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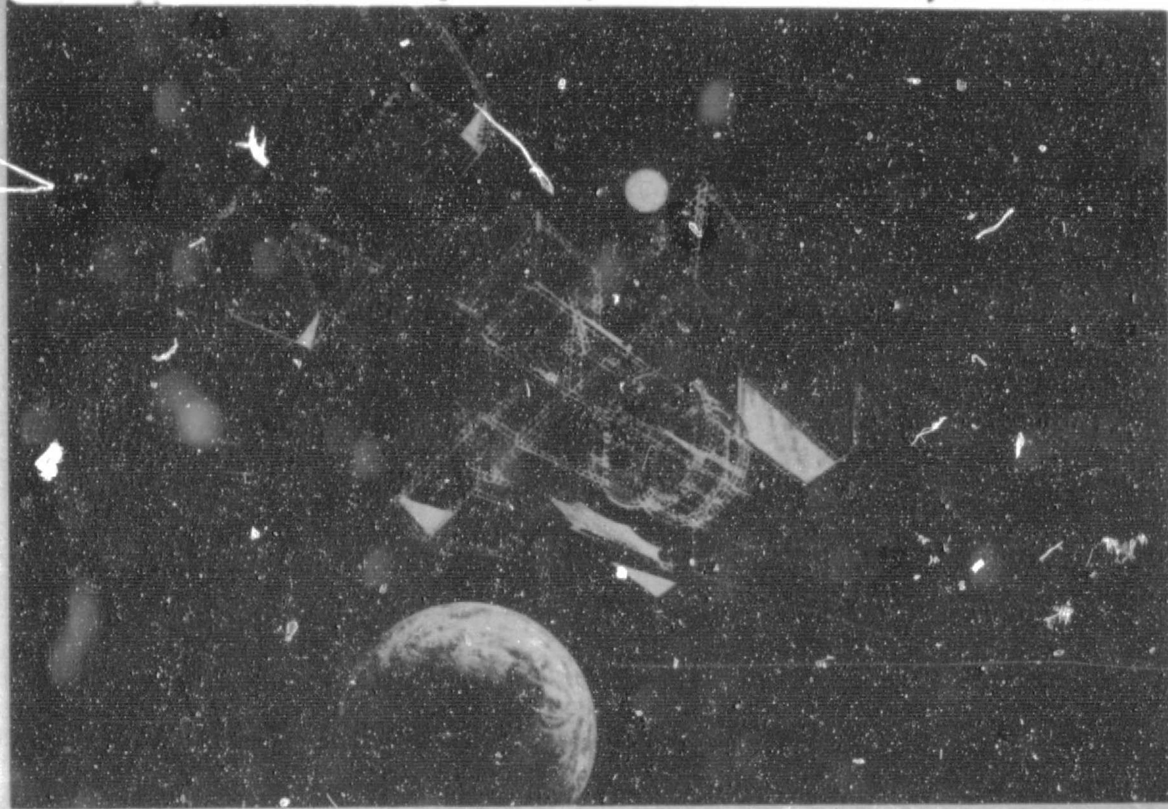

Satellite Power Systems (SPS) Concept Definition Study

FINAL REPORT

VOLUME VII

SPS PROGRAM PLAN AND ECONOMIC ANALYSIS

Rockwell International
Space Division
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Downey, California 90241

SD 78-AP-0023-7

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FINAL REPORT
VOLUME VII

SPS PROGRAM PLAN AND ECONOMIC ANALYSIS

CONTRACT NAS8-32475
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FOREWORD

This document, *SPS Program Plan and Economic Analysis*, is Volume VII of the SPS Concept Definition Study (Contract NAS8-32475), Exhibits A and B, and also incorporates results of NASA/MSFC in-house effort. The three appendixes to Volume VII are bound separately:

Appendix A - Satellite Power System Work Breakdown Structure Dictionary

Appendix B - SPS Cost Estimating Relationships

Appendix C - Financial and Operational Concept

Other volumes of the final report that provide additional detail are listed below.

Volume	
I	Executive Summary
II	SPS System Requirements
III	SPS Concept Evolution
IV	SPS Point Design Definition
V	Transportation and Operations Analysis
VI	SPS Technology Requirements and Verification

ACKNOWLEDGMENTS

The treatment of Satellite Power Systems economic and program planning definitions in this report represent the results of many hours of work by a number of professionals in each of the required areas. They have applied their individual skills in the analysis, evaluation, and documentation of results and conclusions as related to the particular economic or programmatic task. Therefore some acknowledgment is required.

Substantial support was received from each member of the SPS programs team and their management. This furthered the objective of providing sound economic and programmatic conclusions as presented in this volume and its appendix. The Rockwell, Space Division SPS Program Development team that contributed significantly to the completion of this work is listed as follows:

Dr. L. R. Blue	Cost/Risk Programming
W. Cooper	Cost Analysis
Dr. I. E. Cornelius	SPS Economics
D. E. Lundin	SPS Schedules/Networks
J. L. Saltz	Taxes and Insurance
K. E. Smith	Program Plans

SPS economics and program planning/analysis tasks were completed under the supervision of F. W. Von Flue, SPS Program Development.

The help and support of representatives from NASA/MSFC and the SPS Program Planning Office is acknowledged as follows:

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 PROGRAM PLAN AND ECONOMIC ANALYSIS

1.1 INTRODUCTION

The demands for energy in the United States are projected to increase dramatically as we approach the year 2000. As a consequence we can expect greater demand, with increased cost as a result of limitations in the supply of global energy resources. It is therefore important that alternate sources be identified to obtain the needed energy. In this regard, the possibility of generating large quantities of electrical power in space and transmitting it to earth offers just such an opportunity. However, economic and technological requirements of such a program need to be established with confidence. This volume considers the economic and programmatic requirements for a recommended SPS solar photovoltaic baseline concept that was established as a result of work performed by the Rockwell International Space Division under NASA/MSFC contracts.[1] The recommended SPS baseline concept is illustrated in Figure 1.1-1.

