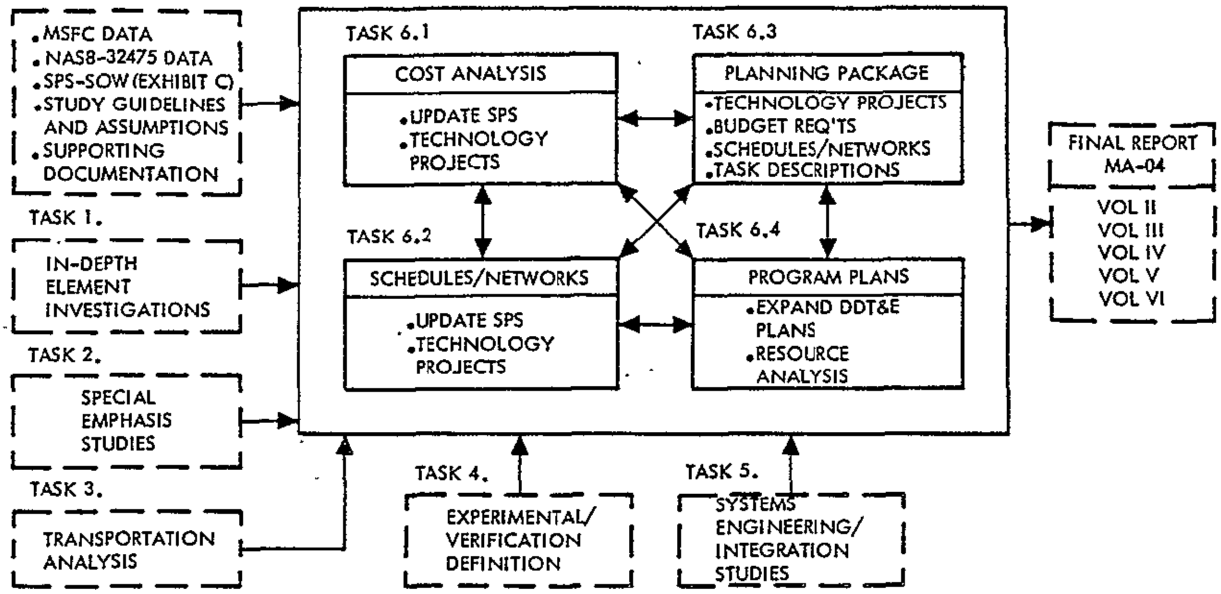

Figure 1.4-1. Cost and Programmatic Approach

2.0 COST ANALYSIS

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2.0 COST ANALYSIS

2.1 INTRODUCTION

Results of SPS cost analyses, trades, and sensitivities are described in this section. Cost estimates of the Rockwell SPS baseline concept were updated in June of 1978, and shortly thereafter the reference NASA SPS concept replaced the earlier configuration. It is the reference configuration, with some design improvement, that was used in the development of cost and programmatics. The following discussion covers the costing approach/methodoloy; cost-effectiveness results; and SPS cost estimates, including time-phased costs of DDT&E and TFU.

2.2 SPS COSTING APPROACH

The SPS cost analysis has been performed on the Rockwell reference configuration discussed in this report. The Exhibit C study considered an SPS option of 60 units with an IOC in the year 2000 and the full 300-GW capability to become operational at the rate of two SPS's or 10 GW per year. The Rockwell cost model was structured to the NASA SPS Work Breakdown Structure and Dictionary of November 1978, utilized the MSFC CER data base, and incorporated grass roots analyses and information from the Rockwell CER data base. This continuous interaction to seek and establish better cost estimates has resulted in a higher degree of confidence in the resultant cost estimates, as compared with those of the Exhibit A/B final report. While the cost estimating relationships were developed to be as accurate as possible, it is too early in the definition process of the SPS to precisely predict either the final system point design or point estimate. However, it is believed that another step has been taken to predict the direction and relative magnitude of cost impacts and to aid in design determination/decisions of preferred concepts.

There are basically four types of cost equations in the model, corresponding to the four WBS accounts—DDT&E, initial capital investment, replacement capital investment, and operations and maintenance. The cost methodology is shown in detail in Appendix B as it covers CD (DDT&E), CTFU and CIPS (initial capital investment); CRCI (replacement capital investment); and CO&M (operations and maintenance). Appendix B also provides a brief narrative description of each CER, its application, input data, and the calculated value for each type of costs.

The DDT&E equation (CD) estimates the cost of design, development test/evaluation and non-recurring costs. Separate factors were utilized to calculate the proportional assessment for management and integration and as a cost contingency for mass growth. In view of the gross nature of the level of information currently available on WBS 1.1.7—System Test (hardware/operations) and Ground Support Equipment—the cost of systems test was assumed at 100% of the satellite system ICI cost; whereas GSE was factored at 10% of the satellite DDT&E cost through 1.1.7.

The applicable total system mass, area, or power was used as the inputs for DDT&E CER's. A development factor (DF) is included in the equation to adjust the cost to reflect only that portion of the total system mass, area, or power considered to be necessary for development of the complete system where it is not required to develop the total mass, area, or power. The CD cost equation also allows for the application of a complexity factor (CF) to adjust the cost results when it is determined that the item being estimated is either more or less complex than the CER base data.

The initial capital investment (ICI) cost equations estimate the initial capital investment cost of hardware items as a function of their mass, area, or power. The ICI cost equation is expressed in several different forms—CLRM, CTFU, CTB, and CIPS. The CLRM (cost of lowest repeating module) equation requires that the point estimate correspond to the mass, area, or power of the lowest repeating module (M). This is necessary because of the physical scale of the SPS and the production quantities required for many of the hardware elements. It is not reasonable to estimate the SPS initial capital investment cost as a historical function of the entire SPS mass, area, or power. Rather, it is desirable to cost the number of repeating modules required per satellite to establish the satellite theoretical first-unit cost (TFU), and then input the satellite TFU cost into a progress (learning) function for the quantity of satellites required to calculate the average unit cost (IPS). This calculation involves two steps in the cost equations. The first step (CLRM) is simply the portion of the equation which estimates the theoretical first repeating module cost as discussed above. The second step (CTFU) has the progress function incorporated into the equation for the quantity of repeat modules required per satellite. This is automatically taken into account with the progress over production quantities as required when calculating the cost to build (CTB). CTB calculations are then factored on the basis of a requirement to construct an SPS divided by the option quantity.

At the current level of SPS definition, it was difficult to define a repeating module. It is often impossible to know with any certainty just what portion of the total mass is appropriate to run through the equation as a module. It is just as difficult to identify how many distinct types or designs of modules will be required for any subsystem or assembly. In such cases, the study simply assumed a module mass (or area or power) based on an engineering best judgment.

Replacement capital investment (CRCI) CER's provide for the multiplication of the annual spares fraction (R) of each system by that system's cost to arrive at an RCI cost per satellite per year.

Operations and maintenance costs (CO&M) are estimated in terms of O&M cost per satellite per year. O&M costs include those expenditures incurred in day-to-day operations, beginning with SPS initial operating capability (IOC) and continuing over the life of each satellite. They consist of wages of O&M personnel, minor repairs and adjustments to systems to maintain an ordinarily efficient operating condition, expendables and consumables, launch costs for delivery and transfer of on-orbit personnel, and cargo resupply of expendables and consumables, etc. O&M costs are calculated by the use of a direct cost input or by an annual factor per SPS times the cost to build the particular system.

The cost methodology seeks to account for five separate effects which influence SPS cost: scaling, specification requirements, complexity, the degree of automation, and production progress. Scaling refers to the relationship in cost between items varying in size, but similar in type. Economies of scale usually ensure that such a relationship will not be strictly linear, but rather as size increases the cost per unit of size will decrease. The scope of this relationship is reflected by the equation exponent which results from the regression analysis of the data used to develop the cost estimating relationship.

Specification requirements have been accounted for by normalizing the CER data base to manned spacecraft specification levels, using factors from the RCA price model.[1] From that model, an average cost factor to adjust MIL-SPEC to manned spacecraft is around 1.75 for DDT&E and 1.6 for production cost. Under the assumption that some relaxation of Apollo-type specifications can be made for the SPS, a factor of 1.5 was assumed for both DDT&E and production cost. Furthermore, it was assumed that a factor of 3.0 would adjust commercial specifications to SPS requirements; therefore, military or commercial cost data used in the CER's were adjusted upward by factors of 1.5 and 3.0, respectively.

The cost equations allow a complexity factor input to adjust the cost result when it is determined that the item being estimated is either more or less complex than the listed CER data base.

The degree of automation is accounted for in certain cost equations through an adjustment to the CER coefficient by the tooling factors given in Appendix B. The effect of tooling is dependent upon the annual production rate. Higher production rates allow harder tooling and, thus, effect cost reductions. The tooling factors are used only on those CER's which are based on historical aerospace programs with limited annual production rates. Tooling factors are not used (and thus are not exercised as part of the equations in Appendix B tables) on those CER's which are based on data already reflecting automated production techniques (e.g., the commercial electronics data for the microwave antenna CER).

Finally, the decreasing cost effects of progress, due to production process improvements or direct labor learning, are accounted for through standard progress functions. Many SPS components will be mass-produced in a capital intensive manner and will experience little labor learning. Other SPS hardware items, however, will be produced at very low annual rates much in the labor intensive manner of historical spacecraft programs and would therefore experience learning. (Technically distinguishable from learning—but still predictable with the same form of exponential function—are the effects of production process improvements. In this model, when progress functions are used, they are meant to account for both of these effects.) A constant relationship has been assumed between the progress fraction and the annual production rate.

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[1]*Equipment Specification Cost Effect Study, Phase II, Final Report,* November 30, 1976, by RCA Government Systems Division.

As required by the costing ground rules and assumptions, all CER's are in terms of 1977 dollars. The study did assume 1990 technology and 1990 supply/demand conditions which, in some cases, resulted in differential (non-general) price inflation or deflation between 1977 and 1990 being included in the CER's. Specifically, it was assumed that composite raw material prices and some electronic component prices will decrease relative to general prices, while aluminum coil stock prices will increase relative to general prices. Such effects are allowed for by the CER's but only to the extent that the expected price changes differ from expected general price changes. The CER's affected are those for the antenna structure, power source structure, and microwave antenna.

2.3 SPS COST ESTIMATES

Total program costs were developed for WBS sub-level elements of DDT&E, production, launch, orbital assembly/construction, ground operations, replacement capital, and operations/maintenance. This section will present summarized cost data and describe the elements contained in each program phase.

Tables 2.3-1 and 2.3-2 summarize cost information for each main segment and phase of the SPS program. Table 2.3-1 shows development cost data through the first full 5-GW operational satellite (TFU) including space transportation, construction, operations, and the ground receiving station plus grid interface and facilities needed to establish the SPS operational capability of the ground and space segments. As such, all cost estimates for the TFU include systems, equipment, facilities, and machinery that have a service life capable of

Table 2.3-1. SPS Program Development Cost

WBS #	DESCRIPTION	DEVELOPMENT DDT&E	TFU	TOTAL
1	SATELLITE POWER SYSTEM (SPS) PROGRAM	33401.762	51103.242	84505.000
1.1	SATELLITE SYSTEM	7933.570	7950.922	15884.492
1.2	SPACE CONSTRUCTION & SUPPORT	7331.180	8602.523	15933.703
1.3	TRANSPORTATION	12468.816	22866.199	35335.016
1.4	GROUND RECEIVING STATION	115.699	3618.727	3734.427
1.5	MANAGEMENT AND INTEGRATION	1392.463	2151.918	3544.382
1.6	MASS CONTINGENCY	4160.031	5912.945	10072.977

building more than one SPS. Table 2.3-2 summarizes (1) the investment per satellite (including ground station) of the option of 60 SPS's at a build rate of two 5-GW systems per year, and (2) the annual cost per satellite for replacement capital and operations/maintenance. Figure 2.3-1 illustrates a distribution of the costs as the program moves through its phases of DDT&E, TFU, and production/operations. The investment per satellite (average cost) includes the cost to build a 5-GW satellite, ground receiving station, and apportioned transportation/space construction requirements.

Table 2.3-2. SPS Program Average Cost

WBS #	DESCRIPTION	INV PER SAT	** OPS COST PER SAT PER YEAR ** RCI	O&M	TOTAL OPS	TOTAL
1	SATELLITE POWER SYSTEM (SPS) PROGRAM	13877.668	451.531	193.713	645.244	14522.910
1.1	SATELLITE SYSTEM	5325.422	205.265	0.705	205.970	5531.391
1.2	SPACE CONSTRUCTION & SUPPORT	1148.332	51.428	11.274	62.701	1211.033
1.3	TRANSPORTATION	1949.004	119.343	80.869	200.212	2149.216
1.4	GROUND RECEIVING STATION	3590.822	0.275	78.377	78.652	3669.474
1.5	MANAGEMENT AND INTEGRATION	600.679	18.815	8.561	27.377	628.055
1.6	MASS CONTINGENCY	1263.413	56.405	13.927	70.332	1333.745

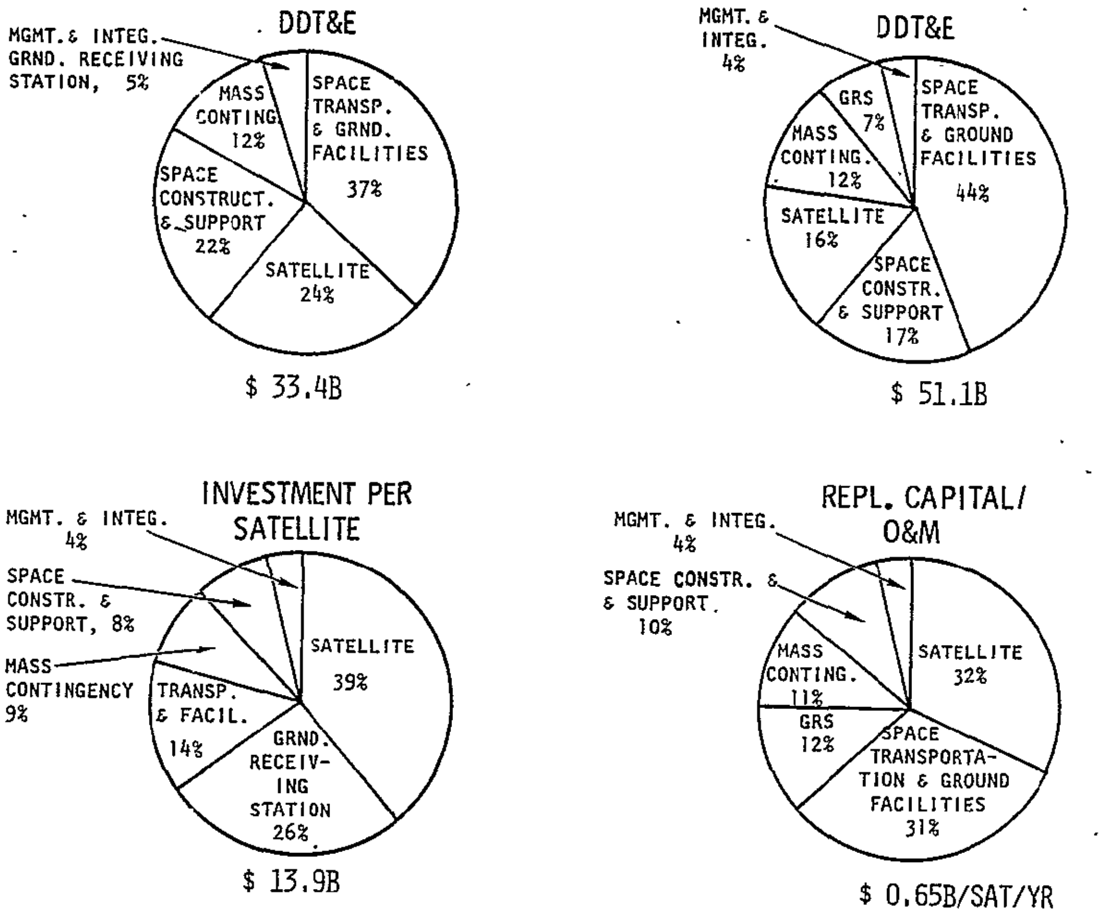


Figure 2.3-1. SPS Cost Relationships

DEVELOPMENT COST

The DDT&E phase consists of the one-time effort associated with designing, developing, and evaluating the components, subsystems, and systems required for the SPS project. It includes the development engineering, testing, and support necessary to translate a performance specification into a design. It encompasses the preparation of detailed drawings for system hardware fabrication, system integration and—depending on the system, subsystem, or component—structural, environmental, and other required tests. It includes the early supporting research and technology analyses, advanced study efforts and requirements definition related to the SPS microwave power transmission system, power conversion, structure and assembly and power distribution; component development; integrated ground test programs; the Geosat space tests and LEO Shuttle sortie demonstrations, both shared and dedicated. It also includes related Shuttle-derived HLLV transportation systems and development of an SPS prototype demonstration test article which, following demonstrations, will be upgraded to an operational EOTV. Also included are the analyses of data and the necessary redesign and retest activities to meet specifications; and ground support equipment, special test equipment, and other program-peculiar costs not associated with repetitive production. All DDT&E effort associated with SPS-related support systems such as transportation, space construction base, and assembly/support equipment necessary to accomplish the satellite DDT&E phase is also included.

DDT&E and TFU costs are combined in Figure 2.3-2, identifying major percentiles that make up the $84.5 billion total. The SPS VTO/HL HLLV is a main contributor to the space transportation requirement along with the rectenna

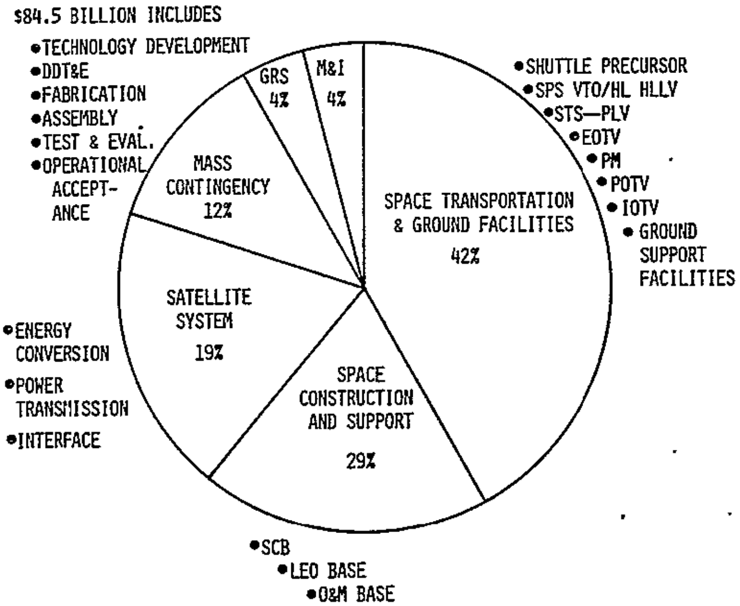


Figure 2.3-2. Cost Relationship Through the First SPS

support structure/power collection elements of the ground receiving station. TFU space transportation at $19.67 billion is divided among vehicle fleet and operations breakdowns as shown in Figure 2.3-3, where the SPS VTO/HL HLLV identifies a five-vehicle requirement and 234 round-trip flights. Space Shuttle

VEHICLE	TFU COST	GOZINTOS
SPS VTO/HL HLLV (1.3.1) • FLEET • OPERATIONS	\$9530.5	• 5 VEHICLES • 234 R.T. FLIGHTS
STS - PLV & CARGO/EM (1.3.3) • FLEET • OPERATIONS	\$6251.2	• 4 VEHICLES • 3 ORBITERS • 261 E.T.'S • 10 LRB'S • 3 CARGO/EM • 261 RT FLIGHTS
EOTV (1.3.2) • FLEET • OPERATIONS	\$3625.7	• 6 VEHICLES • 7 FT FLIGHTS
POTV (1.3.4) PM (1.3.5) IOTV (1.3.6) • FLEET • OPERATIONS	\$ 263.8	TFU FLEET WILL BUILD: • EOTV TEST ARTICLE • LEO BASE • SCB • FIRST SATELLITE
	$\$19671.2 \times 10^6$	

Figure 2.3-3. TFU Space Transportation

requirements represent vehicles and operations of the traffic model necessary to build the TFU and complete precursor activities covering the early program microwave test article, LEO base, satellite construction base (SCB), initial EOTV's; and to provide personnel during TFU fabrication/assembly and checkout activities. The SCB comprises over 76% of the \$8.6 billion estimated for space construction and support, with about \$4 billion required in work support facilities, and \$2.6 billion in crew support facilities. Energy conversion (25%) and power transmission (48%) comprise the majority of satellite system costs projected at \$7.95 billion. The TFU GRS breakdown identifies 88% of the cost in the rectenna support structure and power collector, with major costs in the steel panel/installation and antenna array elements as shown in Figure 2.3-4.