1.2 ECONOMIC AND PROGRAM PLANNING PARAMETERS

1.2.1 SPS WORK BREAKDOWN STRUCTURE

SPS economic and programmatic requirements and results presented in this volume were developed in response to the NASA/MSFC Contract NAS8-32475. The purpose of this document is to present the results of cost analyses, economic determinations, and programmatic planning tailored to the magnitude, complexity, design/producibility, and operational lifetime requirements for this type of program. In order to promote equitable, complete, and understandable comparisons of SPS concepts and to maintain compatible economic and programmatic references, the contract SPS Work Breakdown Structure (WBS) Dictionary[2] was used as the initial baseline for the definition and organization of program elements. This structure subdivided the program into its lowest elements and associated these definitions with special accounts within phases unique to the program. Accounts and phases were designated for the DDT&E; Initial Capital Investment (covers initial procurement and emplacement of each SPS plant and equipment); Replacement Capital Investment (capital asset replacement over the SPS operating life); Operations and Maintenance (expendables, minor maintenance, repair crews); and Taxes/Insurance. As this structural interrelationship

[1] *Satellite Power Systems (SPS) Concept Definition Study* (NAS8-32475), March, 1977; and *Satellite Power System (SPS) Feasibility Study* (NAS8-32161), August, 1976.

[2] *Satellite Power System Work Breakdown Structure Dictionary*, Engineering Cost Group (PP03), Marshall Space Flight Center, IN-PP03-76-1 (November, 1976).

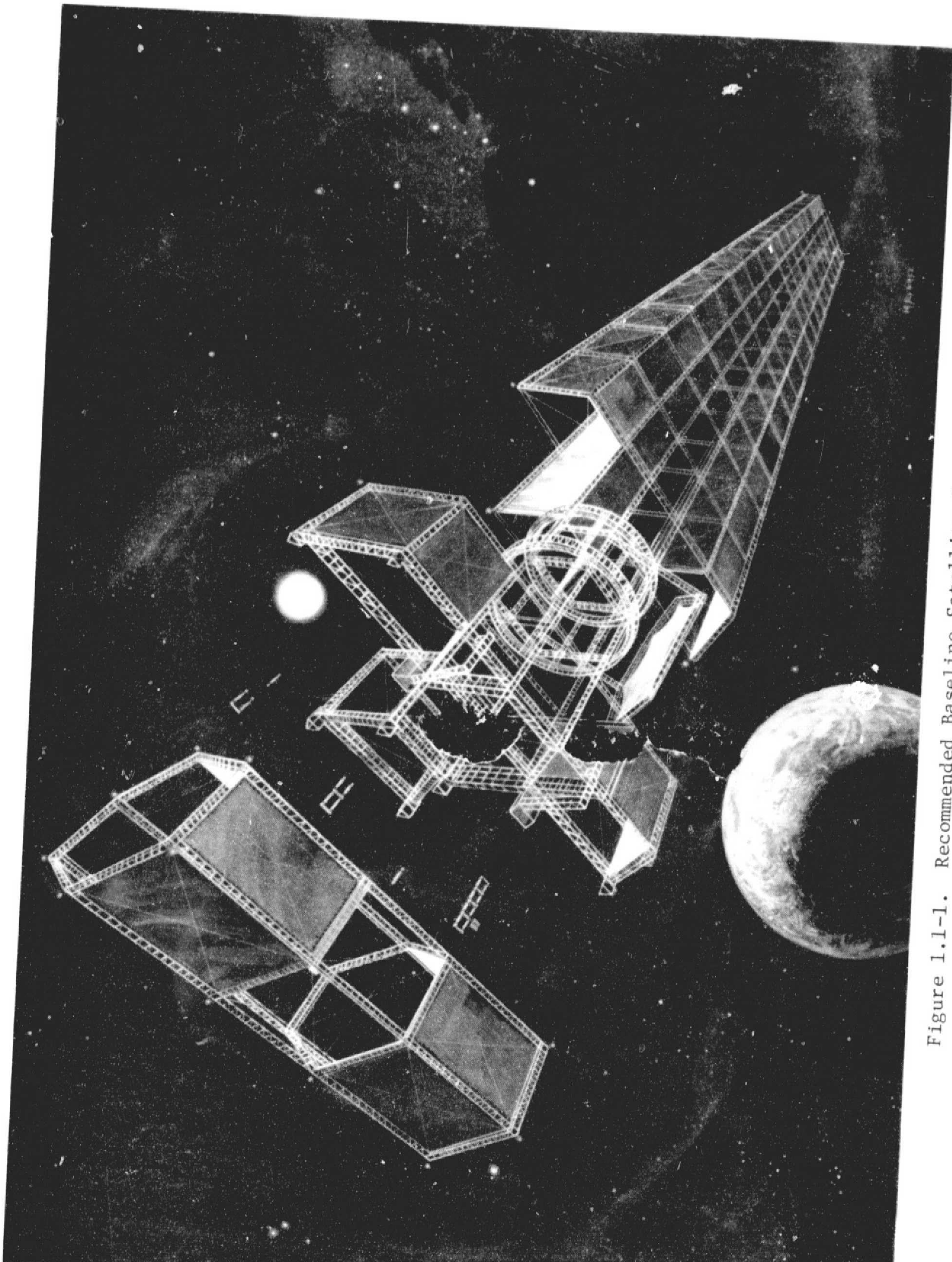

Figure 1.1-1. Recommended Baseline Satellite Concept

provided the capability to view and analyze the SPS from a number of different programmatic, economic, and management aspects- it was carefully maintained and updated as a programmatic baseline throughout the study.