Costing of DDT&E for the space base elements, STS-HLLV, and the assembly and support equipment followed the more conventional method of determining DDT&E cost—that is, based upon total subsystem mass, area, or power. This technique was used mainly from the standpoint that the cost data utilized to develop the applicable CER's for these elements were comparable and were developed on the basis of total subsystem mass, area, or power. In the case of the satellite, comparable historical DDT&E cost data were just not available for the magnitude of the satellite subsystems.

In view of the physical size of the satellite subsystems and the large quantities required for certain parts and components, it was not considered reasonable to estimate the satellite subsystem DDT&E costs as a function of the total mass, area, or power per satellite as is generally the method. Rather, it was considered desirable to determine the satellite subsystem DDT&E costs by the application of a development factor.

WBS ELEMENT	GOZINTOS	TFU COST ($ x 10^6)
RECTENNA SUPPORT STRUCTURE (1.4.2)	• STEEL PANEL FAB & INSTALL (92%) • TRENCHING & CONCRETE	1849.6
POWER COLLECTION (1.4.3)	• ANTENNA ARRAY ELEMENTS (83%) • POWER DISTRIBUTION • INSTALLATION & CHECKOUT	1353.2
SITE & FACILITIES (1.4.1)	• LAND & PREPARATION • ROADS & BUILDINGS • UTILITIES & MAINTENANCE EQUIP.	195.2
GRID INTERFACE (1.4.5)	• ELECTRICAL EQUIPMENT • TOWERS	145.7
CONTROL (1.4.4)	• CONTROL CENTER EQUIPMENT • CONTROL ELECTRONICS	75.0
		$3618.7 x 10^6

Figure 2.3-4. TFU Ground Receiving Station

The development factor was determined by engineering and, in general, was estimated at a factor considered appropriate to the development of total system or subsystem based on parameters of mass, area, or power. In some cases it was determined that the factor should be slightly higher or directly related to the development scenario of the particular system. For example, crew and work support modules of the LEO, SCB, or satellite operations and maintenance base are of common design but required at different times of the program. Appropriately then, development factors were assessed at 100% for modules required at the first point of usage, whereas a factor of lesser value was used on subsequent modules as a means of compensating for subsequent development or design integration costs.

INVESTMENT AND OPERATIONS

Investment and operations costs developed during the study were presented in Table 2.3-2 and Figure 2.3-1. Investment costs were developed at two levels —initial capital investment (ICI) which is the cost of production, assembly, installation, transportation, and testing of each individual satellite produced, ground station system, and associated effort necessary to bring the power satellite on line to a full 5-GW operational capability; and replacement capital investment (RCI) which are those expenditures relating to capital asset replacement and major maintenance overhauls that are expected to last for more than one year and result in an improvement to the operating system. Replacement capital requirements for the systems used to construct the satellite through IOC are included in the initial capital investment costs. Costs for the fleet, for example, needed to support O&M, are estimated and included as replacement capital investment. Operations costs consist of the effort required to operate and maintain the SPS project over its operational lifetime.

Investment per satellite is equivalent to the average unit cost of the total SPS requirement (TFU plus Satellites 2 through 60). This total average cost of $13.88 billion includes a 15% cost contingency for growth in the mass of WBS elements 1.1, 1.2, and 1.3. Satellite system costs of $5.33 billion are made up of power transmission (59%) and energy conversion (35%). The GRS estimate of $3.59 billion is primarily in the rectenna support structure and power collection system. SPS replacement capital and operations/maintenance phases are estimated at a total annual cost of $0.65 billion per year per SPS. The total average (investment) cost per nominal 5-GW satellite yields an investment cost of $3010/kW.

An analysis of potential major cost drivers (Table 2.3-3) was prepared for the Rockwell SPS CR-2 reference configuration of March 1979. Over 90% of the costs are represented within each program phase DDT&E, TFU, average satellite, and RCI/O&M. Close review will show that certain elements are consistently cost drivers requiring programmatic studies and analyses of SPS design and technical approaches.

Table 2.3-3. Potential Cost Drivers
Rockwell SPS Reference Configuration (March 1979)

MAJOR PROG. ELEMENT	DDT&E $33.40B	TFU $51.10B	AVG. SATELLITE $13.88B	RCI/O&M $0.65B/SAT/YR
PERCENTAGE OF TOTAL	95%	96%	91%	90%
Satellite Syst. (1.1)	21% • Ground test hardware & operations • Power transmission • Precursor EOTV	15% • Power transmission • Energy conversion • EOTV test article	36% • Power transmission • Energy conversion	30% • Power transmission
Space Construction & Support (1.2)	22% • Space construct. base • LEO base	15% • Space construct. base • Satellite O&M base	7% • Satellite O&M base	5% • Space construct. base
Transportation/Ground Facilities (1.3)	35% • SPS VTO-HL HLLV • Ground facilities • Pers. launch vehicle	44% • SPS VTO-HL HLLV • PLV • EOTV • Ground facilities	12% • SPS VTO-HL HLLV • PLV	28% • SPS VTO-HL HLLV • PLV
Ground Receiving Station (1.4)		6% • Rectenna support structure • Power collection	23% • Rectenna support structure • Power collection	12% • Operation
Management/Integration (5%) and Mass Contingency (15%)—(1.5, 1.6)	17% • Management & integra. • Mass contingency	16% Management & integra. Mass contingency	13% • Management & integra. • Mass contingency	15% • Management & integra. • Mass contingency

SPS COST BY YEAR

A spreading function curve (ojive) was used in the time-phasing of costs against each main line item of the SPS WBS at a subsystem level. The cost spreading was projected for DDT&E and TFU costs by using various functions between the 20/80 and 80/20 curve spread. This approach provided distributions supporting a low front-end buildup with the flexibility to shift costs in a manner suitable to the phasing of subsystem development and start-up requirements.

Table 2.3-4 summarizes full-scale DDT&E and the incremental cost buildup leading to the TFU IOC by the year 2000. A relatively low profile prevails through the 1980's, reflecting activity of the ground-based experimental research and technology development programs on power transmission, PD&C, energy conversion, large space structures, and space transportation. The costs expand rapidly through the mid/late 1990's as the DDT&E activities accelerate and the Phase C/D programs begin on the satellite, space operations, transportation, and ground receiving station including facilities and equipment for hardware buildup in support of early launches, ground operations, and space construction tasks.

Table 2.3-4. DDT&E Plus TFU Cost By Year ($ Millions)

YEAR	1.1	1.2	1.3	1.4	1.5/1.6	TOTAL
1980	0.16	0.0	7.07	0.0	2.10	9.32
81	1.55	0.0	47.26	0.00	14.15	62.96
82	5.41	0.0	121.37	0.02	36.81	163.61
83	12.54	0.0	222.23	0.05	68.44	303.26
84	23.96	0.0	342.31	0.09	107.34	473.71
85	44.17	0.0	473.73	0.14	151.74	669.78
86	77.57	0.0	608.27	0.20	199.80	885.83
87	126.36	127.61	777.32	0.25	249.63	1281.19
88	194.19	700.97	1060.78	0.29	299.25	2255.49
89	304.04	1385.59	1379.06	0.33	525.73	3594.75
90	467.19	1812.37	1742.91	1.35	911.76	4935.58
91	670.72	1760.71	2281.63	2.03	1240.52	5955.59
92	943.40	1158.46	2957.09	93.87	1481.14	6633.96
93	1445.59	501.35	3082.37	364.65	1613.62	7007.59
94	2047.68	659.73	3426.86	663.12	1628.74	8426.14
95	2534.40	1386.53	4017.93	798.15	1528.12	10265.13
96	2601.31	1900.73	4358.34	759.63	1324.23	10944.24
97	2202.48	1968.53	3957.70	601.30	1040.33	9770.32
98	1423.47	1557.52	2848.46	341.65	710.51	6881.62
99	603.89	836.79	1452.49	96.89	379.71	3369.76
2000	157.39	176.82	269.81	10.40	103.67	718.08
	0.0	0.0	0.0	0.0	0.0	0.0
	0.0	0.0	0.0	0.0	0.0	0.0
TOT	15884.46	15933.69	35334.97	3734.42	13617.33	84504.87

Figure 2.3-5 graphically displays the funding requirements and peak year distributions for DDT&E and TFU, where DDT&E costs peak at $4.27 billion in 1991. This time period corresponds to the activation of Phase C/D operations on the TFU. The TFU costs peak at $9.18 billion in 1996, which is the period of system/hardware production.

2.4 COST EFFECTIVENESS

During the study, a number of analyses were completed on the satellite, transportation, space construction, and ground station elements of the SPS program to develop specific system requirements for use in costing. These included traffic models, mass statements, system definitions, vehicle usages, and trade studies for cost assessments. The majority of these parameters are included in the discussions with appropriate CER's submitted in Appendix B.

Study activities completed under the Exhibit C contract include:

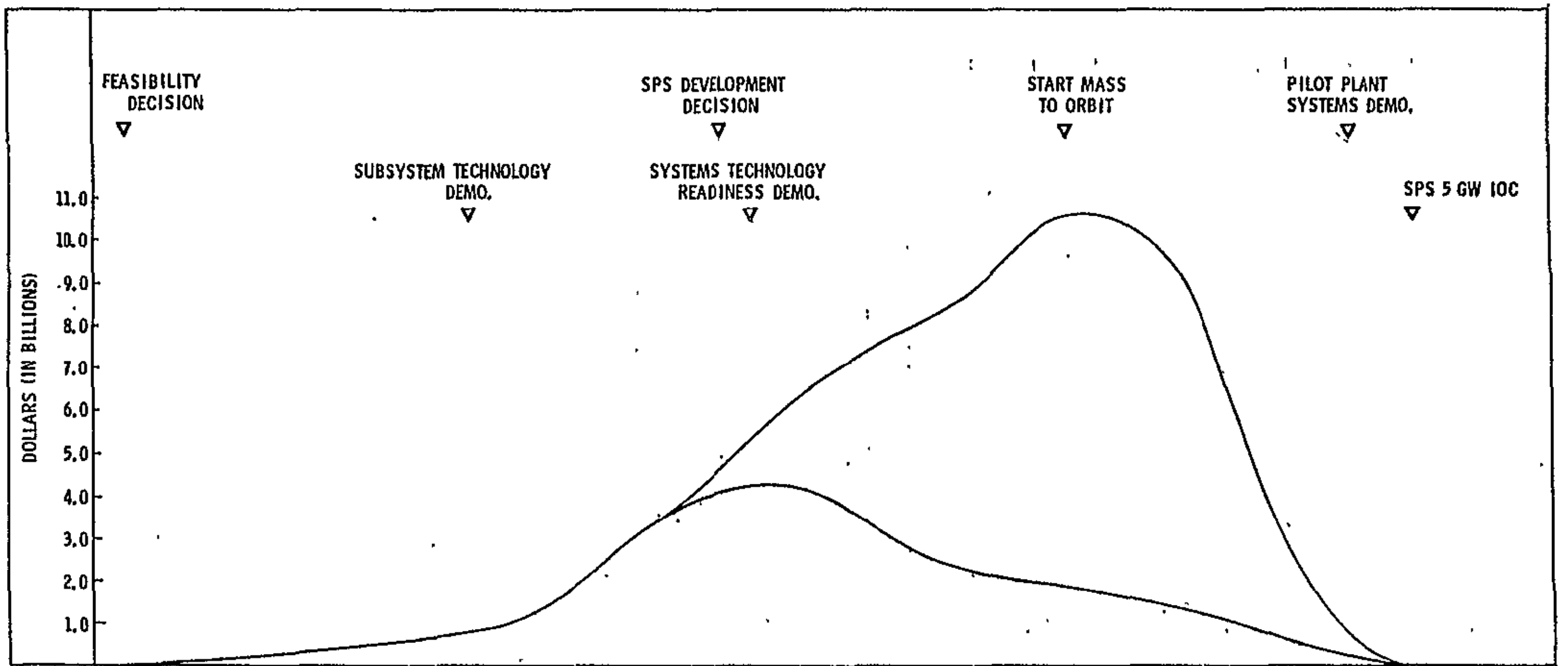
- A detail review and update of SPS economic/cost data as completed and submitted on the Rockwell SPS Point Design Concept of June 1978, focusing on operational requirements of the satellite, ground receiving station (rectenna), and transportation systems for that configuration. The analysis of space transportation elements identified construction and operations/maintenance flights, vehicle usages, and fleet attrition/spares.

- CER's were implemented and programmed on the computer as supplemented with the results of grass roots analysis and engineering assessments based on cost information in the NASA data base, Rockwell contracts, and company-sponsored studies.

- A transportation system study normalized cost data from NASA/Boeing contracts and the Rockwell Shuttle Growth contract study to project costs on the VTO-HL HLLV, Space Shuttle, orbiter, and PLV.

- A grass roots analysis was completed on the GRS to establish rectenna panel, concrete, power distribution, and supporting system costs. The results were compiled into line item estimates and total costs for GRS DDT&E, TFU and investment.

A rectenna panel payback analysis was completed to determine the cost effectiveness of a panel located in the perimeter of the rectenna farm. Revenue calculations were based on the incident microwave power per panel in the outer edge (Zone V) of the rectenna, as shown in Figure 2.4-1. The annual revenue from electric power was based on 40 mils per kWh, or $350 per year. An average cost of $5000 per panel was projected for the fixed costs, including some mark-up. Variable costs per panel considered replacements and O&M projections. Figure 2.4-2 identifies a payback period for panels in Zone V as varying from 3.5 to 14 years. However, the analysis shows that a panel intercepting 6 W/m^2 can break even in a 30-year period.



YEAR	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	TOTAL ($B)
DDT&E	0.009	0.063	0.164	0.303	0.474	0.670	0.886	1.281	2.256	3.363	4.125	4.266	3.699	2.753	2.203	2.070	1.769	1.316	0.893	0.606	0.233	0	33.402
TFU	0	0	0	0	0	0	0	0	0	0.232	0.810	1.690	2.832	4.254	6.223	8.195	9.175	8.454	5.988	2.764	0.486	0	51.103
TOTAL	0.009	0.063	0.164	0.303	0.474	0.670	0.886	1.281	2.256	3.595	4.935	5.956	6.531	7.007	8.426	10.265	10.944	9.770	6.881	3.370	0.719	0	84.505

Figure 2.3-5. Time-Phased DDT&E and TFU Costs

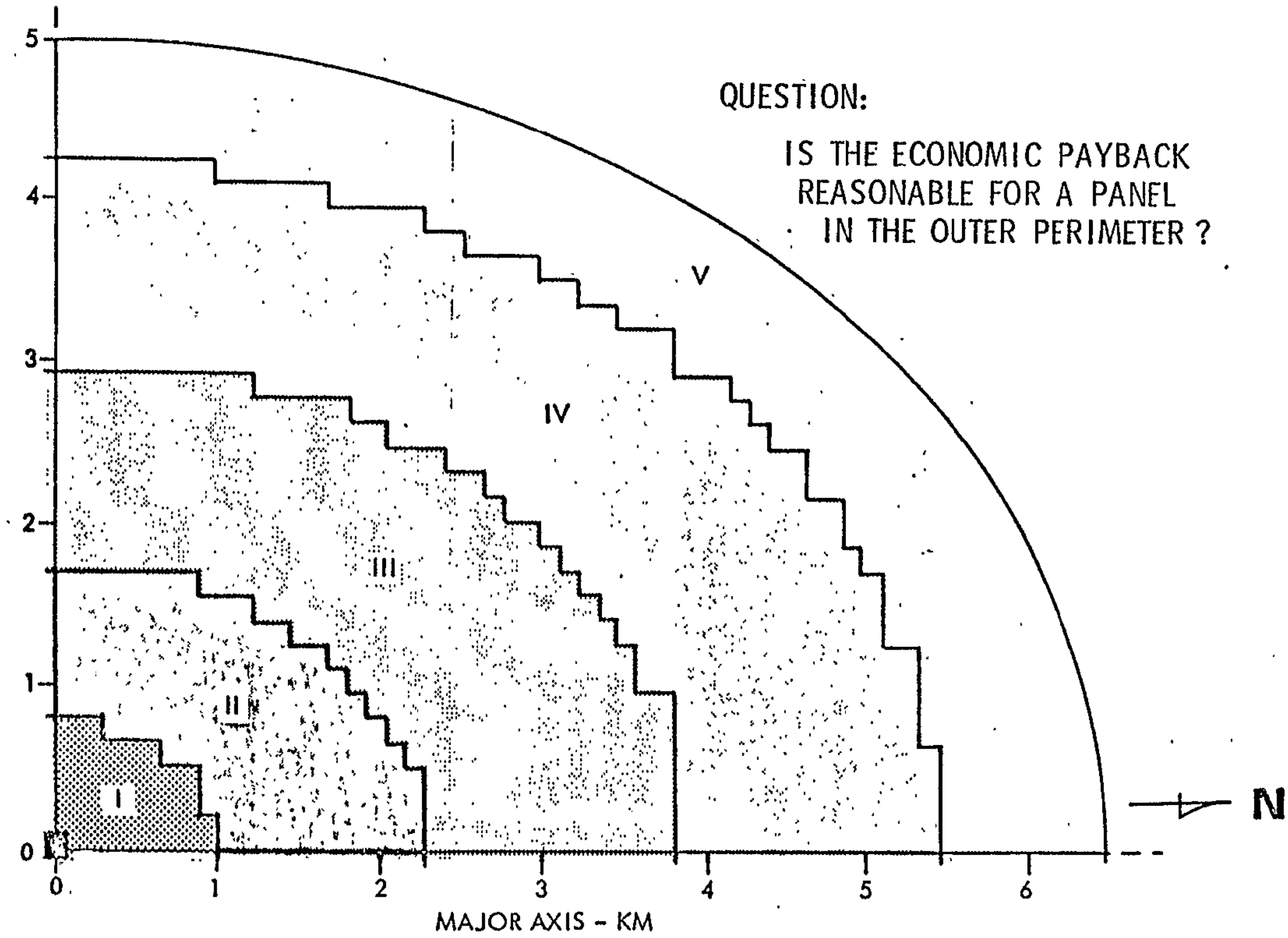


Figure 2.4-1. Rectenna Panel Payback

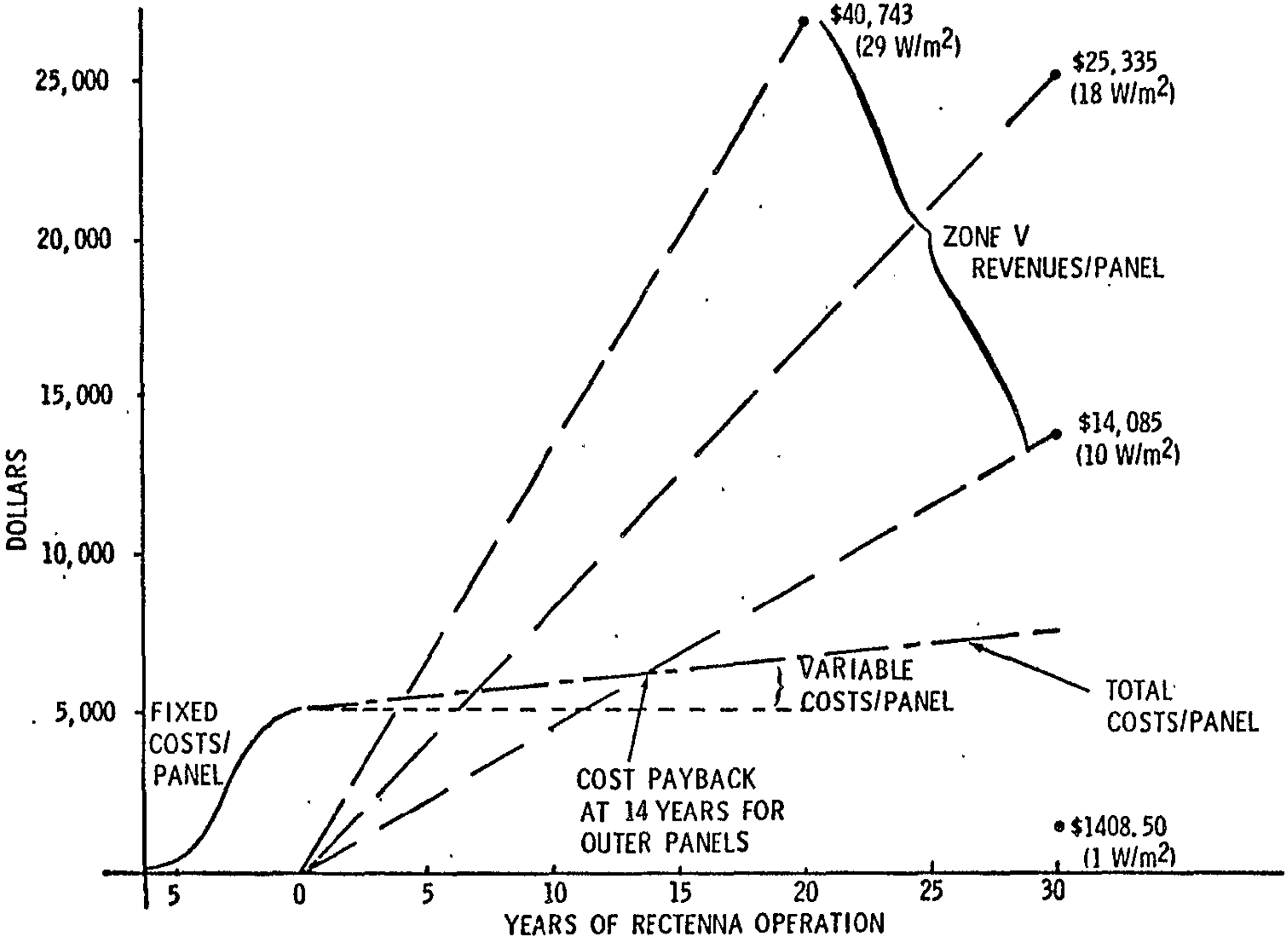


Figure 2.4-2. Zone V Payback Analysis

One of the "grass roots" analyses on the ground receiving station focused on a method of concrete placement supporting each of the 580,500 9.33 m by 14.69 m rectenna panels. Alternative footing configurations were designed for an optimized economical and structural means of concrete support. The continuous concrete ribbon (footing) satisfied our criteria. Material requirements and costs per panel resulting from this analysis are given in Table 2.4-1. A total of 6.8 yd^3 will be needed to support the panel and withstand a 90-mi/hr wind condition.

Table 2.4-1. Rectenna Concrete Requirements/Panel

CONCRETE INGREDIENTS	MIX/YD^3 (LB)	6.8 YD^3/ PANEL (LB)	PRICE/ TON ($)	MATERIAL COST/ PANEL ($)
CEMENT (5 SACK)	470	3,196	42.00	67.12
SAND	1,400	9,520	4.51	21.47
ROCK 1"-1½"	1,830	12,444	4.39	27.31
WATER	300	2,040	Ø	Ø
TOTAL	4,000 LB/ YD^3	27,200 LB/ 6.8 YD^3	-	$115.90
DELIVERED 1977 MILL PRICES PER ENGINEERING NEWS RECORD (ENR) - McGRAW HILL, AN INDUSTRY PUBLICATION				

3.0 SPS PROGRAMMATICS

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3.1 INTRODUCTION

This section presents SPS program plans for the implementation of Phase C/D activities leading to the initial operational capability of the first SPS by the year 2000. These plans describe SPS program schedules and networks, critical items of system evolution/technology development, and the natural resource analysis.

Most key technological issues (as described in Volume III) will have been resolved prior to the main Phase C/D effort and, therefore, technology in that sense is not the real concern of this section of the report on plans. Rather, the size of the SPS undertaking, its producibility, testing, logistics, facilitization, and support requirements dictate the main program plan areas covered in this section (Table 3.1-1). As a secondary objective, planning areas requiring substantial effort in the immediate future were identified. This work concentrated on the definition of specific problems, the solution of which might require the longest lead times for accomplishment or implementation.

Table 3.1-1. SPS Program Plans

• Program Management	• Product Assurance
• Systems Engineering and Integration	• Facilities
	• Ground Operations
• Design and Development	• Space Operations
• Systems Testing	• Launch Operations
• Ground Support Equipment—D&D	• Specification Tree
• Manufacturing	• Natural Resource Analysis

The SPS is a vast undertaking, requiring commitments of significant magnitude and long duration. Therefore, a well planned and funded SPS program is essential and the orderly, in-phase development of program plans is necessary to the accomplishment of long-range objectives and in permitting budgetary requirements to be established with sufficient lead time to assure commitment.

Success of the SPS program is critically dependent on bringing together a number of related system projects. In addition to the satellite and ground station, as major items of operational hardware, associated programs such as the Space Transportation System and supporting SPS facilities should be conducted in parallel and time-phased to interface as an integral part of a coordinated SPS program. Failure to complete any of these program efforts, in keeping with the SPS master schedule, would result in a corresponding delay in the availability of an operational system to serve as a significant national power resource.

3.2 PROGRAM PLANS APPROACH

The basic approach in plans development is to establish interrelationships between specific SPS program plan areas and elements of the WBS. Thirteen program plans (one divided into three sub-plans) were, therefore, identified and analyzed against elements of the SPS WBS. When combined with over 70 WBS elements, the resultant working-level matrix indicated 900 potential intercepts. At this time, however, we are concerned only with those intercepts for which long-range planning would be required or where the requirements analysis indicated major resource considerations, development or producibility concerns, areas of technology advancement, or support system sensitivity. Accordingly, Table 3.2-1 presents a summary of principal intercepts resulting from an evaluation of each plan at a working level, as compared with SPS reference solar photovoltaic design data. A total of 115 intercepts was established in three categories—A, B, and C. There are 27 Category A intercepts indicating the potential need of major resources, technology advancement, or support system requirements. Twenty-five Category B intercepts were secondary in magnitude, but important because of the long-term effort. A full description of these categories (including coverage of Category C) is presented in the following paragraphs.

- *Category A*—Implementation requires major resources in terms of manpower, dollars, raw materials or new facilities, etc. High-voltage test facilities for power distirbution equipment is an example. Major new system programs, critical to the overall SPS such as Shuttle-derived STS and EOTV, would also fall into this cateogry. HLLV, while not scheduled to support the prototype, needs to be time-phased to become operational by IOC to preserve program continuity. Therefore, HLLV would also be in Category A. New or greatly improved technology, requiring extensive and long-term development, would be placed in this category. One example would be high-rate production capability of thin-film GaAs solar blankets. Finally, items of special concern—but which may be of unknown magnitude—are placed in Category A. Examples would be verification of microwave beam control and utility interface considerations.

- *Category B*—Requires minor commitment of resources relative to Category A, but nonetheless, substantial long-term commitment may be required. An example would be verification tests of the rotary joint and slip rings.

- *Category C*—Certain programmatic aspects must be implemented and maintained over the long term to provide continuity and coordination. All planning areas should be maintained at some level of effort, and are so designated at the program management or SE&I levels.

Table 3.2-1. SPS Program Plans/DDT&E Relationship Matrix

SOLAR PHOTOVOLTAIC, CR–2 CONCEPT:

CAT. A – MAJOR RESOURCES, TECHNOLOGY ADV OR SUPPORT SYS PROGRAM REQD
CAT. B – SECONDARY IN MAGNITUDE BUT CRITICAL REQUIRING LONGTERM EFFORT
CAT. C – LONGTERM PROG PLANNING REQD
(–) EVALUATED AT NEXT HIGHER LEVEL

		SPS PROGRAM PLAN														
		1	2	3	4	5	6	7	8	9 GND OPS			10	11	12	13
WBS NO.	WBS TITLE	PROGRAM MANAGEMENT	SYSTEMS ENGRG & INTEGRATION.	DESIGN AND DEVELOPMENT	SYS. TESTING	GSE DESIGN & DEVELOPMENT	MANUFACTURING	PRODUCT ASSURANCE	FACILITIES	GROUND INTEG	MAINTENANCE & REFURBISHMENT	LOGISTICS	SPACE OPS	LAUNCH OPS	SPECIFICATION TREE	RESOURCE AVAIL. ANALYSIS
1.1	SATELLITE	A	C	A	A		B	C					A			C
1.1.1	ENERGY CONVERSION			A	A	B	A	C	A	C		C				C
1.1.2	POWER TRANSMISSION			A	B		B	B	B							
1.1.3	INFORMATION MANAGEMENT AND CONTROL															
1.1.4	ATTITUDE CONTROL AND STATIONKEEPING							C								
1.1.5	COMMUNICATIONS															
1.1.6	INTERFACE			B	B											
1.1.7	SYSTEMS TEST	C		B	A		B			C		B				
1.1.8	GSE					C										
1.2	SPACE CONSTRUCTION & SUPPORT	C	C	A	C		C						C			
1.2.1	CONSTRUCTION FACILITIES (SCB)												C			
1.2.2	LOGISTICS SUPPORT FACILITIES (LEO)												C			
1.2.3	O&M SUPPORT FACILITIES												C			

Table 3.2-1. SPS Program Plans/DDT&E Relationship Matrix (Cont.)

SOLAR PHOTOVOLTAIC, CR–2 CONCEPT:

CAT. A – MAJOR RESOURCES, TECHNOLOGY ADV OR SUPPORT SYS PROGRAM REQD
CAT. B – SECONDARY IN MAGNITUDE BUT CRITICAL REQUIRING LONGTERM EFFORT
CAT. C – LONGTERM PROG PLANNING REQD
(–) EVALUATED AT NEXT HIGHER LEVEL

		SPS PROGRAM PLAN														
		1	2	3	4	5	6	7	8	9 GND OPS			10	11	12	13
WBS NO.	WBS TITLE	PROGRAM MANAGEMENT	SYSTEMS ENGRG & INTEGRATION	DESIGN AND DEVELOPMENT	SYS. TESTING	GSE DESIGN & DEVELOPMENT	MANUFACTURING	PRODUCT ASSURANCE	FACILITIES	GROUND INTEG	MAINTENANCE & REFURBISHMENT	LOGISTICS	SPACE OPS	LAUNCH OPS	SPECIFICATION TREE	RESOURCE AVAIL. ANALYSIS
1.3	TRANSPORTATION	B	C	B									C			C
1.3.1	VTO-HL HLLV	B	C	A	C	C	C		C					B		
1.3.2	EOTV	B	C	A	C	C	C						C			
1.3.3	PLV	A	C	B	C		C		C		C	C	C	C		
1.3.4	POTV	B	C	A	C	C	C						C			
1.3.5	PM															
1.3.6	IOTV															
1.3.7	GROUND SUPPORT FACILITIES	A	C	C	A		A		A					A		C
1.4	GROUND RECEIVING STATION	B	C	C	A				A							C
1.4.1	SITE AND FACILITIES								A							
1.4.2	RECTENNA SUPPORT STRUCTURE						C									
1.4.3	POWER COLLECTION			B			A									
1.4.4	CONTROL															
1.4.5	GRID INTERFACE			C	B											
1.4.6	OPERATIONS										C	B				
1.5	MANAGEMENT AND INTEGRATION	C	C	C	A	C	C	B	A	C	C	B	A	B	C	C

The next step, as shown in Figure 3.2-1, was to prepare a summary planning sheet for each of the designated program plans. These were structured to include (1) a description of the plan; (2) a synopsis of requirements on technical and programmatic definition, associated with elements of the SPS point design description; (3) major resource considerations; and (4) a discussion section that established parameters, guidelines, assumptions, or constraints with regard to the respective plan. Areas considered critical or important to the completion of a specific WBS element were researched, identified, and studied. SPS point design requirements were constantly iterated during this period to develop line item descriptions, within identified categories, of Phase C/D DDT&E program planning concerns. The results of this work are presented on *impact sheets* as attached to the various plans included in a subsequent part of this section.

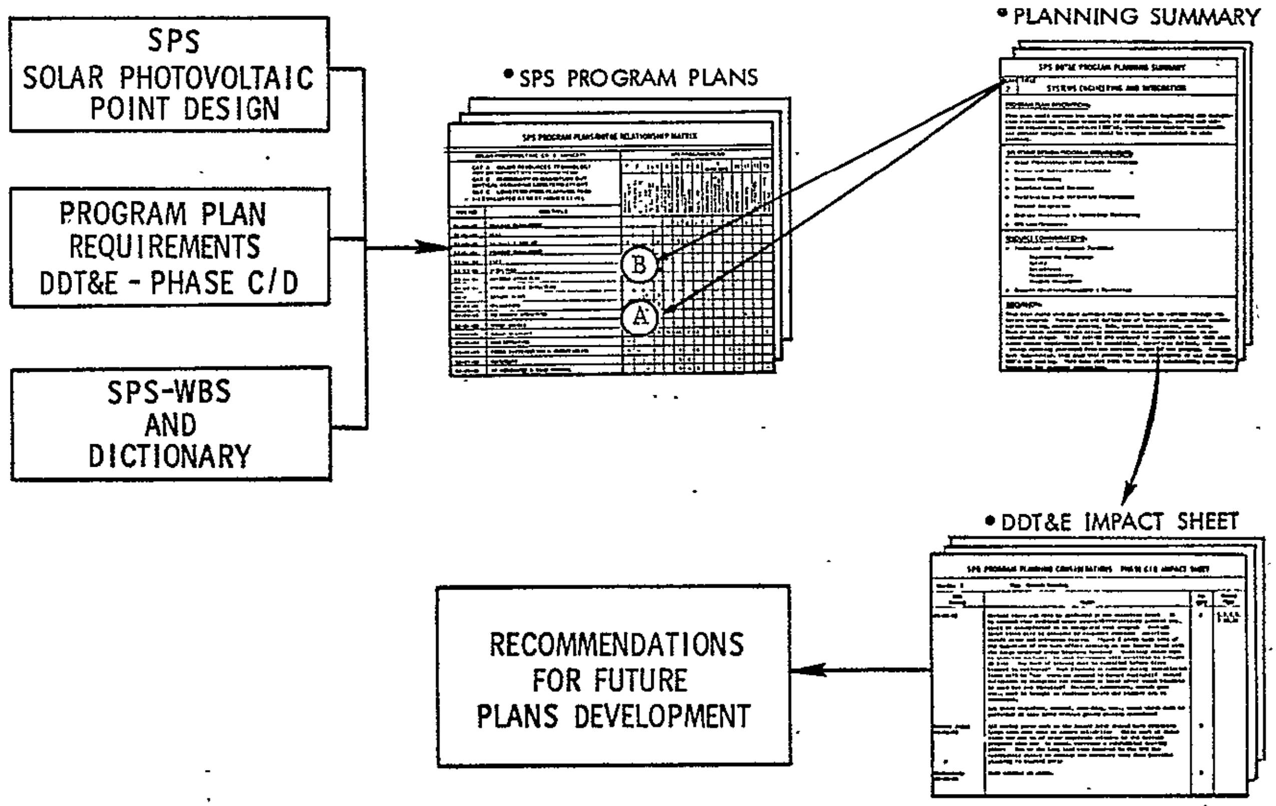


Figure 3.2-1. Program Plans Development Logic

3.3 PROGRAM PLANS

The implementation of each plan entails a scope of work such that the summation of all plans will cover every facit of organization, management, and hardware/software activity necessary to carry out the Phase C/D SPS efforts. Although the implementation of certain planning activities may be delayed, it is necessary to conduct some effort in each plan area throughout all phases of the program for purposes of coordination and continuity.

Overall program planning requirements, schedules, milestones, and master network are contained in this part of the report. Program elements are described as they apply within the program plan area. Special emphasis is placed on any major or critical area that is likely to have an impact or add some degree of risk in meeting SPS program objectives, schedules, and cost constraints. Where appropriate, the data are supported with analyses or discussions to provide the applicable level of assessment based on the SPS concept definition at this time, such as that presented in Plan 13 on natural resources.

The planning data presented in this section are contained within the following program plan areas:

1. Program Management—SPS schedules were developed over the program through year 2000, with emphasis on the 1980-1990 period. These schedules are developed to incorporate NASA, MSFC and DOE programmatic milestones applying to the DDT&E phases. On this basis, a series of SPS schedules showing design, development, technology advancement, production, operations, and initial phasing were developed and have been included in this plan.

2. Systems Engineering and Integration

3. Design and Development

4. Systems Testing

5. Ground Support Equipment (GSE) Design and Development

6. Manufacturing

7. Product Assurance

8. Facilities

9. Ground Operations
   - Ground Integration
   - Maintenance and Refurbishment
   - Logistics

10. Space Operations

11. Launch Operations

12. Specification Tree

13. Natural Resource Analysis

SPS DDT&E PROGRAM PLANNING SUMMARY

PLAN	TITLE
1	PROGRAM MANAGEMENT

PROGRAM PLAN DESCRIPTION

This plan shall include project schedules showing key milestones, test, decision points, interfaces with other program elements, hardware deliveries, facility requirements, major reviews, reporting requirements, etc.; and logic networks depicting major milestones and the interrelationship of events and activities throughout the design, development, operations, technology advancement, technology verification, and commercialization phases with the identification of critical paths. Any analyses necessary to support the defined program and schedules shall also be included. Particular emphasis shall be placed on the 1980-1990 time frame.

All major hardware and software—flight, as well as GSE—required for the development and operational phases, and identified in other sections, shall be scheduled including any hardware, equipment, and services required to be government-furnished and any long-lead hardware.

Major make-or-buy assumptions used in developing the recommended program shall be identified with supporting rationale.

SPS GaAlAs ROCKWELL REFERENCE CONFIGURATION PROGRAM REQUIREMENTS

- Solar Photovoltaic CR-2 Concept Definition
- 30-Year Design Life with Maintenance
- Nominal 5-GW Busbar Output at End of Life
- Satellite-DDT&E Configuration
- SPS Phase C/D DDT&E Program Coverage
- 2000 IOC for SPS Operation
- State-of-the-Art Technology, 1987
- Technology Verification Period, 1981-1987
- Planning in Accordance with SPS Work Breakdown Structure (November 1978)
- SPS Schedule and Network Approach
- Specify Key Milestones, Decision Points, Interfaces
- Identify Make-or-Buy Approach

RESOURCE CONSIDERATIONS

- Technical and Management Personnel
  - Program Planning and Control
  - Engineering Management
  - Manufacturing Management
  - Contract Administration
  - Support Management
  - Quality Assurance Management
  - Configuration Management
  - Data Management
- Support Materials, Equipment, and Facilities

SPS DDT&E PROGRAM PLANNING SUMMARY

PLAN	TITLE
1	PROGRAM MANAGEMENT (Cont.)

DISCUSSION

The program management plan addresses all schedules, logic, budget planning, and decision-making functions. Its implementation produces only software. However, it is the only level at which all SPS activities are coordinated. It is also the level at which major system interfaces occur, such as between satellite/rectenna and satellite/STS. Therefore, although it represents no major impact on its own, it is essential that the plan be started early and updated continuously to reflect both current activity and future planning at this summary level.

Major systems which are coordinated through this plan are:

- Satellite
- Space Construction and Support
- Transportation
- Ground Receiving Station

One function of the plan is to assure continuity and an orderly transition from Phase C/D through IOC and into the operational phase. Often, large programs encounter peaks and valleys in funding and manpower needs. When these occur, the overall economy is normally elastic enough to accommodate such changes; but this is not the case for SPS. Due to the huge size of the SPS undertaking and the order-of-magnitude increase in resource requirements after IOC, it is essential to plan an orderly buildup as a continuous process during Phase C/D and beyond. Only in this way can a healthy economy be maintained and the solar resource be exploited without a large gap occurring between IOC and significant operational buildup. The program management plan provides the vehicle for planning this buildup and making the necessary transition. As an example, the HLLV will not be operational during the main Phase C/D. However, its development will require a major program which must be time-phased to integrate with the overall SPS in the IOC time frame as an essential element in follow-on construction and operation of multiple systems.

A summary SPS schedule is presented in Figure 1-1. It identifies ground-based exploratory research activities and key technology programs preceding the 1990 Phase C/D commercialization decision. The 335-MW EOTV precursor pilot plant is shown as an extension of the systems test activity. The 1990 C/D kick-off will activate work on all major elements leading to the SCB fabrication, EOTV test article assembly, transfer to GEO, and precursor testing/beam mapping. The growth Shuttle and Shuttle-derived cargo carrier will have an earlier start to transfer the necessary mass to orbit. Subsequent SPS VTO-HL HLLV operations will combine with the Shuttle for full-scale build of the TFU. The GRS is proceeding as an earth-based receiver of MW energy.