In addressing overall costs, economics, and programmatics of the SPS program, a series of tasks were concerned with relationships between total concepts, systems, and elements of the SPS program. The framework for developing the cost work, technical plans, and development schedules was consistent with the maintained SPS WBS and dictionary. The results of current system baselines are documented in the SPS Solar Photovoltaic unique WBS. The WBS was tailored to the requirements of the Rockwell GaAlAs concept with a concentration ratio (CR) of 2. Figure 1.2-1 displays this structure where each of the elements is described in the WBS Dictionary of Appendix A.

1.2.2 GUIDELINES AND ASSUMPTIONS

During the contract, a series of SPS guidelines and ground rules were maintained for the uniform development of SPS technical and economic results. They are identified in the following statements:

- The SPS initial operational capability is planned for 1998.
- A 5-GW rectenna power output is assumed for the Electric Utility.
- The SPS end-of-life power generation capability is established at 5 GW.
- A program buildup scenario of three options (120 - 5GW, 67 - 5GW, and 28 - 5GW) is assumed; this report contains economic and programmatic results of a 120 - 5GW station program.
- All operational costs will be recovered from operational revenues.
- The DDT&E unit becomes the first satellite of the commercialization phase.
- DDT&E costs will be amortized over the investment phase of the SPS program.
- A 1985 technology base and resource demand/supply conditions will apply in cost calculations.
- A 90-percent payload weight packing factor is used for space transportation.
- An operational plant load factor of 85 percent is used in calculating generation costs.
- The cost estimate is in constant mid-1977 prices (7.5% discount rate).
- The estimate includes the cost of a 30-percent satellite weight contingency.

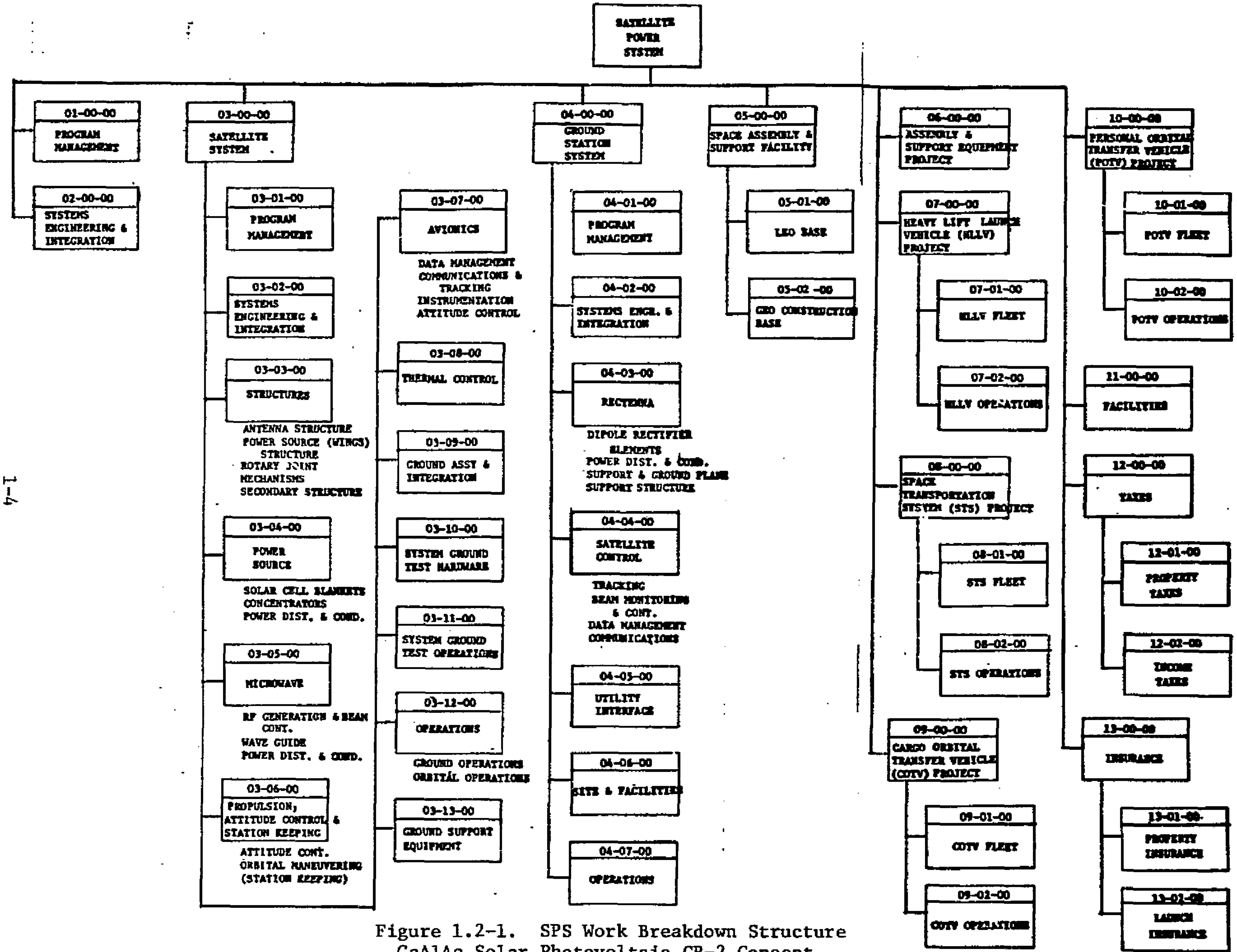

Figure 1.2-1. SPS Work Breakdown Structure
GaAlAs Solar Photovoltaic CR-2 Concept

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- Advanced transportation systems
  - Shuttle available in 1981
  - IUS available in 1981
  - SEPS available in 1983
  - Personnel OTV available in 1986

1.3 STUDY TEAM AND INTERFACES

The Rockwell Space Division SPS Program Development team assigned to the completion of tasks was an integral part of the SPS program structure, they were located within the same area, and conducted regular exchanges with other members of the staff. In addition to the constant interface with MSFC and continuing literature searches, a number of contacts were maintained with organizations such as the following:

- Jet Propulsion Laboratories (JPL) on SPS related documentation for comparative analysis.
- Electric Power Research Institute (EPRI) to discuss aspects of SPS/utility interface.
- E.I. DuPont regarding costing information on the satellite concentrators (reflectors).
- Southern California Edison (SCE) to discuss SPS financial and operational concepts on several occasions where organizational approaches were reviewed on the formation of consortia for the funding of the SPS ground station segment.