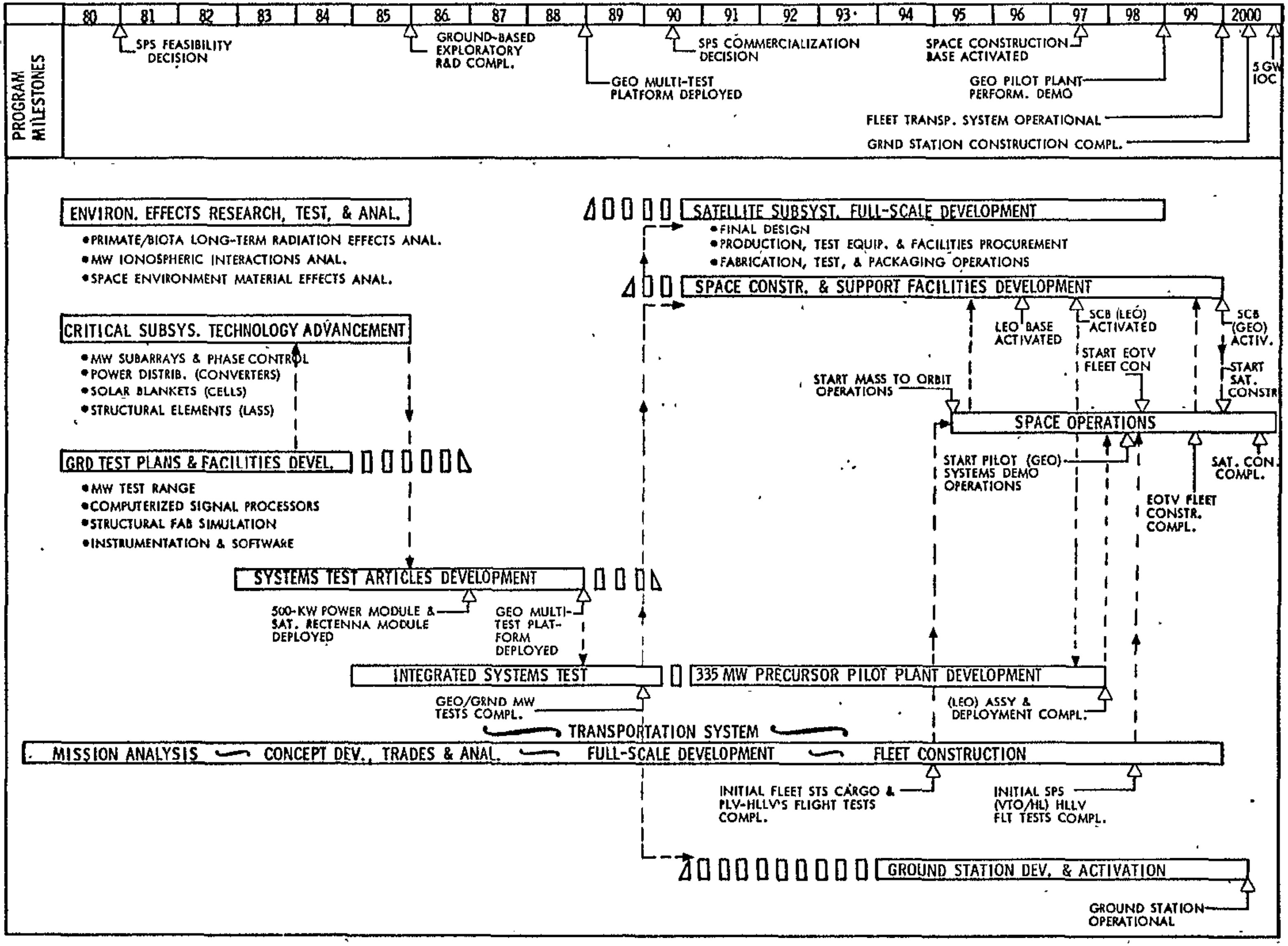


Figure 1-1. SPS Summary Schedule

SPS DDT&E PROGRAM PLANNING SUMMARY

PLAN	TITLE
1	PROGRAM MANAGEMENT (Cont.)

SPS Program Schedules

The objectives, magnitude, complexity, and duration of the SPS program demand an orderly and logical approach that will provide full implementation of program projects to achieve an operational SPS consistent with the plan. Accordingly, a major requirement existed for the development of fully integrated schedules/networks at all levels of the multi-faceted WBS. To provide an overall control of the scheduling activity, control milestones were established and maintained in a logic network of integrated program activities (Figure 1-2).

The network divides the program milestones into four major sub-categories which include:

- Technology verification and full-scale prototype development
- Support facilities and equipment development, including transportation
- Major programmatic milestones
- Continuation decision points

These milestones logically support succeeding events in their own sub-categories and, in certain cases, will support or impact succeeding milestone events in other sub-categories.

The central catalyst for development of the satellite power system and its primary supporting equipment and facilities is the SPS decision category of milestones. Examination of the network will demonstrate that supporting equipment and facility developments encompass a scope of effort nearly equal to development of the satellite system itself; therefore, with due consideration taken for the technical lead times required for development of each major subsystem, an overall plan was established that incorporates parallel development of the several major subsystems in order that their timely completion supports major satellite system development objectives.

The decision milestone sequence was developed to program the flow of separate developmental subprograms. Timely promulgation of these decisions will undoubtedly exercise overriding impact on the program and its progress. Further, justification for each of these decision areas—for the most part—will be predicated on the achievement of specified goals within a subprogram and may be only casually related to the results of major efforts in other subprograms at that point in time. As an example, the long-lead technology required for development of an HLLV transportation system whose availability is critical to the construction and deployment of the initial satellite in the year 2000, necessitates initiation of a full-scale development program in the year 1988. This precedes a satellite systems technology readiness demonstration conducted with the "multi-test platform: test article by two full years.

SPS DDT&E PROGRAM PLANNING SUMMARY

PLAN	TITLE
1	PROGRAM MANAGEMENT (Cont.)

To delay a transportation development decision until a high-confidence level is achieved through the satellite systems demonstration would vitally impact the program capability to achieve IOC by the year 2000.

Other SPS program schedules have been prepared to identify (1) systems technology development tasks, as will be shown on the *DDT&E Technology Advancement Program Schedule*; (2) detail design, production engineering, equipment and production operations activities as will be shown on the *DDT&E/TFU Full-Scale Development Schedule*; (3) a "special emphasis" network on the technology development steps of a microwave transmission system; and (4) a phasing schedule on the site activation and construction sequence of the ground receiving station (GRS).

1. *SPS DDT&E Technology Advancement Program Schedule*

The objective of this phase is to develop a system/subsystem technology base upon which a full-scale development program may systematically evolve. The schedule of Figure 1-3 addresses those key technology elements whose development is requisite to an overall SPS subsystem performance design and definition and the development of test equipment and facilities needed to support this technology effort. SPS hardware development in this phase is confined to experimental and limited prototype articles needed to prove out design concepts such as the areas covered in MPTS, power conversion, power distribution, and structures. The transportation effort during this phase is primarily directed at providing preliminary design definition to those vehicles needed for specific transportation missions further identified in subsequent program phases.

The culmination of this phase is through the integration of these subsystems into a GEO multi-test platform and application of this test article in performance of a total system technology readiness demonstration by late 1989.

2. *DDT&E/TFU—Full-Scale Development Program*

The objective of this program phase is to produce and operate a full-scale prototype 5-GW satellite power generating system whose performance characteristics will be the basis of justification for continued satellite power systems commercial development. Therefore, the schedule of Figure 1-4 addresses only those tasks and program elements which directly impact development of prototype operational power system hardware/software plus development of equipment and facilities which directly support tasks aimed at this objective.

Included in this schedule are broad-based iterations of (1) designs and definitions of subsystem production hardware (based upon data, specifications, and experimental hardware developed during the technology verification program phase); (2) manufacturing technology, equipment, and facilities that need

SPS DDT&E PROGRAM PLANNING SUMMARY

PLAN	TITLE
1	PROGRAM MANAGEMENT (Cont.)

development; and (3) the prototype production operations and sequences. Emphasis in this schedule is also placed upon ground/space power system assembly and integration operations and the major equipment and facility development programs required to support these operations. The transportation schedule section is confined to those vehicles needing development for mission use during this particular program phase. It describes the phasing of (1) STS growth/derivative HLLV's which will be used to transport the mass to orbit, facilities, equipment, and personnel to LEO in support of the satellite construction base and its activation; (2) SPS-dedicated HLLV's (VTO-HL) to transport the main satellite construction mass to LEO; (3) the COTV (EOTV) which will be used for large interoribtal cargo mass transfer; and (4) the personnel and high-priority cargo-carrying space vehicles (IOTV, POTV. and PM). The ground station system/subsystem design, development, and construction scenario has been addressed as it will support the overall program. WBS numbers and titles are referenced in the margin, and have been used to provide the basic structure and layout for this schedule.

3. *Special-Emphasis Network—Microwave Technology*

Current technology exploration studies indicate that microwave technology advancement will be a single most-significant pacer in total program development. In order to illustrate the need for early resource allocation directed toward near-term technology exploration and test verification of the concepts now under consideration, a time-oriented logic network was developed as shown in Figure 1-5. It traces the full microwave scope of this effort and highlights program continuation decision gates at critical junctures.

Phase I (1980 through 1985) describes the tasks (including their timing and interrelationships) needed to define requirements, develop concepts, perform trades, conduct analysis on alternate designs, perform tests and evaluations on these alternative concepts and, finally, make a concept selection which will be the baseline for full-scale development.

The network also describes parallel development programs on ground test facilities, equipment, instrumentation, and software needed to support the engineering development process.

Phase II (1986 through 1989) describes the development of equipment and test articles needed to provide performance verification of the complete microwave system alone, and the microwave system integrated with key elements of the multi-test platform program for a complete earth/ground-based technology demonstration scheduled for late 1989.

Phase III (1990 through 2000) describes the full-scale development of the subsystem along with the parallel development of all other satellite subsytems. The program culminates with a performance demonstration of multiple subarrays as integrated with other systems in the precursor pilot plant and, finally,

SPS DDT&E PROGRAM PLANNING SUMMARY

PLAN	TITLE
1	PROGRAM MANAGEMENT (Cont.)

in the all-up systems test of the 5-GW initial satellite. To reiterate, the results of earlier ground-based microwave technology development and performance verification activities will be a most significant factor in evaluating the feasibility of continued total system development.

4. *GRS Site Activation Schedule*

A series of detail phasing schedules were developed on the activation of each of the first four ground station receiving sites (Figure 1-6). Operational sequences were identified for site survey, ground preparation, panel fabrication, concrete placement, facilities installation, and checkout activities. Contacts with A&E, equipment manufacturing, concrete, and construction firms provided additional information on the duration and sequence of operations from their experience on programs of this size. Figure 1-7 is an integrated summary schedule of major events in constructing the ground receiving station and emphasizes the utilization of construction equipment and its transfer from site to site as required to maintain the build-rate of two rectennas per year. It was concluded that the equipment from Site 1 would be available for use on Site 3. This information on equipment utilization, site sequencing, and equipment lifetimes was used to establish total resource requirements and cost estimates for the program.

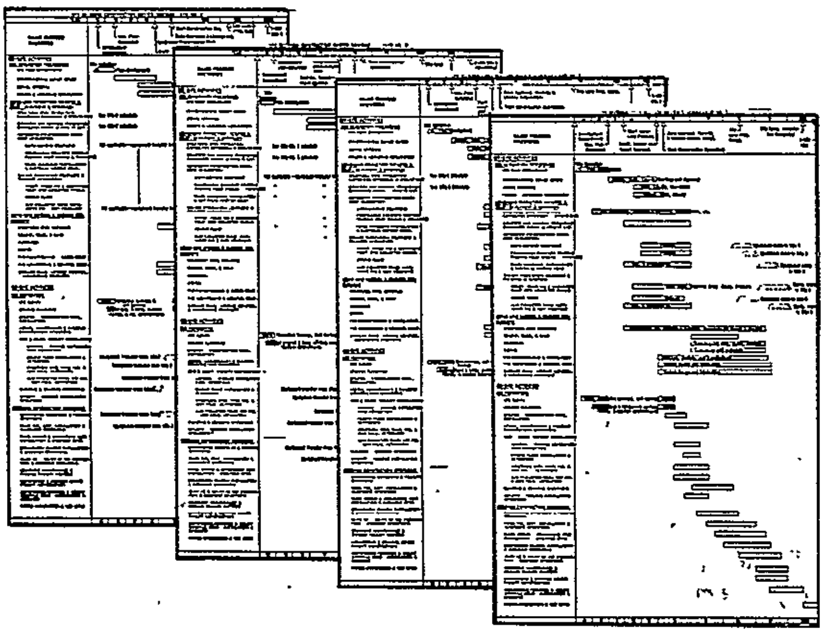


Figure 1-6. GRS Phasing Schedules

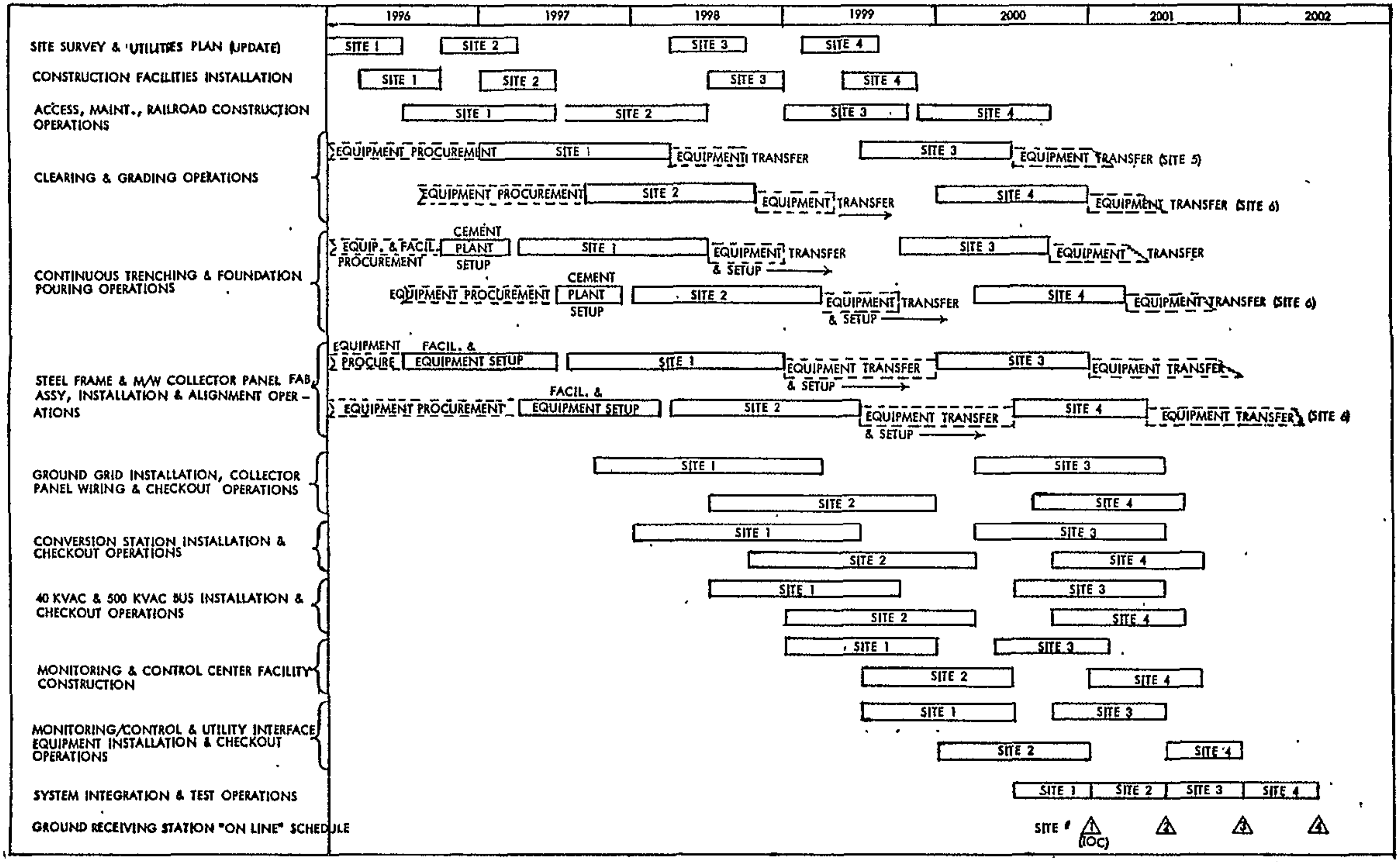


Figure 1-7. SPS Rectenna Construction Sequence Summary Schedule Flow

Satellite Systems Division
Space Systems Group
Rockwell International

SPS DDT&E PROGRAM PLANNING SUMMARY

PLAN	TITLE
2	SYSTEM ENGINEERING AND INTEGRATION

PROGRAM PLAN DESCRIPTION

This plan shall address the planning for the systems engineering and integration functions to include items such as mission planning, system and subsystem requirements, interfaces (ICD's), verification testing requirements, and payload integration. Costs shall be a major consideration in this planning.

SPS POINT DESIGN PROGRAM REQUIREMENTS

- Solar Photovoltaic CR-2 Concept Definition
- System and Subsystem Requirements
- Mission Planning
- Interface Control Documents
- Verification Test Definition Requirements
- Payload Integration
- Systems Development and Operations Monitoring
- SPS Cost/Economics

RESOURCE CONSIDERATIONS

- Technical and Management Personnel
  - Engineering Management
  - Safety
  - Reliability
  - Maintainability
  - Support Management
- Support Materials/Equipment and Facilities

DISCUSSION

This plan deals with many software items which must be carried through the entire program. Typical are the definition of hardware requirements verification testing, mission planning, ICD's, payload integration, and costs. Each of these elements may affect hardware design and development in the conceptual stages. Major systems are assigned to Category C under this plan since system requirements must be established, interfaces defined, and continuous updating performed from the earliest stages of the program. Perhaps most importantly, this plan will provide for the development of all cost data, CER's, and costing. These data will form the basis for establishing long-range budgeting for economic projections.

SPS DDT&E PROGRAM PLANNING SUMMARY

PLAN	TITLE
3	DESIGN AND DEVELOPMENT

PROGRAM PLAN DESCRIPTION

This plan shall address the design and development of the system and subsystems, including design engineering, development and qualification testing. The hardware and software to carry out these activities shall be identified. The technology and/or development status of each subsystem shall be discussed in sufficient detail to allow for a management assessment of program development risks.

SPS POINT DESIGN PROGRAM REQUIREMENTS

- Solar Photovoltaic CR-2 Concept Definition
- System and Subsystem Drawing/Specification Requirements
- Supporting Software and Hardware Requirements
- Development Program Definitions and Design Requirements
  - Structural elements—joining and stiffening
  - Beam machine development
  - Solar blanket design efficiency and reliability
  - Microwave reliability and efficiency requirements
  - Rectenna design optimization
  - Utility interface design requirements
- Qualification Test Procedures and Requirements
- Design Interfaces of Systems/Subsystems

RESOURCE CONSIDERATIONS

- Technical and Management Personnel
  - Design, development, and qualification testing manpower
- Supporting Hardware and Software
- Support Materials/Equipment and Facilities

DISCUSSION

This plan provides for all design and, as such, produces drawings, specifications, and other software. It is a major engineering effort and therefore will have significant impact in terms of manpower requirements. However, there is reason to believe that these resources can be made available from existing technical labor markets, such as the aerospace industry, as needed. The same can be said for technology needs in terms of analytical tools, computer software, etc. Two areas are of present concern. First of all, the status of technology and development related to key subsystems and components must be determined and extrapolated to the time frame where needed for the SPS prototype. (Examples are klystrons and GaAs solar cells.) This will permit a risk assessment to be made and justify the allocation of resources to most critical developmental areas. For example, stockpiling of solar cells for the SPS prototype will require a production rate of about 500 MW per year

SPS DDT&E PROGRAM PLANNING SUMMARY

PLAN	TITLE
3	DESIGN AND DEVELOPMENT (Cont.)

starting in the late 1980's. Risk assessments under this plan would be a basis for implementing major developmental effort on GaAs to provide thin-film, high-efficiency cells.

Secondly, developmental programs must be identified, planned, and carried out to assure that proof-of-concept will actually take place as scheduled. This effort assumes that the resolution of key issues or research activities will have been completed under technology development projects. It may, however, include development of equipment such as beam machines, development of large-scale, in-space life support and operational capability, and development of critical components or modules such as prototype solar blankets. Several critical long-range areas of concern are identified in Table 3-1.

Table 3-1.
SPS DDT&E Program Planning Considerations (Phase C/D) Impact Sheet

PLAN NO. 3	TITLE: DESIGN AND DEVELOPMENT	
WBS ELEMENT	IMPACT	CATEGORY
1.1 Satellite System	Satellite design and supporting development will be a major undertaking due to size and complexity well beyond anything previously attempted in space.	A
1.1.1.1, 1.1.2.1, 1.1.6.1 Structure	The methods of designing the satellite construction base (SCB) and EOTV test article structure will evolve as smaller structural platforms for demonstration projects as designed and developed during earlier phases. The design approach must be closely coordinated with the development of in-space processes and manufacturing equipment throughout the program. This will assure that the design of the structural elements, their joining and stiffening will be compatible with the most effective approach to manufacturing. Design and development of beam machines and fixtures specific to the SCB and EOTV are included under WBS 1.2. Capability for producing large structures in space must be developed.	B
1.1.1.4, 1.1.6.2, 1.1.6.3 Rotary Joint, Mechanisms	Special consideration must be given to design and development to provide high reliability of the slip rings and brushes. Parts replacement must be considered.	B
1.1.1 Energy Conversion	Design and development of solar blankets must address the integrated power source at this level although most hardware-related effort will be at a lower level. Energy conversion is among the most critical subsystems requiring extensive development and long lead times. The design and development of the solar blanket will be, perhaps, the most critical item in the SPS. Considerable development will be required, extending over a long period before a suitable design evolves which combines the essential features of lightweight, high efficiency, high reliability, high proton damage resistance, satisfactory handling, and high production and low cost.	A

Table 3-1.
SPS DDT&E Program Planning Considerations (Phase C/D) Impact Sheet

PLAN NO. 3 TITLE: DESIGN AND DEVELOPMENT

WBS ELEMENT	IMPACT	CATEGORY
1.1.2, 1.1.2.2 Power Transmission/Subarrays	Design and development of regulators, switch gear, circuit breakers, klystrons, beam control, etc., cathode structure will be extensive to assure high efficiency and reliability. Considerable investigations of alternate PDC subsystem and component approaches are foreseen.	A
1.1.7 Systems Test	Comprehensive overall effort involving two or more systems tests including hardware and operations plus design of all STE and facilities not included elsewhere. A major planning effort is required for development and qualification testing.	B
1.2 Space Construction and Support	Design and development of SCB, LEO base, satellite O&M base, and support equipment is a major task involving such items as assembly fixtures, beam machines, teleoperators, etc. This is one of the most critical areas of development. ICD's must be considered throughout design and development. Concerns include life support, logistics, docking, flight control, personnel/cargo transfer, etc.	A
1.3 Transportation	Major parallel programs on HLLV, EOTV, PLV, POTV, PM, and IOTV. Therefore, ICD's must be considered throughout design. Engine development and vehicle design critical for multimission use.	B
1.4 Ground Receiving Station, Dipole/Rectifier Elements, Power Distribution and Conditioning, Utility Interface	Because of large overall size and number of elements, must emphasize minimum use of materials; high reliability and low maintenance must be emphasized in overall design. Power collector design must permit mass production at minimum cost with on-site fabrication of dipole panels. Converter stations require long-term planning and reliability in design. As the ultimate user, the utilities will have requirements for regulation and reliability. The value of SPS-generated power to the utility must be addressed by taking margin requirements, load factor, etc., into account. Power value and requirements can be expected to vary for each grid network with which an interface is contemplated.	C A

SPS DDT&E PROGRAM PLANNING SUMMARY

PLAN	TITLE
4	SYSTEMS TESTING

PROGRAM PLAN DEFINITION

This section shall address the approach to systems verification testing with supporting rationale. Also, the system test hardware and any unusual or unique facilities required to carry out the program shall be identified.

SPS POINT DESIGN PROGRAM REQUIREMENTS

- Solar Photovoltaic CR-2 Concept Definition
  - Solar blankets—27 x 10^6 m^2 per satellite
  - Power distribution and control
  - Rotary joint
  - Microwave power
  - Rectenna
  - Space transportation
- System and Subsystem Verification Test Requirements
- System Test Hardware/Software Definition
- Unique Test Facilities—Ground and Space

RESOURCE CONSIDERATIONS

- Technical and Management Personnel
- Operational/Support Personnel
- Supporting Hardware and Software
- Support Materials/Equipment and Facilities
- Special/Unique Test Equipment

DISCUSSION

The overall testing hierarchy for Phase C/D consists of:

- Development
- Production
- Qualification
- Verification
- Operations

This plan addresses system verification and includes any tests which involve two or more subsystems and are for the purpose of verifying that the systems will perform to specifications. Verification tests may be performed on either end-item prototype hardware or on hardware specifically designated for verification purposes. For example, the first flight tests of the EOTV will be in orbit and presumably will be of short duration to verify performance prior to actual use of the vehicle for interorbital transfer. The EOTV in this case is a deliverable operational end item. On the other hand, verification tests of beam accuracy, control, and safety interlocks may be conducted during final phases of the GEOSAT, as shown in Figure 4-1. These tests are critical to SPS acceptance and will be conducted on an interim test platform.

3-30 30

SPS DDT&E PROGRAM PLANNING SUMMARY

PLAN	TITLE
4	SYSTEMS TESTING (Cont.)

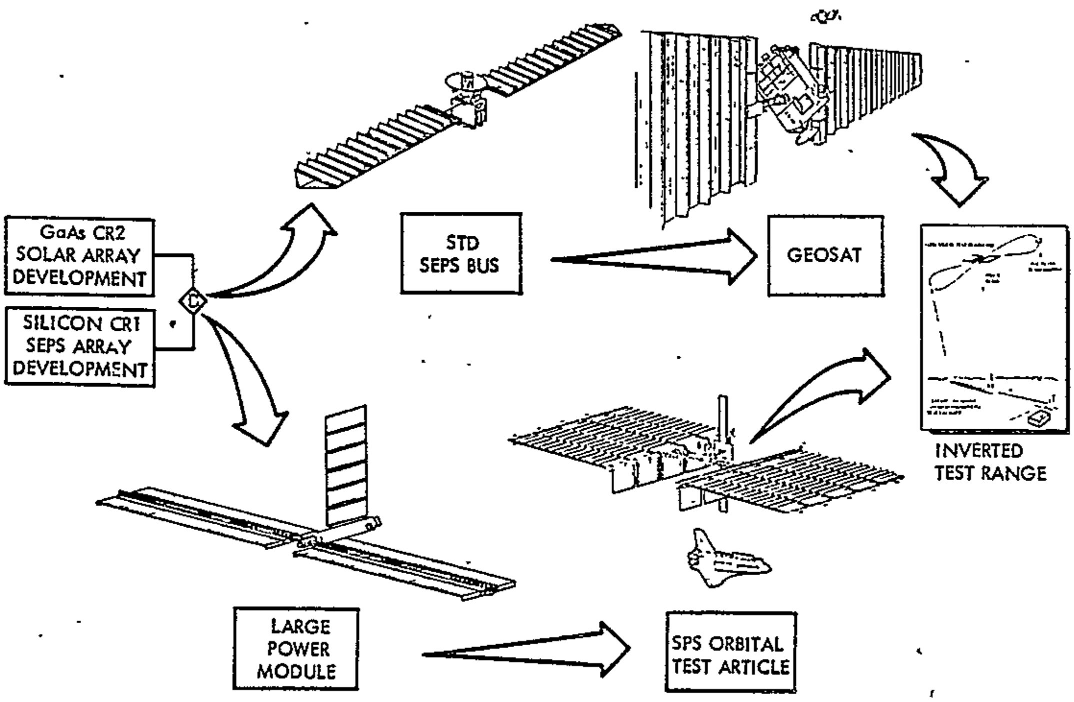


Figure 4-1. SPS Multi-Test Platform Evolution

It remains to be resolved at what levels of assembly actual systems tests will take place and what scope these tests will assume. However, Table 4-1 identifies several areas of concern for reference at this point in time as they apply to main elements of the SPS program.

Table 4-1.
SPS DDT&E Program Planning Considerations (Phase C/D) Impact Sheet

PLAN NO. 4 TITLE: SYSTEMS TESTING

WBS ELEMENT	IMPACT	CATEGORY
1.1 Satellite System, Rotary Joint, Mechanisms	Certain tests can only be performed at the satellite level. It is assumed that combined power source/MWPTS/attitude control, etc., would be accomplished as an integrated test program. Systems-level tests will be preceded by component checkout, interface verification, and subsystem testing. Questions which must be answered include: In what increments will a satellite be brought on line? How much of the antenna must be installed before first blanket is activated? Must blankets be covered during installation? (They will be "hot" whenever exposed to direct sunlight.) Should reflectors be installed for checkout, or later after total blankets in each bay are installed? Rectenna converters, switch gear, etc., must be brought to readiness before any blanket can be connected. In addition, are there stability, control, switching, etc., tests which must be performed at this level without ground station interface?	A
	All moving parts such as the rotary joint should have extensive long-term test data to assure reliability. While each of these items may not be of major magnitude relative to the systems programs they may, in total, represent a substantial testing effort. Due to the long lead time involved on the SPS, the opportunity exists to develop the necessary test data provided planning is started early.	B
1.1.1 Energy Conversion	Similar questions arise. What is the testing concept and sequence? For test purposes, will the smallest unit be a single blanket (say, 750×25 m)? How will power source modules include switch gear, regulators, etc., for testing purposes?	A
1.1.1.3 Solar Blankets	The SPS will require approximately 27×10^6 m^2 of solar blankets starting in 1996 for delivery and installation through 2000. Buildup will require average production of 675×10^6 m^2/year for four years starting in 1996. Testing will require ten or more "blimp hangar" size test stands capable of testing blankets on a three-shift basis. Testing of each solar blanket would be done	A

Table 4-1.

SPS DDT&E Program Planning Considerations (Phase C/D) Impact Sheet

PLAN NO. 4 TITLE: SYSTEMS TESTING

WBS ELEMENT	IMPACT	CATEGORY
	on test stands adjacent to the factory. These stands would each have solar spectrum simulation capability. Test stands will be located at factory sites.	
1.1.1.4 Power Distribution and Conditioning	High-rate, high-voltage (45 kV) testing of equipment will be involved. Question: What special problems and requirements are involved in high-voltage testing of regulators and switch gear and dc/dc converters?	A
1.1.2 Power Transmission, RF Generation & Beam Control, Power Distribution & Cond.	Verification tests must satisfy beam control and interlock capability relative to safety concerns. High-rate, high-voltage testing at component level for klystrons, driver amplifiers, etc. High-rate, high-voltage testing of conduction network at subsystem level and at component level of switch gear, conditioning electronics.	B
1.1.7 Systems Test & Operations	Comprehensive test requirements needed. Includes all ground systems tests involving two or more subsystems for purposes of qualification and development. Does <u>not</u> include individual component tests such as solar blankets, klystrons, etc. Does not include flight hardware.	A
1.3.7 Facilities	Large facilities will be required for systems tests, particularly those in conjunction with energy conversion and STS.	A
1.4 Ground Receiving Station	Tests must verify 580,500 dipole subarrays plus distribution and conditioning system. Coordination of rectenna construction and operation with the satellite power source and/or MPTS must assure the phased buildup of an integrated power system. What systems level tests must be conducted?	A
1.4.5 Utility Interface	Utility must be prepared to accept interim and incremental power as part of systems testing.	B

Table 4-1.
SPS DDT&E Program Planning Considerations (Phase C/D) Impact Sheet

PLAN NO. 4 TITLE: SYSTEMS TESTING

WBS ELEMENT	IMPACT	CATEGORY
1.5 Program Management	This level brings together major systems and requirements, a substantial long-term commitment for systems testing. The satellite/rectenna, for example, will undergo combined testing at various times during phased buildup of the prototype which will take place over a period of years. STS, OTV, and control interfaces must be tested and verified at this level.	A

SPS DDT&E PROGRAM PLANNING SUMMARY

PLAN 5 | TITLE

GROUND SUPPORT EQUIPMENT (GSE) DESIGN AND DEVELOPMENT

PROGRAM PLAN DEFINITIONS

This plan shall address the design and development of the GSE and its associated software required for checkout of the systems and subsystems at the various locations, i.e., factory, launch site, etc. The hardware required in the design and development of the GSE shall be identified.

SPS POINT DESIGN PROGRAM REQUIREMENTS

- Solar Photovoltaic CR-2 Concept Definition
- GSE Design/Drawing and Specification Requirements
- Supporting Software and Hardware Checkout Requirements

RESOURCE CONSIDERATIONS

- Technical and Management Personnel
- Supporting Hardware and Software
- Support Materials/Equipment and Facilities

DISCUSSION

In total, GSE requirements will be substantial, particularly in support of launch and transport vehicles. Individual support equipment for satellite/rectenna systems, however, should not require major expenditure of resources percentagewise. Long-range planning should be a natural fallout of the design process which must consider those items that are larger in size or quantity, such as the solar blankets or rectenna dipole panels, methods of transporting, servicing, and handling (Table 5-1).

Table 5-1.
SPS DDT&E Program Planning Considerations (Phase C/D) Impact Sheet

Sheet 1 of 1

PLAN NO. 5 TITLE: GSE DESIGN AND DEVELOPMENT

WBS ELEMENT	IMPACT	CATEGORY
1.1.1.3 Solar Blankets	Equipment to handle, transport, deploy, and service solar blankets after manufacture may be critical due to large size and fragile nature of blankets.	C
1.3 Transportation	Major system program/major support equipment	C
1.3.7 Facilities	Heavy investment required for solar blanket and high-voltage testing.	C
1.4 Ground Receiving Station	Checkout, maintenance, repair, and replacement of large number of dipole panels in place may require special support equipment exclusive of test gear.	C
	Note. Although GSE will represent a substantial investment, neither the resource allocation and planning nor technology appear to be of sufficient criticality for consideration at this time.	

SPS DDT&E PROGRAM PLANNING SUMMARY

PLAN	TITLE
6	MANUFACTURING PLAN

PROGRAM PLAN DESCRIPTION

This plan shall address the manufacturing requirements for all the development and deliverable hardware (flight systems and GSE) required in the program. Included shall be a compilation of all the hardware and software requirements from other sections. The major make-or-buy assumptions identified in the section on program management shall be used as a basis for developing the manufacturing requirements. Particular emphasis shall be placed on any unusual or unique facilities, tooling, and STE required to support the manufacturing activities and any advancements in the manufacturing processes and related technology that could impact the program. Quality control requirements shall also be assessed.

SPS POINT DESIGN PROGRAM REQUIREMENTS

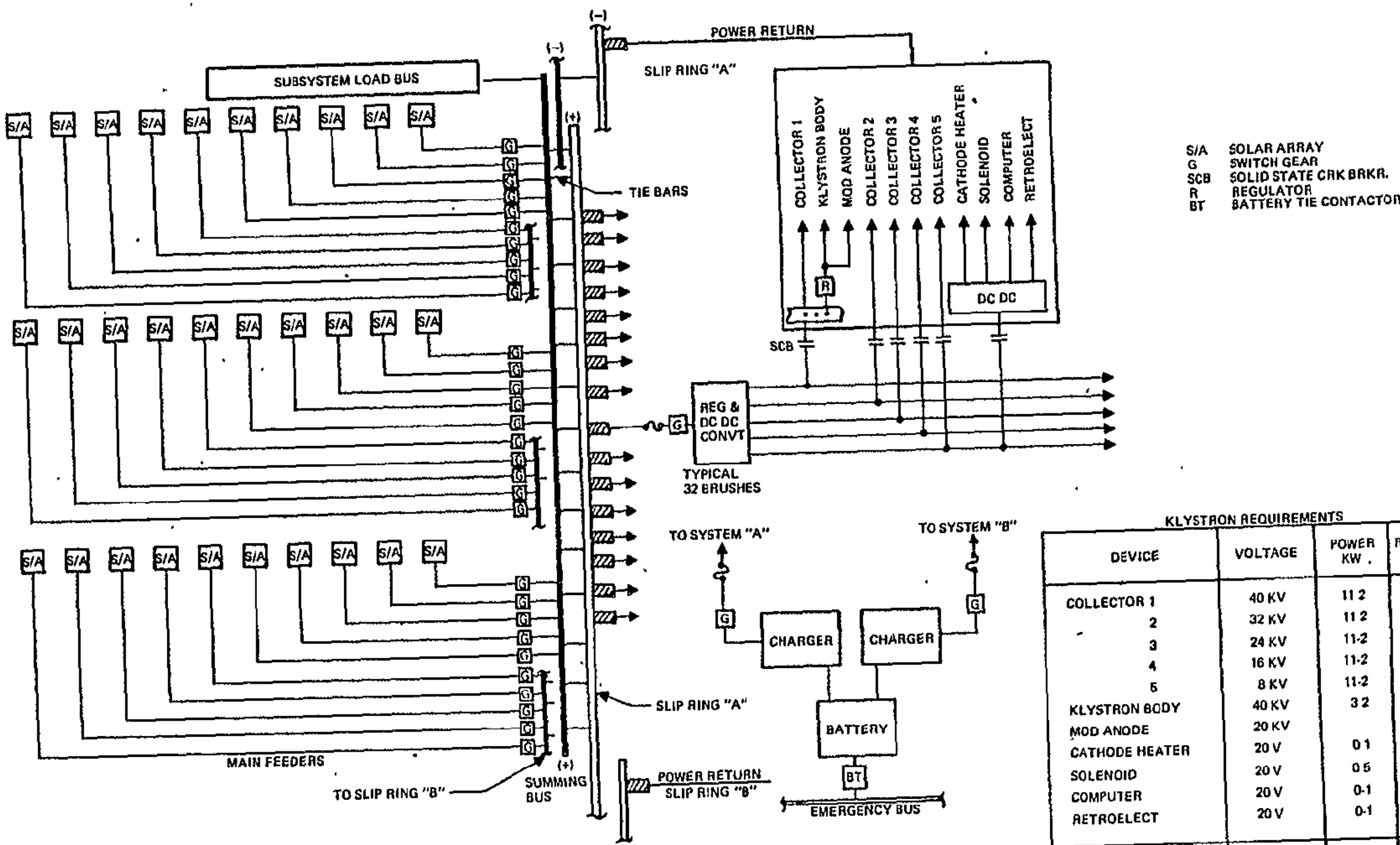
- Solar Photovoltaic CR-2 Concept Definition
  - Structure
  - Solar blankets, 27×10^6 m^2 per satellite
  - Power distribution and conditioning
  - Microwave power
  - Rectenna
- Flight and Ground System Manufacturing Requirements and Producibility Rates
- Unique Manufacturing Facilities—Ground and Space
- Special Test Equipment and Support Tooling
- Quality Control Support Requirements

RESOURCE CONSIDERATIONS

- Technical and management personnel
- Operational/support personnel
- Supporting hardware and software
- Support materials/equipment and facilities
- Special/unique test equipment

DISCUSSION

This plan covers all deliverable hardware. As such it includes ground systems, flight systems, and GSE. Make-or-buy assumptions of the program management plan will be used to develop detailed manufacturing plans which relate to a particular supplier of specific hardware. Such plans obviously are strongly dependent on having a firm design concept established. Unique facilities, tooling, and STE required to support manufacturing activities must be identified. High-voltage test equipment, for example, must be developed for use in manufacturing the multitude of items, indicated in Figure 6-1, at the component level (such as switch gear, regulator, and circuit breakers). Quality control requirements and procedures must be identified and developed. Again, these are strongly dependent on the design concept.



KLYSTRON REQUIREMENTS

DEVICE	VOLTAGE	POWER KW	REGULATION
COLLECTOR 1	40 KV	11.2	
2	32 KV	11.2	
3	24 KV	11.2	
4	16 KV	11.2	
5	8 KV	11.2	
KLYSTRON BODY	40 KV	3.2	1%
MOD ANODE	20 KV		1%
CATHODE HEATER	20 V	0.1	10%
SOLENOID	20 V	0.5	10%
COMPUTER	20 V	0.1	10%
RETROELECT	20 V	0.1	10%
TOTAL		69.8	

Figure 6-1. SPS Power Distribution

SPS DDT&E PROGRAM PLANNING SUMMARY

PLAN	TITLE
6	MANUFACTURING PLAN (Cont.)