1.4 MAJOR TASK ACTIVITY—PROGRAM PLAN

The results documented in this volume evolved through completion of two major tasks—Program Analysis and Planning, and SPS Cost Analysis. The objectives achieved in the area of program planning were to (1) formulate preliminary SPS program planning, (2) develop project schedules/networks, and (3) to address critical items and sensitivities that would be compatible with SPS key issues as defined in Task 1.0 of the study. These planning data were supported by requirements/alternatives analyses and trades that culminated in the results and conclusions of Section 2.0 to this volume. The logic flow diagram of Figure 1.4-1 identifies this work activity and illustrates typical processes, with input and output identification, as followed to arrive at: (1) schedule sequencing of the SPS program integrating DDT&E, Investment, and Operational phases; (2) technology plan and supporting schedule assessments; and (3) DDT&E program plan definition during the Phase C/D period. It should be noted that programmatic analyses/trades were conducted on several SPS concepts during the first part of the contract and subsequently focused on the recommended Solar Photovoltaic concept as the study continued. This report concentrates on that concept.

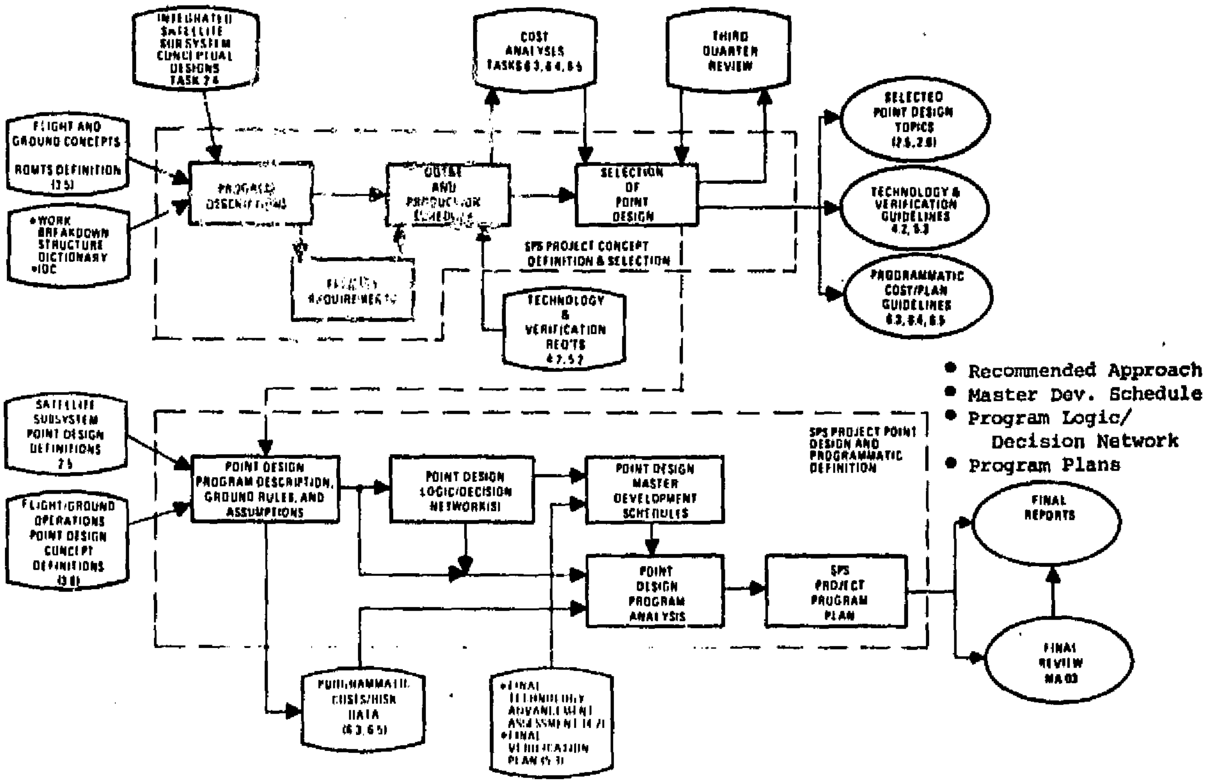

Figure 1.4-1. Program Planning and Analysis

Individual program planning requirements have been identified in 15 areas of the Phase C/D SPS activity of the DDT&E effort and addressed the following main areas:

- Program Management
- Systems Engineering and Integration
- Design and Development
- Systems Testing
- Ground Support
- Manufacturing
- Product Assurance
- Facilities
- Ground and Space Operations
- Launch Operations
- Natural Resource Availability

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1.5 MAJOR TASK ACTIVITY—ECONOMIC ANALYSIS

SPS cost and economic analyses were performed within five subtasks as illustrated in Figure 1.5-1. The objectives of these tasks were to establish cost baselines, conduct cost comparisons/trades, analyze and evaluate SPS economics, and prepare risk assessments. Study guidelines and ground rules were expanded as the study proceeded. These definitions were consistent with the SPS WBS and CER data base in support of cost trades and sensitivity analyses that aided in the selection of alternate subsystems, operations, technology, and verification options. Total program cost analyses focused on the candidate concepts that evolved into baseline concept definitions of DDT&E, production, launch, orbital construction, and operations/maintenance cost estimates (reference Tasks 6.2 and 6.3).