Development of high-production, thin-film GaAs technology is probably the most critical item and will require a long-term, well-funded program. An equivalent amount of GaAs production will be required in the same time frame to support buildup of a prototype stockpile and continuation in support of the operational SPS fabrication.

Large investments will also be required to manufacture power distribution, conditioning, and transmission components. Examples are switch gears, converters, and klystrons. (Assembly of the satellite as a power station would be covered under Plan 10, Space Operations.) Such items as beam machine complexes, templates, etc., must be developed specific to the prototype. These may differ considerably from those necessary to support construction of the Nth satellite due to the longer period permitted for staged fabrication of the former. A multitude of special assembly, fabrication, inspection, and test techniques must be developed which pertain to manufacturing in orbit. Some items may be partially fabricated and assembled under this plan with completion under Plan 10 (Space Operations). "Waveguides" is an example. These may be built as full box sections or in half-sections to save volume. The latter would then be transported to the satellite and assembled. Manufacturing and product assurance techniques must be such that waveguides can be placed into operation with "zero" defects since internal arcing due to burrs or whiskers would result in early failure of the guide.

An assumed buildup for one of the most critical items (solar blankets) is presented in Figure 6-2 in order to provide some perspective for the scope of the required manufacturing effort. It should be noted that production will peak at 1145 m per hour in 1997, and will need to increase in subsequent years to support the mature commercial program. Table 6-1 broadly addresses some of the manufacturing facilities development tasks needed to support subsystem production for planned prototype and commercial space operations.

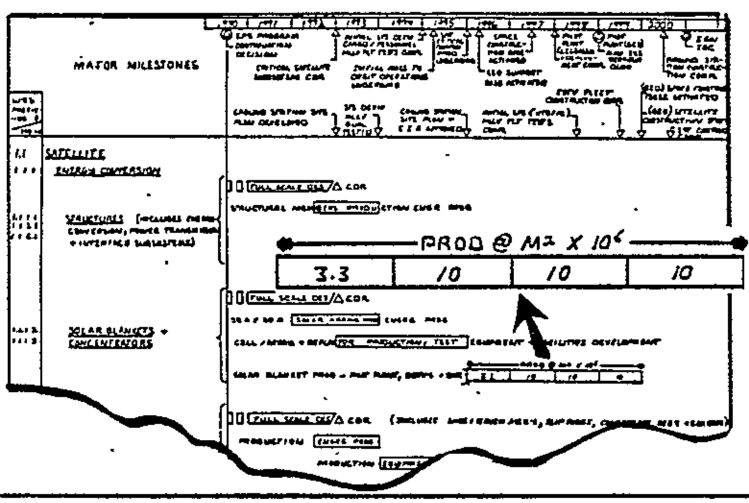


Figure 6-2. SPS Program Schedule (DDT&E/TFU Development Phase)

Table 6-1.
SPS DDT&E Program Planning Considerations (Phase C/D) Impact Sheet

Sheet 1 of 2

PLAN NO. 6	TITLE: MANUFACTURING	
WBS ELEMENT	IMPACT	CATEGORY
1.1 Satellite System	Once point design is firm, an overall satellite manufacturing plan must be provided in detail.	B
1.1.1.3 Solar Blankets	For the prototype SPS alone, a 27×10^6 m^2 area of solar blankets is required. Starting in 1996 it is suggested that a production rate be developed to support test, TFU, and follow-on production. Average production during 1996 would be 3.3×10^6 m^2 per year. The development of GaAs solar blankets meeting production, reliability, efficiency, and weight goals will be a major SPS technical challenge.	A
1.1.1.4 Power Distribution and Conditioning	Problems relate to the large quantity of high-voltage, highly reliable components which must be produced. Figure 6-1 provided some idea of the complexity of the power distribution subsystem. High-rate, automatic production of 1-mil aluminum wire junctions with zero defects is required. Large numbers of regulators, switch gears, and dc/dc converters will be involved, plus system complexity with IMS control for array regulation, load control, and associated interfaces.	A
1.1.2.2 Microwave Subarrays	Comments similar to the above apply to the MWPTS. If a decision were made to fabricate microwave resonant cavity radiators of ten types at the launch site, a manufacturing facility of approximately 150,000 m^2 must be provided. It is envisioned that the facility will have ten automated lines for cutting, perforating, and corner-welding of power modules. To achieve maximum payload density objectives, consideration is being given to packaging these panels and all other requisite components into appropriate payload configuration for further assembly into klystron power modules, subarrays, and mechanical modules for final installation in the antenna. There are 135,864 power modules, 6993 subarrays, and 777 mechanical modules per each antenna. The manufacturing plan for actual installation, connection, and checkout of this equipment will be covered under Plan 10 (Space Operations).	B

Table 6-1.
SPS DDT&E Program Planning Considerations (Phase C/D) Impact Sheet

PLAN NO. 6	TITLE: MANUFACTURING	
WBS ELEMENT	IMPACT	CATEGORY
1.1.7 System Test Hardware	Test articles for all components and subsystems will be built for qualification testing. This does not include flight or operational hardware.	B
1.2 Space Construction and Support	Includes all special support equipment (teleoperators, beam machines, etc.) to assemble, check out and maintain the satellite system.	C
1.3 Transportation	Each transportation element requires a separate manufacturing plan as part of the individual program effort.	C
1.3.7 Facilities	Manufacturing requirements for solar blankets, power conditioning and distribution components and rectenna modules will require extensive facilities.	A
1.4.2 Support Structures	Arrays will require roughly 4 million pedestals plus provisions for mounting switch gear, dc/dc connectors and cable runs. Large undertaking for planning purposes but not a technical problem.	C
1.4.3 Dipole/Rectivier Elements (Power Collection)	Similar technology could be used as for the solar blankets. However, modules could be of more manageable size. Weight will not be a problem but strength/weatherability will be factors not encountered in space. High-rate production must be accomplished on site for production of over 11,400,000 multi-layered panels of four types assembled into 580,500 subarrays.	A

SPS DDT&E PROGRAM PLANNING SUMMARY

PLAN	TITLE
7	PRODUCT ASSURANCE

PROGRAM PLAN DEFINITION

This plan shall address the program requirements for quality assurance, reliability assurance, and systems safety. NHB 5300.4 (ID-1) shall be used as a guide in developing these requirements.

SPS POINT DESIGN PROGRAM REQUIREMENTS

- Solar Photovoltaic CR-2 Concept Definition
- Quality Assurance Requirements—NHB 5300.4 (ID-1)
- Reliability Assurance Requirements—NHB 5300.4 (ID-1)
- Systems Safety Requirements—NHB 5300.4 (ID-1)

RESOURCE CONSIDERATIONS

- Technical and Management Personnel
- Support Equipment/Facilities and Software

DISCUSSION

Product assurance plans, comprising the disciplines of safety, reliability, and quality assurance, will provide direction for the overall satellite system. These plans will be applicable to vehicle contractors (SPS, HLLV, COTV, STS, and support equipment) and site contractors (ground receiving station). The plans, reflecting NHB 5300.4 (ID-1) requirements and associated data reporting requirements, will provide the basis for more detailed plans at the various vehicle and site levels during design/development, manufacturing, test, and operations. Subsequently, plans will be required from the industrial subcontractors. The scope of these plans will vary, depending on the type of procurement.

Quality assurance plans relate primarily to the vehicles; site (facility) operations normally are administrated through quality procedural manuals covering all quality aspects of site operations. These manuals will be compatible with overall program quality requirements.

While the implementation of product assurance plans will entail a relatively small expenditure of resources, the consideration entailed in product assurance may have far reaching effects in terms of providing for reliability and safety of equipment and personnel.

NHB 5300.4 (ID-1) provides guidelines for development of product assurance plans relative to the Space Shuttle. These plans encompass the areas of safety, reliability, maintainability, and quality assurance. While each of these will require planning unique to the SPS, the area overriding concern is safety. The logistics, fabrication, operation, and maintenance activities associated with the satellite system will require manned space activity well beyond any previous space endeavor. Due to the large size of the satellite,

SPS DDT&E PROGRAM PLANNING SUMMARY

PLAN	TITLE
7	PRODUCT ASSURANCE (Cont.)

rapid means of transporting men and materials to the most remote areas must be developed. This, along with associated inspection and maintenance must be accomplished safely with minimal need to shut down any portion of the high-voltage grid. Replacement of certain items might be scheduled for periods of eclipse; however, most activities will take place aboard a fully operating power station.

Ground safety will also be of concern. Consider the rectenna site, for example. Besides the microwave potential hazard, the high ac or dc voltage conditioning equipment represents potential lethal voltages to maintenance personnel required to repair or service that equipment. The heights of the various equipments represent an occupational hazard relative to falls or tool droppage. Also, lightning strike potential is affected by the heights, conductors, and array size.

Considerations for other major systems and subsystems are similar in scope. Routine in-orbital operations, for example, will be undertaken on a large scale. Life support and safety will be major drivers in the design of each space system. The more significant product assurance considerations are summarized in Table 7-1.

Table 7.
SPS DDT&E Program Planning Considerations (Phase C/D) Impact Sheet

PLAN NO. 7	TITLE: PRODUCT ASSURANCE	
WBS ELEMENT	IMPACT	CAT-EGORY
1.1 Satellite System	Product assurance elements must be established which apply to daily operations in the major manufacturing, installation, and operations in space. Safety aspects must consider protection of personnel and equipment during inspection, maintenance, repair, and replacement operations in the midst of an operating antenna or solar blanket field.	C
1.1.1 Energy Conversion	System safety and reliability will be addressed at the system level since inspection, M/R, etc., must be performed on equipment with the photovoltaics and concentrators operating in combination.	C
1.1.1.3 Solar Blankets	27,500 m^2 or more of solar blankets will be produced each day with associated checkout, inspection and repair. This element includes product assurance considerations on the ground and in orbit.	C
1.1.2 Power Transmission	Verification of pointing accuracy and interlock capability will be essential to public acceptance of SPS. Quality assurance considerations will relate to producing zero-defect waveguide assemblies in orbit.	B
1.1.4 ACS	Safety aspects of fueling and performance M&R, etc., of multiple thrusters of the attitude control and stationkeeping system.	C
1.5 Program Management	The product assurance plan will not entail substantial financial commitment in itself relative to some other plans. However, it is assigned to a high category at the summary level to emphasize the critical impact of safety and reliability on the SPS. Requirements established by the product assurance plan will have a strong influence on design and may result in considerable budgetary impact in testing, manufacturing, and operations.	B

SPS DDT&E PROGRAM PLANNING SUMMARY

PLAN	TITLE
8	FACILITIES

PROGRAM PLAN DEFINITION

This plan shall provide a compilation of the facility requirements (identified in other sections) for the total program, including development, testing, manufacturing, checkout, and operations. Budgetary estimates shall be provided for the major/critical new facilities and/or major modifications. Options shall be described which will assist in determining whether these costs shall be contractor capital equipment or government facilities. Usage schedules shall be determined and any known conflicts shall be identified.

SPS POINT DESIGN PROGRAM REQUIREMENTS

- Solar Photovoltaic CR-2 Concept Definition
  - Development facilities requirements
  - Testing facilities requirements
  - Manufacturing facilities requirements
  - Checkout and operations facilities requirements
  - Ground support requirements
- Requirements for Major/Critical New Facilities
  - Financial and organizational concept financing
    - Space segment
    - Ground segment

RESOURCE CONSIDERATIONS

- Technical and Management Personnel
- Architectural and Engineering Capability
- Maintenance and Operational Workers
- Site and Facilities Availability
- Materials and Support Equipment
- Heavy Construction/Industrial Equipment

DISCUSSION

Major facilities will be required for manufacturing, testing, ground support, and warehousing—such as those related to power generation and transmission. The same will apply to major systems such as STS and HLLV which must include launch, recovery, and refurbishment facilities (Table 8-1).

Table 8.
SPS DDT&E Program Planning Considerations (Phase C/D) Impact Sheet

Sheet 1 of 1

PLAN NO. 8 TITLE: FACILITIES

WBS ELEMENT	IMPACT	CATEGORY
1.1.1.3 Solar Blankets	Production, test, storage facilities	A
1.1.1.4, 1.1.2.3, 1.1.6.3 Power Distribution and Conditioning	Production and high-voltage test facilities	A
1.1.2 Power Transmission	Production and high-voltage test facilities	B
1.3.7 Facilities	This will provide facilities resulting from requirements generated under other plans. Of particular concern are STS launch/recovery and logistics/payload integration facilities.	A
1.4 Ground Receiving Station	Production facilities for rectenna support structures and power collectors Includes all land, site preparation, buildings, access, and utilities interface for rectenna and other elements of ground station. Site may encompass over 150 km^2. Several thousand workers must be accommodated during construction, with considerable reduction when the site is placed into operation.	B
1.5 Program Management	Top-level planning function; major cost commitment required in subordinate areas indicated.	A

SPS DDT&E PROGRAM PLANNING SUMMARY

PLAN	TITLE
9a	GROUND OPERATIONS—Ground Integration

PROGRAM PLAN DEFINITION

This plan will cover integration of equipment and instruments into payloads. (Launch site integration of payloads into vehicle carriers will be covered under Space Operations, Plan 10.) An assessment of the manpower, facilities, equipment, and hardware to support these ground integration activities is required.

SPS POINT DESIGN PROGRAM REQUIREMENTS

- Solar Photovoltaic CR-2 Concept Definition
  - Operational instruments and payload integration requirements
  - Launch site/vehicle carrier definitions
  - Supporting equipment and facility requirements
  - Test and verification requirements

RESOURCE CONSIDERATIONS

- Technical and Management Personnel
- Supporting Hardware and Software
- Test Equipment and Facilities

DISCUSSION

Ground integration will have no major impact; however, early consideration should influence certain designs (i.e., waveguides) to assure optimum mix of payloads for STS. Table 9a-1 identifies ground assembly and integration considerations relative to its programmatic impact.

Table 9a-1.
SPS DDT&E Program Planning Considerations (Phase C/D) Impact Sheet

Sheet 1 of 1

PLAN NO. 9a	TITLE: Ground Operations—Ground Integration	
WBS ELEMENT	IMPACT	CATEGORY
1.1.7 Systems Test Operations	The integration task is comprehensive involving all aspects of assembly, test, and checkout of components, subsystems, etc., into payloads. This includes automated and, in some cases, sortie payloads. Integration aspects must be considered in all phases of design to assure optimum combination of payload space and weight resulting in minimum flights to orbit.	C
1.5 Management and Integration	Provides consideration for policy and procedure required to conduct operations and integration.	C

SPS DDT&E PROGRAM PLANNING SUMMARY

PLAN	TITLE
9b	GROUND OPERATIONS—Maintenance and Refurbishment

PROGRAM PLAN DEFINITION

This plan will provide identification of expected maintenance and refurbishment requirements, assessment of how these activities would be accomplished and the resources required, i.e., manpower, facilities, and equipment.

SPS POINT DESIGN PROGRAM REQUIREMENTS

- Solar Photovoltaic CR-2 Concept Definition
  - Rectenna maintenance and refurbishment requirements
  - Shuttle-derived HLLV maintenance/refurbishment requirements
  - Launch site operations

RESOURCE CONSIDERATIONS

- Technical and Management Personnel
- Operations and Maintenance Personnel
- Support Equipment and Facilities
- Special/Unique Refurbishment Equipment
  - Rectenna panel checkout
  - Shuttle-derived HLLV

DISCUSSION

This plan will entail major effort primarily in the areas of rectenna and STS. The 5-GW rectenna site will, for example, contain 580,500 rectenna dipole panels (9.33 m high by 14.69 m long) covering an area of 78.5 million square meters.

Refurbishment techniques for STS should derive directly from the Shuttle. The STS M&R plan area, while substantial will evolve over several years as the prototype ground station and launch/transportation system are being developed and brought up to operational status.

The requirements for inspection, cleaning, maintenance, and some replacement of failed panels will require a sizeable direct labor force and supporting equipment to maintain the operational antenna once installed (Table 9b-1).

Table 9b-1.
SPS DDT&E Program Planning Considerations (Phase C/D) Impact Sheet

Sheet 1 of 1

PLAN NO. 9b	TITLE: GROUND OPERATIONS—Maintenance and Refurbishment	
WBS ELEMENT	IMPACT	CATEGORY
1.4.6 Operation	Maintenance and refurbishment will cover all areas of ground stations including dipole subarrays and all associated power conditioning, distribution, and interface equipment.	C
1.5 Management and Integration	Policy and procedural requirements necessary for maintenance and refurbishment are included.	C

SPS DDT&E PROGRAM PLANNING SUMMARY

PLAN	TITLE
9c	GROUND OPERATIONS—Logistics

PROGRAM PLAN DESCRIPTION

This plan will address logistic requirements to include planning, warehousing, facilities and equipment, transportation, training, manpower, operations supply and maintenance, etc., utilizing the spare parts requirements identified in other sections.

SPS POINT DESIGN PROGRAM REQUIREMENTS

- Solar Photovoltaic CR-2 Concept Definition
- SPS Training Requirements
- Warehousing Operations—Spares
- Logistic Support Definitions—Provisioning
- Facilities and Equipment Requirements—Spares Depots
- Logistics and Transportation Requirements—Spares
- Operational Supplies and Maintenance

RESOURCE CONSIDERATIONS

- Technical and Management Personnel
  - Logistics Planners
  - Training Personnel
  - Operational/Support Personnel
- Transportation Systems
- Support Materials/Equipment and Facilities

DISCUSSION

While logistics for the purpose of supporting the SPS alone will be fairly extensive, the major impact of the Phase C/D logistics plan is that it be prototypical of the plan for the following operational phase. This approach is essential since the plan must provide for rapid, orderly expansion toward the end of Phase C/D. Considerations include such items as land transportation networks, training schools and planning facilities for stockpiling and warehousing of materials. Figure 9c-1 provides some indication of the scope of the logistics activities for the launch site, for example. Key elements will include the final selection and design of launch and transport vehicles, all of which must be supplied with trained flight and support crews, fuel, and spare parts. Similar flow charts must be developed for the rectenna site and for the overall logistics ground network. Subplans for space logistics would be a part of Plan 10, Space Operations.

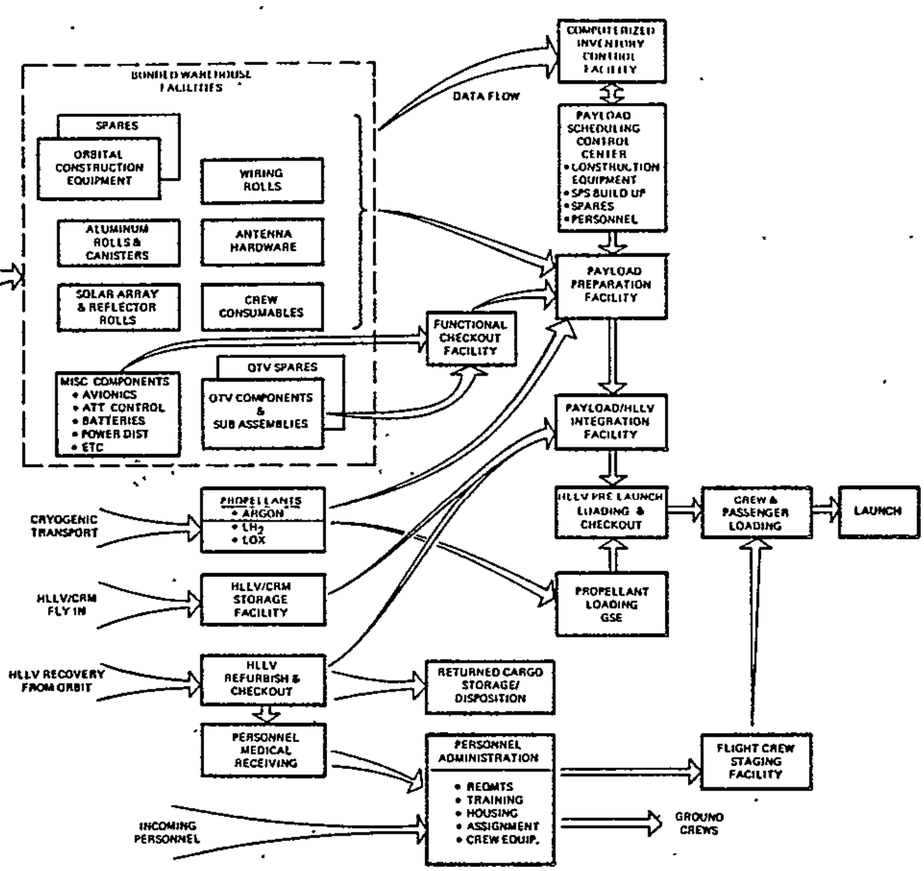


Figure 9c-1. Launch Site Logistics

SPS DDT&E PROGRAM PLANNING SUMMARY

PLAN	TITLE
10	SPACE OPERATIONS

PROGRAM PLAN DESCRIPTION

This plan shall address all of the activities associated with space/mission operations. Mission operations cover those activities from liftoff through on-line operations including ground operations, and shall include the requirements for manpower, facilities, and equipment to support the various ground and orbital on-site operations. (Actual procurement and training of manpower, construction of facilities, etc., will take place under the respective plans such as 9c (Logistics) and 8 (Facilities).

SPS POINT DESIGN PROGRAM REQUIREMENTS

- Solar Photovoltaic CR-2 Concept Definition
- Mission Planning Definitions (Plan 2)
- Transportation System Definitions
- Orbital Operations Definitions
- Space/Ground Operational Interfaces
- Operational Hardware/Software Requirements

RESOURCE CONSIDERATIONS

- Technical and Management Personnel
- Operational and Support Personnel
- Supporting Hardware and Software
- Materials/Equipment and Facilities

DISCUSSION

The conduct of large-scale space operations leading to routine construction operation and maintenance of space complexes such as SPS represents, perhaps, the major challenge in space for the remainder of this century. To fully exploit the potential that space provides will require devoting extensive resources and long-range planning to space programs of which SPS is the major one foreseen. The Space Operations Plan will require a breakdown into subplans which could include the following:

- Construction (Manufacturing)
- Space Base
- Logistics (including Life Support)
- Maintenance and Refurbishment
- Interstation/Interorbital Transportation
- Product Assurance (including Safety)
- Ground Support (i.e., operations, not logistics/facilities planning and operation, not construction)

SPS DDT&E PROGRAM PLANNING SUMMARY

PLAN	TITLE
10	SPACE OPERATIONS (Cont.)

Some of the above such as construction, manufacturing and product assurance are now incorporated as part of existing plans. Consideration might be given to including these unique facets of the Space Operations Plan.

Operational control will include both on-station operations, such as satellite construction, and control of transportation vehicle and construction bases. Planning considerations of space operations are shown in Table 10-1.

C-2

Table 10-1.
SPS DDT&E Program Planning Considerations (Phase C/D) Impact Sheet

Sheet 1 of 2

PLAN NO. 10	TITLE: SPACE OPERATIONS	
WBS ELEMENT	IMPACT	CAT-EGORY
1.1 Satellite System	Operations performed on the satellite as a power-generating and transmitting station. Does not include checkout of satellite proper or its subsystems.	A
1.1.1.1, 1.1.2.1, 1.1.6.1 Structure	Manufacturing of the production satellites is based on orientation of beam machines in a complex, spatially controlled by a full cross-section template, as shown in Figure 10-1. The resulting manufacturing sequence provides for full construction in a total elapsed time and requires supporting several hundred men in orbit. The EOTV, on the other hand, will be assembled to permit wide flexibility in sequencing and rate of assembly. Considerable study will be required to identify an optimum approach to continuous manufacturing. This must be followed by development and demonstration on the ground and in space of equipment (i.e., beam machines) and operations (i.e., joining) applicable to the prototype.	A

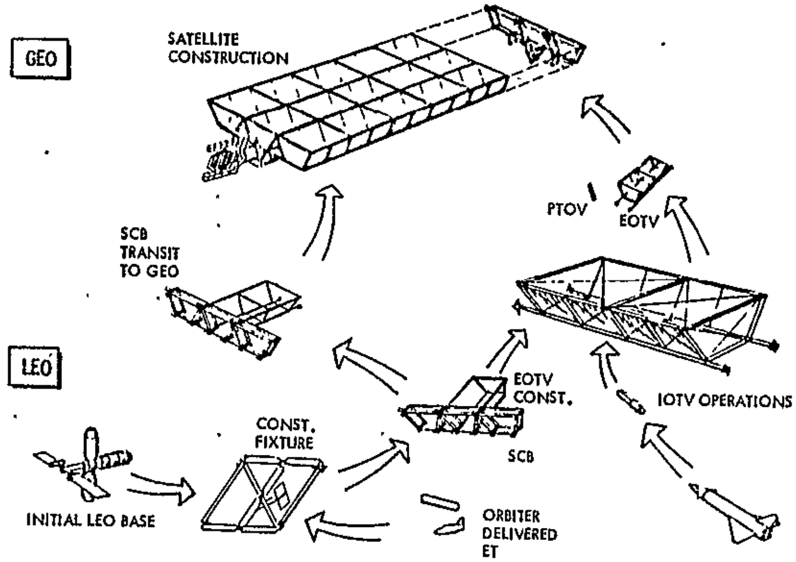


Figure 10-1. Overall Satellite Construction Scenario

Satellite Systems Division
Space Systems Group
Rockwell International

Table 10-1.
SPS DDT&E Program Planning Considerations (Phase C/D) Impact Sheet

PLAN NO. 10	TITLE: SPACE OPERATIONS	
WBS ELEMENT	IMPACT	CATEGORY
1.2 Space Construction & Support	Solar blankets operational capability for larger-scale assembly, checkout, and maintenance in orbit represents the significant challenge to SPS. Included also are the power transmission system elements.	C
1.3 Transportation	Operational requirement planning and control.	C
1.5 Program Management	Summary planning functions integrating all major flight and supporting ground systems.	A

SPS DDT&E PROGRAM PLANNING SUMMARY

PLAN	TITLE
11	LAUNCH OPERATIONS

PROGRAM PLAN DESCRIPTIONS

This plan shall address all the activities associated with launch operations. Launch operations cover those activities from arrival of the payload at the launch site until liftoff. This shall include, but not be limited to, handling, inspection, assembly/integration/installation, checkout, calibration, etc.

SPS POINT DESIGN PROGRAM REQUIREMENTS

- Solar Photovoltaic Cr-2 Concept Definition
- Launch Site Payload Integration Definitions (Plan 9a)
- Transportation System Definitions
- Launch Site Facility Definition (Plan 8)
- Launch Site Support Equipment Utilization
- Test and Verification Definition (Plan 4)

RESOURCE CONSIDERATIONS

- Technical and Management Personnel
- Operations and Maintenance Personnel
- Support Equipment and Facilities
- Special/Unique Processing Equipment/Facilities

DISCUSSION

Launch operations will involve expanding the capability already developed under the basic Shuttle program. Because of the number and frequency of launches, this will require considerable expansion of current launch facilities. As with the Logistics Plan, however, the major impact is to incorporate within the plan and its implementation the tremendous capability needed for multiple daily flights of HLLV's and provisions for rapid turnaround needed during post-IOC period. Important considerations are shown in Table 11-1.

Table 11-1.
SPS DDT&E Program Planning Considerations (Phase C/D) Impact Sheet

Sheet 1 of 1

PLAN NO. 11 TITLE: LAUNCH OPERATIONS

WBS ELEMENT	IMPACT	CAT-EGORY
1.3 Transportation Operations	Operational policy and procedure planning required for the handling of STS and VTO/HL HLLV vehicle turnaround.	C
1.3.7 Facilities	Facilities planning requirements will be needed to support STS and VTO/HL HLLV operations. Included are facilities for launch, recovery, fuel, logistics support, and operations.	B
1.5 Management and Integration	Due to the large number of launches and long period over which launch operations will take place the development of routine, rapid turnaround capability will be a major undertaking. Estimates are that in the order of 200 launches of a Shuttle-derived HLLV will be required to support precursor/prototype assembly over the period 1996 through 1008. This is an average of almost two launches per week.	B

SPS DDT&E PROGRAM PLANNING SUMMARY

PLAN	TITLE
12	SPECIFICATION TREE

PROGRAM PLAN DESCRIPTIONS

A specification tree shall be developed, beginning with the project level at the top.

SPS POINT DESIGN PROGRAM REQUIREMENTS

- Solar Photovoltaic CR-2 Concept Definition
- System and Subsystem Definitions
- Make-or-Buy Decisions (Plan 1)
- Development and Procurement Definitions

RESOURCE CONSIDERATIONS

- Technical and Management Personnel
- Support Materials/Equipment and Facilities

DISCUSSION

This plan might be incorporated under Plan 1 or 2 and should be maintained as a natural part of the top-level planning function.

SPS DDT&E PROGRAM PLANNING SUMMARY

PLAN	TITLE
13	NATURAL RESOURCES ANALYSIS

PROGRAM PLAN DESCRIPTION

This plan assesses the degree and rate of consumption of critical materials, the degree of utilization of both material extraction and production plants, and the sensitivity of this consumption toward meeting the program objectives, major milestones, and the initial operational capability of the Satellite Power System (SPS). It expressly covers a natural resource analysis of only the first Rockwell SPS reference configuration.

SPS PROGRAM REQUIREMENTS

Program requirements and detail system definitions are based on the SPS reference configuration of a three trough planar array with an end mounted tension web antenna. Programmatic ground rules and guidelines are:

- Key dates for program planning:

  1981-1987 - Key Technology Program Activities

  1990 - Decision Point for SPS Commercialization (Phase C/D)

  2000 - IOC of First SPS including Ground Receiving Station

- SPS build rate at two nominally 5 GW SPS's/year for 30 years to provide a 60 system capability by 2030.

The resource analysis considered these ground rules and SPS program schedules to identify the timing of system acquisitions and main operational elements. The following paragraphs summarize the analyses for use in identifying potential impact on U.S. productive capacity.

SPS PROGRAM ELEMENTS

Main elements of the SPS program include the satellite; space construction bases and support assembly equipment; space transportation and ground facilities; the ground receiving station; and management/integration activities. Principal resource requirements of the satellite, space construction, ground receiving station, and transportation elements are discussed in the following paragraphs.

Satellite System

The elements/systems of a space satellite are grouped into the categories of - energy conversion, power transmission/antenna, information management and control, attitude control and stationkeeping, and communications. Each of these items were analyzed and researched for its major resource requirement that focused on structures, concentrators, solar blankets, power distribution and conditioning, and the klystron power module. A 25% weight growth factor was added to the basic system design weight statement for resource calculations. This is equivalent to the normal factor used in calculating the total mass to provide for contingency.

<u>Structure</u>. The primary structure which supports the solar array and antenna segment is composed of graphite impregnated composites. The total weight of the composites is 1.028×10^6 kg or 2,265,000 lb. Approximately 30% by weight would be graphite (0.309×10^6 kg/681,200 lb); 15% by weight would be glass fibers (0.154×10^6 kg/339,570 lb); and 55% resin (0.565×10^6 kg/1,246,000 lb). The secondary structure/mechanisms of the solar arrays and antenna segments are considered mainly of aluminum and weighs 1.769×10^6 kg or 3,900,000 lb.

<u>Concentrators</u>. The concentrators (reflectors) consist of aluminum coated 0.5 mil Kapton - Type H sheet. The total weight is 1.296×10^6 kg or 2,857,000 lb of which 1.283×10^6 kg or 2,828,000 lb is Kapton and $.013\times10^6$ kg or 29,000 lb is aluminum.

<u>Solar Blanket</u>. The solar blanket consists of a variety of materials as listed in Table 13-1. The total amounts required are factored from the work completed under Arthur D. Little contract with NASA (NAS9-15294).

Table 13-1. Solar Blanket Material Mass

MATERIAL	AMOUNT REQUIRED	
	10^6 kg	$\times 10^6$ lb
ALUMINUM	0.008	0.018
GALLIUM	0.432	0.952
ARSENIC (99.999%)	0.465	1.025
SELENIUM (00.999%)	34 kg	75 lb
ZINC (99.999%)	11 kg	24 lb
ALUMINUM (99.999%)	0.005	0.011
SILVER	0.172	0.379
GOLD	1.640	3.615
TIN	0.488	1.076
SAPPHIRE (Al_2O_3)	2.700	5.952
COPPER	0.476	1.049
TEFLON	0.915	2.017
KAPTON	1.219	2.687
TOTAL	8.518	18.781

<u>Power Distribution and Conditioning</u>. This category includes the power conditioning equipment and conductors in both the solar array and the antenna. Also included are the power-transmitting slip rings. The total weight of power distribution and conditioning equipment, etc., amounts to 8.884×10^6 kg, or 19.585×10^6 lb and consists of the following materials (Table 13-2):

Table 13-2. PD&C Materials

MATERIAL	AMOUNT REQUIRED $\times 10^6$ kg	AMOUNT REQUIRED $\times 10^6$ lb
ALUMINUM	6.824	15.044
STEEL	0.506	1.115
TITANIUM	0.028	0.062
COPPER	0.839	1.850
PLASTICS	0.681	1.501
SILVER	0.006	0.013
TOTAL	8.884	19.585

Power Modules (Klystrons). The weight of klystrons required on the SPS is estimated to be 5.206×10^6 kg or $11,477\times10^6$ lb. The materials required for their construction are listed in Table 13-3.

Table 13-3. Power Module Composition

MATERIAL	AMOUNT REQUIRED $\times 10^6$ kg	AMOUNT REQUIRED $\times 10^6$ lb
ALUMINUM	0.265	0.584
STEEL	0.690	1.521
COPPER	2.550	5.621
ALNICO-V	1.010	2.227
54% Fe	0.545	1.201
24% Co	0.242	0.533
14% Ni	0.141	0.311
8% Al	0.081	0.179
ALUMINUM OXIDE	0.531	1.171
GRAPHITE EPOXY	0.160	0.353
30% GRAPHITE	0.048	0.106
15% GLASS FIBER	0.024	0.053
55% RESIN	0.088	0.194
TOTAL	5.206	11.477

Material Requirements for Main Elements of the Satellite System. A tabulation of satellite system material requirements in each of the study areas is presented in Table 13-4. The total weight of 26.700×10^6 kg or 58.873×10^6 lb is distributed over 22 materials as listed.

Ground Receiving Station (GRS) Definition

Key elements of the ground receiving station that might impact resource availability consists of the site and facilities requirements, the rectenna support structure, and the power collection system requirements. Other elements such as conversion stations, the grid interface and the operations requirements are basically identical to those required by conventional power.

Table 13-4. Material Requirements for Main Satellite System Elements

MATERIAL	STRUCTURE/ MECHANISMS x 10^6 KG	CONCEN- TRATORS x 10^6 KG	SOLAR BLANKET x 10^6 KG	POWER DISTR. & COND. x 10^6 KG	POWER MODULE (KLYSTRONS) x 10^6 KG	TOTAL WEIGHT KG x 10^6	TOTAL WEIGHT LB x 10^6
ALUMINUM	1.769	0.013	0.013	6.824	0.346	8.965	19.768
ALUMINUM OXIDE					0.531	0.531	1.171
ARSENIC			0.465			0.465	1.025
COBALT					0.242	0.242	0.533
COPPER			0.476	0.839	2.550	3.865	8.520
GALLIUM			0.432			0.432	0.952
GLASS FIBER	0.154				0.024	0.178	0.392
GOLD			1.640*			1.640	3.615
GRAPHITE	0.309				0.048	0.357	0.787
IRON					0.545	0.545	1.201
KAPTON		1.283	1.219			2.502	5.517
NICKEL					0.141	0.141	0.311
PLASTIC				0.681		0.681	1.501
RESIN	0.565				0.088	0.653	1.440
SAPPHIRE			2.700			2.700	5.952
SELENIUM			(34 KG)			(34 KG)	(75 LB)
SILVER			0.172	0.006		0.178	0.392
STEEL				0.506	0.690	1.196	2.637
TEFLON			0.915			0.915	2.017
TIN			0.488			0.488	1.076
TITANIUM				0.028		0.028	0.062
ZINC			(11 KG)			(11 KG)	(24 LB)
SUBTOTAL	2.797	1.296	8.518	8.884	5.205	26.700	58.873
OTHER (ACS & THERMAL)						6.318	13.931
					TOTAL WEIGHT	33.018	72.804

*Not economically feasible—Assume the use of an aluminum base material.

generating systems and are not anticipated to impose significant resource re-requirements. Likewise, the control system, while unique to the GRS concept, is not anticipated to require either unusual types or large quantities of natural resources.

Site and Facilities. The ground receiving station will require an area of approximately 35,000 acres. The rectenna field will occupy approximately 25,000 acres with a surrounding buffer zone of 10,000 acres. The land will need to be cleared and leveled and a rainfall run-off system would need to be constructed. Several alternative layouts were examined, however, the amount of excavation and concrete was found to be relatively insensitive to the layout alternatives. Concrete footings (2 parallel rows) would need to be poured for each row of antenna panels. Concrete requirements for GRS rectenna panel footings and for the water channels were translated into the constituent materials (see Table 13-5).

Table 13-5. Cement/Aggregate Requirements

CEMENT	949,000 TONS
SAND	2,827,000
ROCK (APPROX. 1" - 1-1/2")	3,695,000
WATER	606,000
	8,077,000 TONS
REINFORCING ROD	19,000 TONS

It was assumed that the access road between panels would consist of a 6 inch deep layer of gravel. The gravel requirements for the access roads would be 9,791,000 yd^3 or approximately 13,707,000 tons. Requirements associated with construction of 10 miles of access roads and 23 miles of perimeter roads plus 20 miles of access railroad, and 25 miles of perimeter railroad were not considered to impose abnormal requirements on natural resources or production capacities.

Rectenna Support Structure. The rectenna support structure consists of steel hat sections, I beams, tube braces, fittings and hardware along with miscellaneous items. The total weight of steel required for rectenna support was calculated to be 1666.7 kg or 3674 lb per panel, or a total of 967.5×10^6 kg or 2132.9×10^6 lb for the 580,500 panels in the rectenna array.

Power Collection. The power collection occurs in the panel array elements mounted on the rectenna panels. The elements consist of three 0.5" layers of a dielectric (plastic compound) that separates four layers of 0.0039 inches of copper, clad to 0.001 inches of Mylar. Interspersed within each panel are 735 diodes, or a total of 426.67×10^6 diodes in the total array of 580,500 panels. The one ounce diodes consist of 44% tungsten, 40% copper, 15% gallium arsenide and 1% gold and other exotic materials. Consequently, the total material requirements for the power collection portion of a single rectenna are itemized in Table 13-6. Miscellaneous materials such as copper wiring, J-boxes, etc., were not considered to severely impact either material availability or production capacity.

Table 13-6. Diode Materials per Rectenna

MATERIAL	AMOUNT REQUIRED $kg \times 10^6$	$lb \times 10^6$
PLASTIC DIELECTRIC	169.96	374.68
MYLAR	11.32	24.95
COPPER (COATED OR MYLAR)	46.13	101.70
DIODES		
TUNGSTEN	5.32	11.73
COPPER	4.84	10.67
GALLIUM ARSENIDE	1.81	4.00
GOLD/EXOTICS	0.12	.27

Space Transportation System Definition

The SPS program will require six new vehicle or growth developments. The listing of vehicles needed to complete the first satellite for an initial operating capability is shown in Table 13-7.

Table 13-7. SPS Fleet/Operations for First Satellite

	NO. OF VEHICLES	NO. OF FLTS.
PERSONNEL LAUNCH VEHICLE (PLV) SHUTTLE GROWTH	2	60
HEAVY LIFT LAUNCH VEHICLE (HLLV)	5	234
PERSONAL ORBITAL TRANSFER VEHICLE (POTV)	4	45
INTERORBITAL TRANSFER VEHICLE (IOTV)	4	408
CARGO ORBITAL TRANSFER VEHICLE-ELECTRICAL (EOTV)	6	7
PERSONAL MODULE (PM - USED WITH POTV)	4	60

In order to be available when required, the development times for the six vehicles would overlap. The vehicles will require large quantities of propellants and possibly the construction of new propellant production facilities. The total annual propellant quantity estimated to be required in support of the construction of the first SPS is shown in Table 13-8. The actual quantities required would be somewhat larger than the amounts shown because losses due to boil-off, evaporation, etc., have not been included.