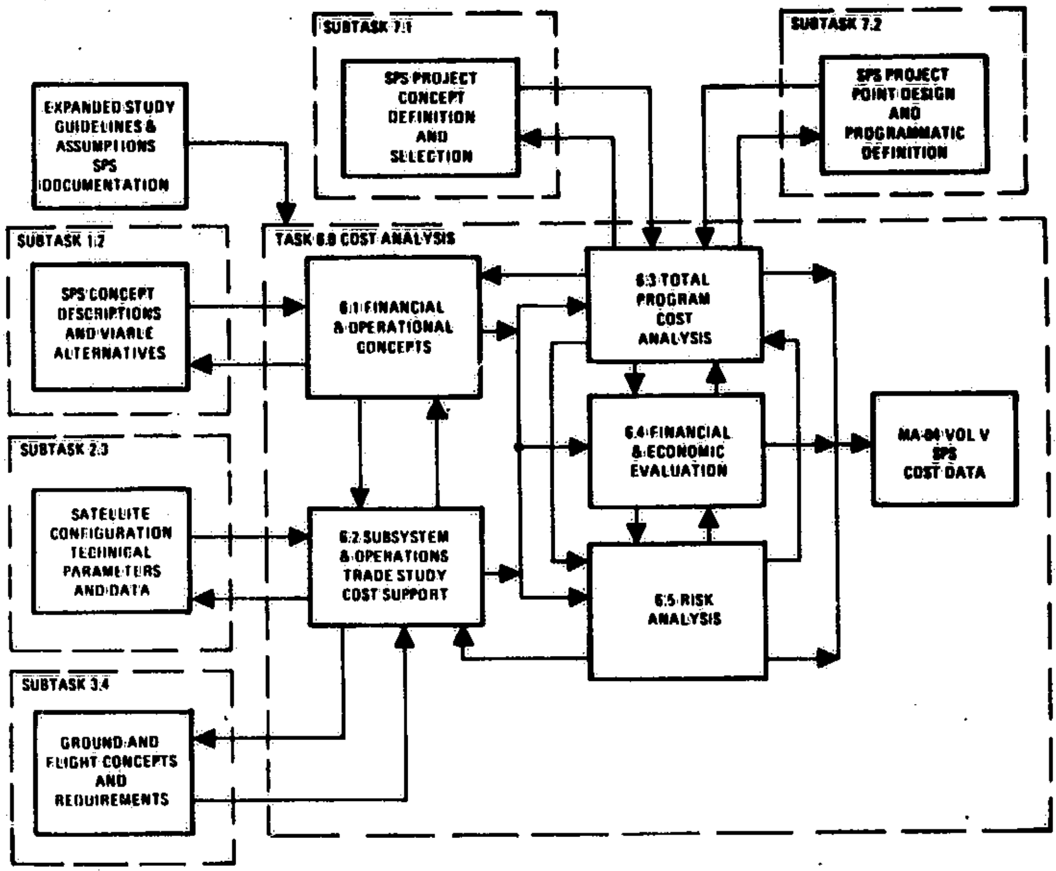

Figure 1.5-1. Economic/Cost and Risk Analysis Approach

Financial and economic determinations initially addressed four basic concepts of how the SPS shall be funded and on how an organizational structure might evolve to manage this program and to provide funding. Further analyses resulted in a single recommended concept that treated the SPS program as being comprised of a space segment and a ground segment. The work in this area was completed under Tasks 6.1 and 6.4, and included an analysis of taxes and insurance considerations.

In support of this total task activity, the Rockwell Risk Analysis Computer Program (RAP-1) was used extensively to obtain cost, risk, and economic data in support of the various concepts.

2.0 SPS PROGRAM PLAN

2.1 INTRODUCTION

This section of the report documents program planning analyses that resulted in the formulation of preliminary program planning requirements, schedules/networks, and the identification of critical items and sensitivities associated with SPS subsystems and elements. Results of this activity are consistent with technical and programmatic definitions applicable to the Rockwell Solar Photovoltaic CR-2 Concept and the supporting SPS work breakdown structure (WBS). As a main objective, major impacts were identified to the Phase C/D (design, development, and operational) activities leading to the completion of one DDT&E satellite power system with an IOC of 1998.

Most of the key technological issues (as described and planned in Volume VI) 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. 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 (Figure 2.1-1). As a secondary objective, planning areas requiring substantial effort in the immediate future were identified. This effort concentrated on the definition of specific problems, the solution of which might require the longest lead times for accomplishment or implementation.