SPS PROGRAMMATIC DEFINITION

Quantities of natural resources required for construction of the SPS, while significant in themselves, may nevertheless be misleading because it is the rate of resource requirements that governs their impact. The elements required for the satellite system (i.e., transportation systems, bases, etc.) will be constructed over a number of years. Thus, the resource requirements

Table 13-8. Propellant Requirements for First Satellite

VEHICLE	× 10^6 kg			
	LOX	LH_2	RP	ARGON
PLV	69.960	11.640		
HLLV	990.288	80.028	201.006	
POTV	2.526	0.421		
IOTV	0.105	0.018		
EOTV				4.690
TOTAL	1062.879	92.107	201.006	4.690
MILLIONS OF LB	2343.117	203.050	443.118	10.339

can be spread over a commensurate period. On the other hand, the ground receiving station is scheduled for IOC approximately four to five years after start of site preparation on the first GRS. Examination of the domestic availability of many of the resources required by the SPS can readily result in the identification of those resource requirements that would not present substantial problems. Similarly, those resource requirements that might tax the current productive capacity of the U.S. can at least be flagged for more detailed analyses in light of the schedules of GRS requirements as shown in Figure 13-1.

RESOURCE REQUIREMENTS

Basic resources considered were: 1) material requirements (i.e., mineral, metal, plastic, etc.); 2) production capacity for processing the materials; and 3) manpower - principal areas of skilled manpower essential for the development and implementation of main elements that comprise the SPS program.

Materials

In assessing the material resources, primary emphasis is placed on the indigenous U.S. supply. However, in some cases such as bauxite which is the basic source of aluminum, the annual U.S. imports from diverse sources are judged to be a more accurate measure of aluminum availability than U.S. bauxite production alone. In other cases, the SPS mineral requirements are assessed in terms of their impact on U.S. government stockpiles.

Production Capacity

The production capacity is assessed in terms of the SPS demand versus the U.S. ability to readily expand its productive capacity to meet new requirements. A major impediment to ready expansion centers is based on the availability of relatively low cost energy sources. New industry may have difficulty in finding readily available locations with low cost energy sources. This is particularly true for production of energy intensive materials such as aluminum or sapphire.

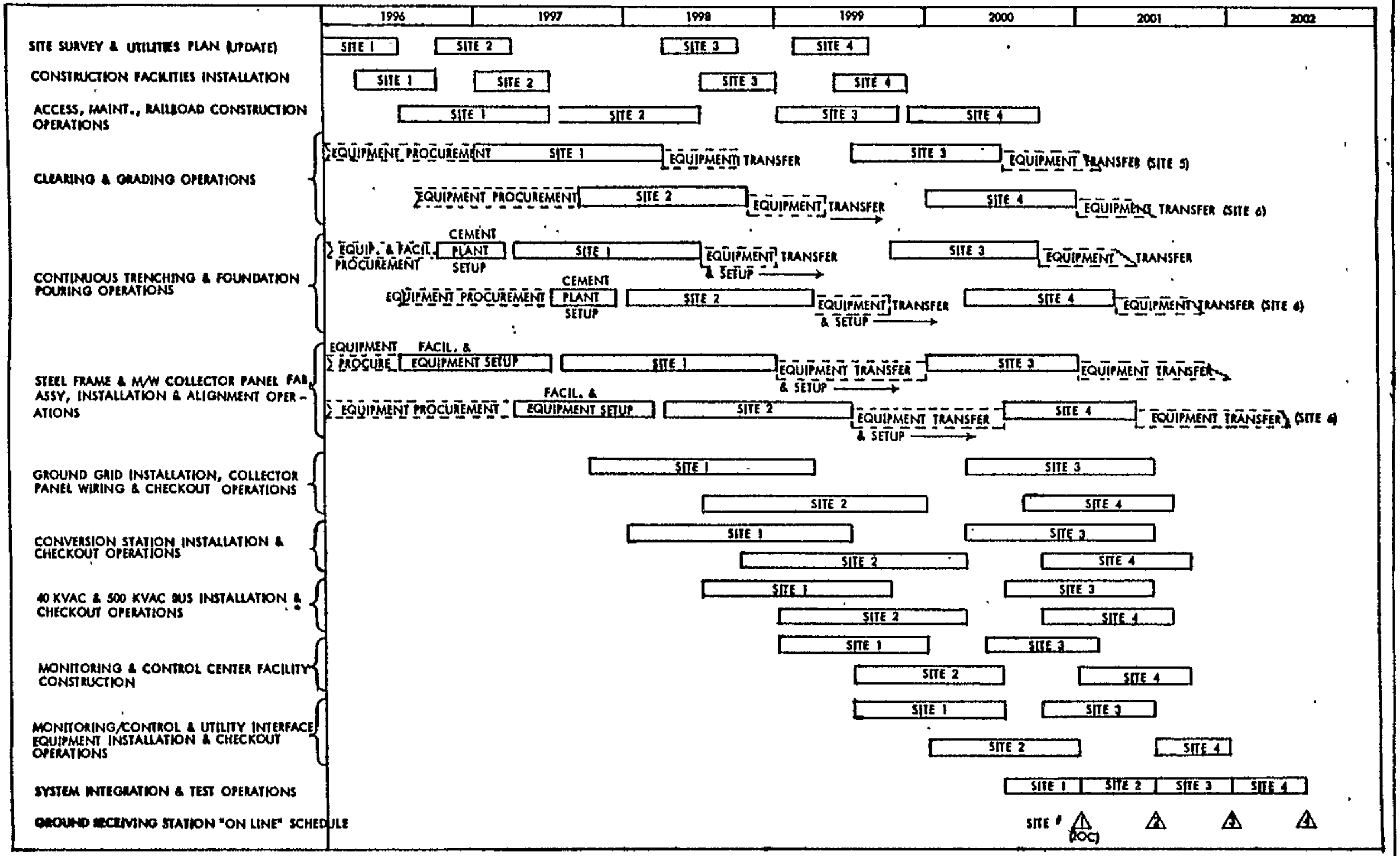


Figure 13-1. SPS Rectenna Construction Sequence Summary Schedule

Manpower

Requirements for skilled manpower can impose constraints on major developments based on the magnitude of SPS and its required disciplines. Two categories of important manpower considerations have been recognized. The first is the engineering manpower necessary for the concurrent development of five new major transportation systems in addition to the simultaneous development of the space bases and the satellite system. The second potential manpower constraint stems from the radiation exposure limitations on the satellite system construction crew. Two crews of 317 each will be required to man the SCB during construction of the first SPS. A work cycle of 3 months in orbit and 6 months on earth is planned for the construction period. This requires 3 full construction crews, plus a complete crew replacement every 3 years without attrition on the basis that five 3-month tours in orbit will result in a maximum lifetime radiation exposure. Consequently, hundreds of satellite construction workers will need to be recruited and trained continuously.

RESOURCE CONSIDERATIONS

Manpower and material requirements imposed by the development and construction of the SPS were identified and analyzed in terms of appropriate manpower and material availability within the U.S. Several potential problem areas were identified.

TECHNICAL AND MANAGEMENT PERSONNEL

Development of eight major systems are required for SPS transportation and space base requirements. These are:

1. Personnel Launch Vehicle/Shuttle Growth Vehicle
2. Heavy Lift Launch Vehicle (VTO/HL)
3. Personnel Orbital Transfer Vehicle (POTV)
4. Interorbital Transfer Vehicle (IOTV)
5. Cargo Orbital Transfer Vehicle (COTV)
6. Space Construction Base (SCB)
7. Low Earth Orbit Base
8. Satellite O&M Base

Three major bases are required in the development and implementation of the SPS, namely the Space Construction Base (SCB), a Low Earth Orbit (LEO) Base and the Satellite O&M Base. The SCB, located in geosynchronous orbit, contains 33 tribeam fabricators (198 beam machines) as well as solar blanket and reflector dispensing areas. It also contains a central and auxiliary habitats, landing area, and warehouse facilities. All of the basic elements of the satellite are constructed through the use of the SCB. The LEO Base is basically a supporting facility for staging cargo and propellants for transfer to GEO. The O&M Base is primarily the maintenance facility for the operational satellite. It contains maintenance supplies as well as a habitat for the maintenance/operations personnel.

Each of these developments constitutes a major program, requiring thousands of skilled engineers. The development schedules for most of these programs will overlap. In view of the current tight supply of skilled aerospace engineers, the unavailability of technical personnel may constitute a major impediment to the establishment of an SPS in accord with the planned schedules.

Another manpower consideration is the manning level for satellite construction. Required crew rotations to support construction of 60 satellites total 120, which results in 24 crews or 14,400 men. Applying a 20% attrition factor (resignations, etc.) raises this figure to 17,280. Similarly, 3,660 maintenance crew rotations at 30 men per crew and including attrition generate a requirement for 26,352 men. An additional 691 men are needed to operate one LEO facility for 30 years.

The need to recruit and train personnel and to develop the required facilities and materials for the programs/courses represent an important aspect of this overall activity.

MATERIALS

A review of materials required for construction of the satellite system and ground receiving station identifies several potential problem areas of material availability. Table 13-9 summarizes eight materials that can pose limitations on SPS requirements. Considerations on material availability are presented in the following paragraphs.

Table 13-9. Significant Satellite and GRS Resource Needs

1.	COBALT:	533,000 lb REQUIRED. IMPORTS FROM PRIMARY SOURCE - ZAIRE - SUSCEPTIBLE TO INTERRUPTION.
2.	GALLIUM:	2,878,000 lb REQUIRED
3.	GOLD	3,750,000 lb REQUIRED
4.	KAPTON:	5,517,000 lb REQUIRED
5.	SAPPHIRE:	5,952,000 lb REQUIRED
6.	SILVER:	392,000 lb REQUIRED
7.	TEFLON:	2,017,000 lb REQUIRED
8.	TUNGSTEN:	11,730,000 lb REQUIRED

DISCUSSION

COBALT

Klystron magnets are assumed to be made of AlNico-V which consists of 24% cobalt. This translates into a cobalt requirement of 533,000 lb. Over 60% of world cobalt production comes from Zaire, principally from Shaba Province. Military conflicts in that region have significantly reduced cobalt production. In 1977, the U.S. imported 17.7 million lb of cobalt. Another 624,000 lb were reclaimed from recycled alloys. The government stockpiles contain approximately 40 million lb of cobalt. There has been no domestic mining of cobalt since 1970. If the price increased from the current $20 per lb to approximately $60 to $80 per lb, then it is expected that domestic production would be quite likely (in limited quantities). Inasmuch as cobalt is in short supply and the SPS would require approximately 3% of the total annual import or 1.33% of the stockpiled amount (if 40 million pounds still remain), cobalt availability should be monitored to track its possible impact on the SPS program.

GALLIUM

Approximately 2,878,000 lb of gallium are required by the SPS program. Gallium is obtained as a by-product of the processing of bauxite into alumina. Sufficient gallium is extracted to meet the demand. The current potential supply of gallium from domestically processed bauxite is over 2 million lb annually. By projecting the anticipated growth of the U.S. aluminum industry to the mid-1990's, the domestically processed bauxite would yield over 5 million lb of gallium annually. However, at present, it appears that the SPS gallium requirements will support program requirements and greater production/recovery is projected for the 1990 gallium production capacity.

GOLD

The 3,750,000 lb of gold required exceeds recent U.S. annual gold production. Approximately 45% of the gold produced in the U.S. is obtained as a by-product from other metal production, primarily copper. In 1977, approximately 75,000 lb of gold were produced domestically, at a value of $148 per troy ounce. With gold currently selling at about $240 per troy ounce, some increased production can be expected, but far short of the SPS requirements. The U.S. Treasury stockpile currently contains approximately 18.5 million lb of gold. Thus, the SPS requirement would constitute approximately 20% of our gold reserve. A substitute material will likely need to be developed to replace the gold requirements of the solar blanket.

KAPTON (POLYAMIDE)

The current U.S. production of polyamides is estimated to be between 4.0 and 5.0 million lb and expanding. In order to supply the 5,517,000 lb required by the SPS, the production capacity would need to be doubled or stockpiles built up. This could readily be accomplished given sufficient lead time.

SAPPHIRE

The aluminum oxide necessary to produce 5,952,000 lb of sapphire ribbon is readily available. The sapphire ribbon availability problem stems primarily from the technology requirements. The crystal growth is a relatively slow process. Considerable research is being performed to resolve the problems associated with sapphire ribbon production. Sapphire ribbon production associated with sapphire ribbon production. Sapphire ribbon production advances should be monitored so that sufficient production facilities will be available to meet the demand.

SILVER

In 1977, the U.S. production of silver amounted to 2,617,000 lb. The 392,000 lb of silver required by the SPS thus constitutes 15% of the annual U.S. production. Silver usage in the United States amounted to approximately 11.0 million lb in 1978. The U.S. government holds a reserve of silver in the strategic stockpile on the order of 8,800,000 lb. The SPS requirement constitutes only 4.5% of the stockpiled amount. Approximately 70% of the silver produced in the U.S. is a by-product or co-product of other metal production -- chiefly copper, lead, and zinc. The 40% increase in the value of silver during the past year will serve to stimulate additional production, both domestically and world-wide.

TEFLON

The SPS requirement for Teflon was established at 2,017,000 lb or 34% of the 6 million pounds estimated to have been produced in 1977. Productive capacity is readily expandable, given sufficient lead time.

TUNGSTEN

The 11,730,000 lb of tungsten required by the SPS constitutes approximately 14% of the annual world production, or 50% more than the total U.S. production of tungsten in 1974. The total annual U.S. consumption of tungsten is on the order of 15 million pounds. U.S. Government stockpiles contain about 110 million pounds of tungsten or 9.4 times the SPS requirement. Consequently, the tungsten requirement of the SPS could present a major problem. Use of alternative materials for the tungsten in the panel diodes should be investigated.

SUMMARY

The above analyses have been based on the construction of one SPS. A construction rate of two SPS per year, for even several years, could substantially compound the material resources availability problems described. A list of data sources used in this analysis are presented in Table 13-10.

Table 13-10. Key Data References

BATTELLE—PACIFIC NORTHWEST LABS DOCUMENTATION

MINERAL FACTS AND PROBLEMS, 1975 EDITION, U.S. DEPARTMENT OF INTERIOR

SURVEY OF AVAILABILITY AND ECONOMICAL EXTRACTABILITY OF GALLIUM FROM EARTH RESOURCES, ALUMINUM COMPANY OF AMERICA, 1 OCTOBER 1976

STATISTICAL ABSTRACT OF THE UNITED STATES 1976, U.S. DEPARTMENT OF COMMERCE

THE WORLD ALMANAC AND BOOK OF FACTS, 1979, GROSSET AND DUNLAP

STATISTICAL ABSTRACTS OF THE UNITED STATES - 1976

MINERAL FACTS AND PROBLEMS (1975), U.S. DEPARTMENT OF INTERIOR

UNITED STATES MINERAL RESOURCES, U.S. DEPARTMENT OF INTERIOR (1973)

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4.0 CONCLUSIONS/RECOMMENDATIONS

4.0 CONCLUSIONS/
RECOMMENDATIONS

4.0 CONCLUSIONS/RECOMMENDATIONS

This section presents summary comments on the methods and rationale followed in arriving at the results documented in this report. Suggestions are also provided in those areas where further analysis or evaluation will enhance SPS cost and programmatic definitions.

4.1 SPS COST ESTIMATES

√ The costing approach in this study considered an SPS option of 60 units with an IOC in the year 2000 and the full 300-GW capability to become operational at the rate of two SPS's or 10 GW per year.

√ Cost estimates developed in this report are the extended products of a Rockwell cost data base uniquely formed for the SPS program. Main elements are categorized into (1) satellite (using MSFC and Rockwell CER's), (2) space construction and assembly (Rockwell CER's with space station backup), (3) transportation (Space Shuttle, company-sponsored studies, Boeing cost data), and (4) the ground receiving station (a grass roots analysis). This same data base was expanded to incorporate cost and programmatic information from discussions with business and industry leaders. These discussions were supplemented by the use of selected literature and periodicals to obtain supporting data. Business/industry and literature sources are listed in Table 4.1-1.

√ The Rockwell cost model and computer program can be used to calculate the costs for differing options in conjunction with an appropriate technical definition, traffic model projection, and operations scenario.

√ A special factor was used when calculating the development cost of a system/subsystem and was based on the overall program scenario of that particular system. For example, crew and work support modules of the LEO, SCB, or satellite operations and maintenance base are of a common design, although required at differing times in accordance with the program schedule. Appropriately then, development factors were used to project costs at a 100-percent factor for the first module—whereas a lesser factor was used for subsequent requirements of the same modules to cover any revised development or integration need when being used in other applications. This represents a realistic programmatic approach to costing. Other areas should be studied for the use of this same logic.

√ TFU costs projected for an SPS operational capability of the ground and space segments include estimates for initial space transportation fleets, satellite construction, operations, and the ground receiving station plus electric utility grid interface and supporting facilities. As such, all cost estimates for the TFU include the full cost of systems, equipment, facilities, and machinery that may have a service life capable of building more than one SPS. Therefore, the TFU cost represents a level of investment that can be expected when building a single-unit SPS option.

Table 4.1-1. Business/Industry and Literature Sources

Organization	Purpose
American Bridge—A division of U.S. Steel	To develop steel requirements, costs, and operations definition for procurement and installation of rectenna support structure.
Riverside Cement—A division of American Cement Corporation; and C. S. Johnson Co.	Provide consultation on cement/concrete specification operational methods; processing/handling equipment.
Townsend & Bottum, Inc., (construction manager) 10-MW Solar Plant—Barstown, CA	Discuss site preparation, construction operations/sequencing, plus activation requirements.
Southern California Edison	To discuss dc/ac power distribution and conversion requirements and obtain cost estimates on installation of lines/towers.
Modern Alloys, Inc.; and Miller Formless Co.	To discuss use and application of equipment/crew for continuous concrete pour of rectenna support structure footing.
Caterpillar; International Harvester; and JETCO, Inc.	Obtain prices on earth moving, grading, and trenching equipment
Literature Sources	
The Richardson Rapid System 1978-1979 Edition	Construction labor and operations prices
Engineering News Record—1977, a weekly McGraw-Hill publication	Cement, aggregate and labor prices
National Construction Estimating Guide (NCE)	Construction operations

√ SPS investment (ICI) costs in this study represent the average of a 60-unit option covering the cost of production, assembly, installation, transportation, and testing needed to produce individual satellites, transportation systems, and ground receiving stations—including required support. SPS operations costs consist of the effort required to operate and maintain the SPS program (including replacement capital items) over its operational lifetime of 30 years.

√ Further study is required to identify and analyze SPS cost drivers. This should be an integrated process where technical and program development activities confirm and optimize SPS designs, or technical approaches, for cost-effective results.

√ Several ground receiving station issues require further design definition. These include rectenna lightning protection, support structure optimization, and the rectenna drainage approach. In addition, the space transportation (HLLV) concept needs further definition.

4.2 ROCKWELL COST MODEL

√ The Rockwell SPS cost model was expanded from its earlier version (Exhibit A/B) to (1) provide for newly added input requirements, (2) handle these new requirements when making cost calculations, and (3) provide a more versatile model. There are now six basic input categories: (1) line item name and units; (2) estimating relationships (CDCER, CICER); (3) design parameters such as CF, DF, and TF; (4) programmatic definitions (Z_1 to Z_5); (5) summing information; and (6) the addition of a "comments" section on each cost sheet to document unique technical or estimating characteristics of the line item. Although not required at this time, it is possible to expand the model with an input for use when calculating the complexity of development cost estimates (CFD) as compared with the complexity factor (CFI) as may be needed to calculate investment costs.

√ Changes to the cost model and computer program have simplified the approach when making inputs to the computer. Previously, fixed locations required careful input preparations on a line item by line item basis. This approach was revised to provide the computer with a simplified input procedure and table that will automatically accept and organize the input by WBS hierarchy. This change has resulted in a more flexible computer program and has significantly reduced the time previously required to organize and prepare input sheets.

√ The addition of a CTB (cost to build) capability in the cost model provides individual system/subsystem costs, with learning, over the total quantity to be produced under the option. This base figure is then used to calculate the average unit cost and the replacement capital cost per SPS if attrition prevails. An additional feature of the program categorizes the cost to construct a satellite option (Z_4) and that needed to support O&M requirements of a satellite option (Z_5) when making calculations affecting each area.

4.3 RESOURCES ANALYSIS

A review of materials required for the construction of the satellite system and ground receiving station identified areas for potential investigation of material availability. These requirements should be more closely analyzed in conjunction with the characteristics of design and potential system improvements. The solar blankets and RF devices are typical examples of resource sensitive items.

4.4 SPS PROGRAMMATICS

Ground-based experimental research and technology advancement programs require further definition as they relate to the Rockwell SPS reference configuration. An overall view of critical technology items should result in a technical definition, interface requirements, expected results, and an integrated schedule/network of the steps required for ultimate resolution. These "planning packages" of data should incorporate NASA decision points and coincide with NASA budget inputs.