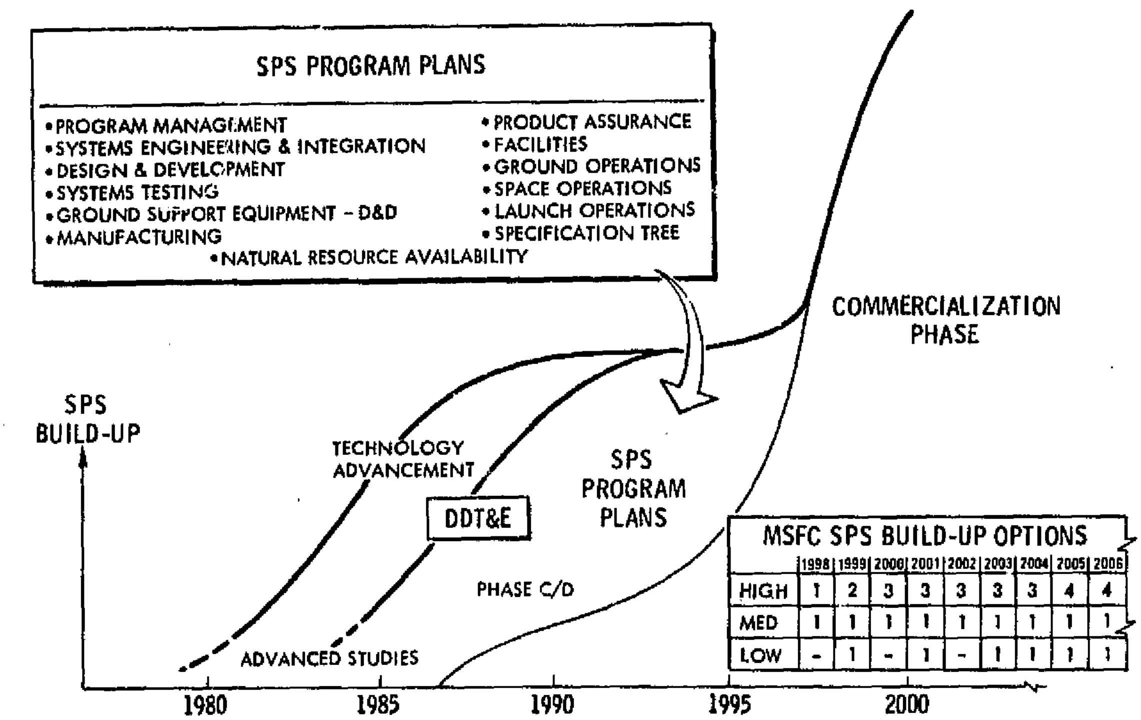

Figure 2.1-1. SPS Program Plans

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 (Figure 2.1-2), would result in a corresponding delay in the availability of an operational system to serve as a significant national power resource.

2.2 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 60 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 2.2-1 identifies the principal areas of intercept as a result of evaluating each plan of the working level matrix in conjunction with the SPS solar photovoltaic point design data. A total of 133 intercepts were established in three categories—A, B, and C. There were 39 Category A intercepts indicating the potential need of major resources, technology advancement, or support system requirements. Thirty-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 distributions 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 category. 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.

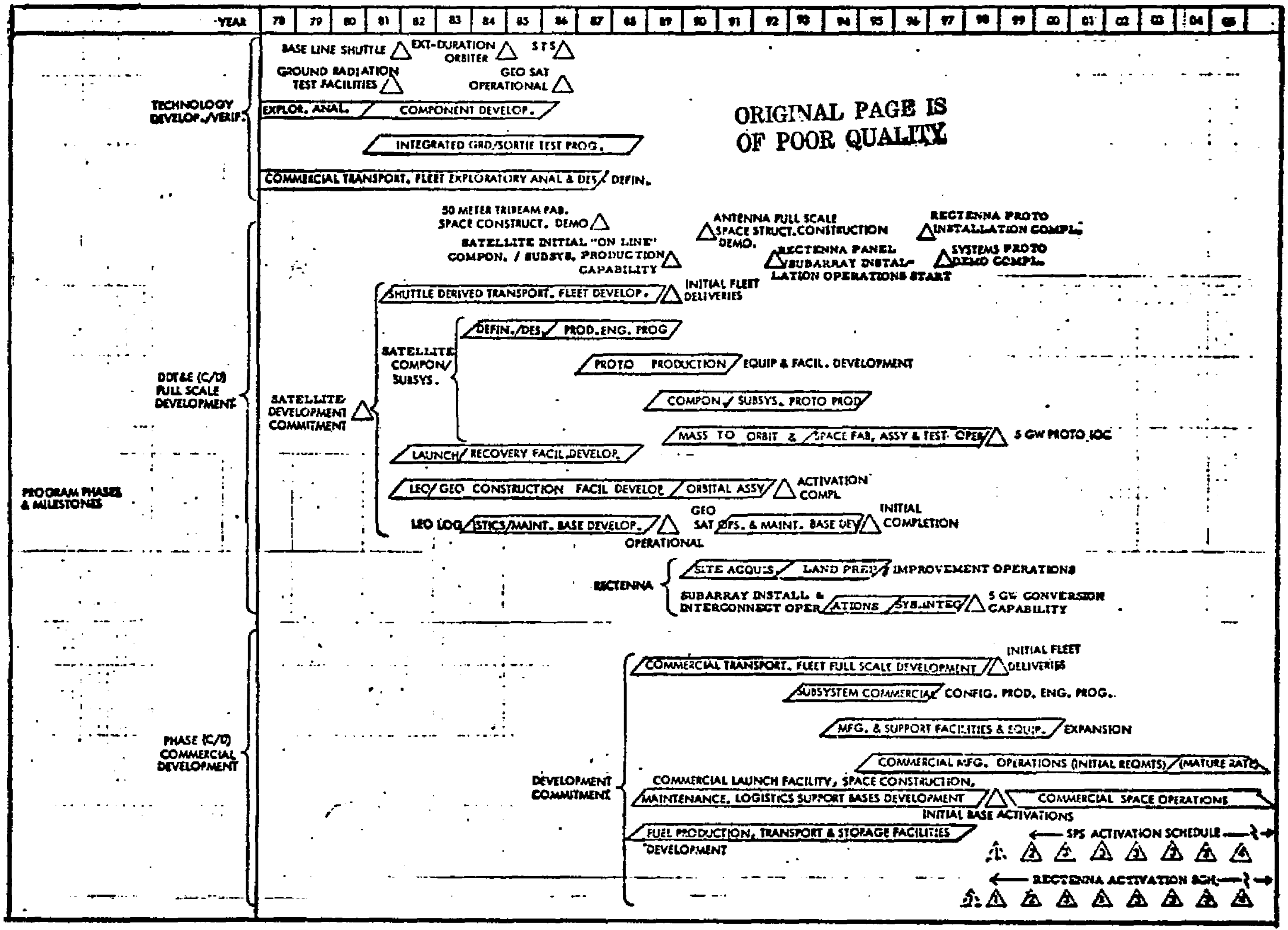

Figure 2.1-2. SPS Summary Program Phases and Milestones

Table 2.2-1. 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
01-00-00	Program Management	C	C	C	A	C	C	B	A	C	C	B	A	B	C	C
02-00-00	SE&I	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
03-00-00	Satellite System	A	C	A	A	–	B	C	–	–	–	–	A	–	–	–
03-01-00	Program Management	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
03-02-00	SE&I	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
03-03-00	Structure	–	–	B	–	–	–	–	–	–	–	–	–	–	–	–
03-03-01	Antenna Structure	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
03-03-02	Power Source Structure	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
03-03-03	Rotary Joint	–	–	B	B	–	–	–	–	–	–	–	–	–	–	–
03-03-04	Mechanisms	–	–	B	B	–	–	–	–	–	–	–	–	–	–	–
03-03-06	Secondary Structure	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
03-04-00	Power Source	–	–	A	–	–	–	C	–	–	–	–	–	–	–	–
03-04-01	Solar Blankets	–	–	A	A	B	A	C	A	–	C	C	–	–	–	C
03-04-02	Concentrators	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
03-04-03	Power Distribution & Conditioning	–	–	–	A	–	A	–	A	–	–	C	–	–	–	–
03-05-00	Microwave	–	–	A	–	–	B	C	–	–	–	–	–	–	–	–
03-05-01	RF Generator & Beam Control	–	–	–	B	–	B	A	B	–	–	–	–	–	–	–

Table 2.2-1. SPS Program Plans/DDT&E Relationship Matrix (Cont.)

SOLAR PHOTOVOLTAIC, CR–2 CONCEPT:

CAT. A – MAJOR RESOURCES, TECHNOLOGY ADV OR SUPPORT SYS PROGRAM REQD
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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
03-05-02	Waveguides	–	–	–	–	–	B	B	–	–	–	–	–	–	–	–
03-05-03	Power Distribution & Conditioning	–	–	–	B	–	B	–	B	–	–	–	–	–	–	–
03-06-00	Propulsion	–	–	–	–	–	–	C	–	–	–	–	–	–	–	–
03-06-01	Attitude Control	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
03-06-02	Orbital Maneuvering	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
03-07-00	Avionics	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
03-07-01	Data Management	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
03-07-02	Communications & Tracking	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
03-07-03	Instrumentation	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
03-07-04	Attitude Control	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
03-08-00	Thermal Control	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
03-09-00	Ground Assembly & Integration	–	–	–	–	–	–	–	–	C	–	–	–	–	–	–
03-10-00	System Ground Test Hardware	–	–	–	–	–	B	–	–	–	–	–	–	–	–	–
03-11-00	System Ground Test Operations	–	–	B	B	–	–	–	–	–	–	–	–	–	–	–
03-12-00	Operations	C	–	–	–	–	–	–	–	–	–	–	–	–	–	–
03-12-01	Ground	–	–	B	–	–	–	–	–	–	–	B	–	A	–	–
03-12-02	Orbital	–	–	A	–	–	–	–	–	–	–	–	A	–	–	–

Table 2.2-1. 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

WBS NO.	WBS TITLE	SPS PROGRAM PLAN 1 PROGRAM MANAGEMENT	2 SYSTEMS ENGRG & INTEGRATION	3 DESIGN AND DEVELOPMENT	4 SYS. TESTING	5 GSE DESIGN & DEVELOPMENT	6 MANUFACTURING	7 PRODUCT ASSURANCE	8 FACILITIES	9 GND OPS: GROUND INTEG	9 GND OPS: MAINTENANCE & REFURBISHMENT	9 GND OPS: LOGISTICS	10 SPACE OPS	11 LAUNCH OPS	12 SPECIFICATION TREE	13 RESOURCE AVAIL. ANALYSIS
03-13-00	GSE	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
04-00-00	Ground Station System	A	C	–	–	–	–	–	A	–	–	–	–	–	–	–
04-01-00	Program Management	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
04-02-00	SE&I	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
04-03-00	Rectenna	–	–	C	B	C	–	C	A	–	–	–	–	–	–	C
04-03-01	Dipole/Rectifier Elements	–	–	B	–	–	A	–	–	–	–	–	–	–	–	C
04-03-02	Power Distribution & Conditioning	–	–	B	–	–	B	–	–	–	–	–	–	–	–	–
04-03-03	Support & Ground Plane Structure	–	–	–	–	–	C	–	–	–	–	–	–	–	–	–
04-04-00	Satellite Control	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
04-04-01	Tracking	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
04-04-02	Beam Monitoring	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
04-04-03	Data Management	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
04-04-04	Communications	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
04-05-00	Utility Interface	–	–	A	B	–	–	–	–	–	–	–	–	–	–	–
04-06-00	Site and Facilities	–	–	–	–	–	–	–	A	–	–	–	–	–	–	–
04-07-00	Operations	–	–	–	–	–	–	–	–	–	B	B	–	–	–	–
05-00-00	Space Station	A	C	C	C	–	C	–	–	–	–	–	C	–	–	–

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Table 2.2-1. SPS Program Plans/DDT&E Relationship Matrix (Cont.)

SOLAR PHOTOVOLTAIC, CR–2 CONCEPT:		SPS PROGRAM PLAN														
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		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
05-01-00	Space Construction Base	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
05-02-00	GEO Space Station	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
06-00-00	Assembly and Support Equipment	A	C	A	–	–	A	–	–	–	–	–	–	–	–	–
07-00-00	Heavy Lift Launch Vehicle	A	C	B	C	C	C	–	–	–	–	–	–	–	–	–
07-01-00	Fleet	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
07-02-00	Operations	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
08-00-00	Space Transportation System	A	C	B	C	–	C	–	C	–	C	C	C	C	–	–
08-01-00	Fleet	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
08-02-00	Operations	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
09-00-00	Cargo Orbital Transfer Vehicle	A	C	B	C	C	C	–	–	–	–	–	C	–	–	–
09-01-00	Fleet	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
09-02-00	Operations	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
10-00-00	Personnel Orbital Transfer Vehicle	A	C	B	C	C	C	–	–	–	–	–	C	–	–	–
10-01-00	Fleet	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
10-02-00	Operations	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
11-00-00	Facilities	A	C	C	A	–	A	–	A	–	–	–	–	A	–	C
12-00-00	Taxes	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–

Table 2.2-1. 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

WBS NO.	WBS TITLE	SPS PROGRAM PLAN: 1 PROGRAM MANAGEMENT	2 SYSTEMS ENGRG & INTEGRATION	3 DESIGN AND DEVELOPMENT	4 SYS. TESTING	5 GSE DESIGN & DEVELOPMENT	6 MANUFACTURING	7 PRODUCT ASSURANCE	8 FACILITIES	9 GND OPS: GROUND INTEG	9 GND OPS: MAINTENANCE & REFURBISHMENT	9 GND OPS: LOGISTICS	10 SPACE OPS	11 LAUNCH OPS	12 SPECIFICATION TREE	13 RESOURCE AVAIL. ANALYSIS
12-01-00	Property	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
12-02-00	Income	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
13-00-00	Insurance	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
13-01-00	Property	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
13-02-00	Launch (Losses)	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–

- *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.

The next step, as shown in Figure 2.2-1, 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 (5) 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.

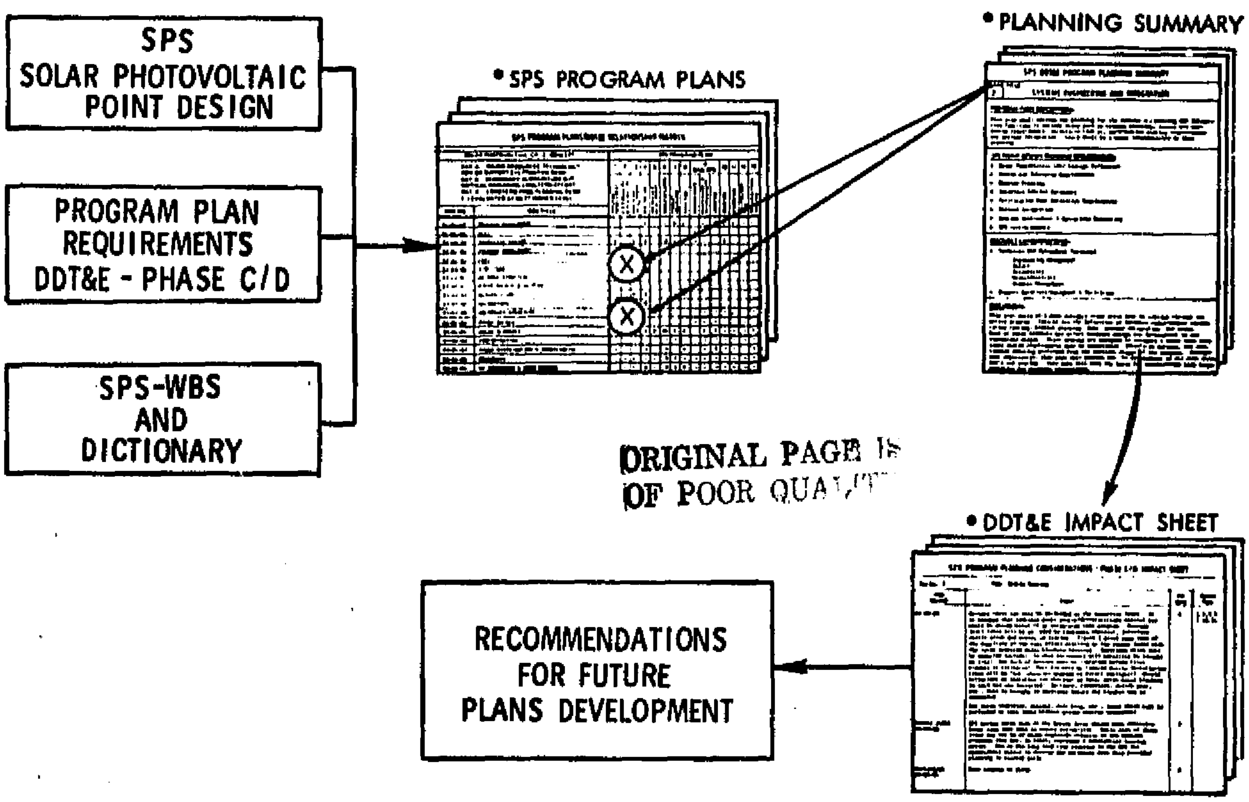

Figure 2.2-1. Program Plans Development Logic

2.3 RECOMMENDATIONS—PROGRAM PLANS

Current effort on program plans is aimed at identifying problem areas. Because of the magnitude of the SPS prototype effort and the long lead times involved, more detailed program plans are suggested to address the period of Phase C/D projects as they become identified. Plans that deserve early development are presented as follows:

- *Design and Development (Plan 3)* - This plan is particularly important in the development of critical components such as the solar blankets and the large quantity of high-voltage electrical and electronic equipment. It would also include the development of assembly and support equipment such as beam machines for space operations.
- *Manufacturing (Plan 6)* - Techniques, procedures, tooling, plant layout, work flow for production and checkout of photovoltaic cells, lightweight blankets, and rectenna modules.
- *Space Operations (Plan 10)* - Provides complete mission profile for prototype satellite assembly. Strengthens requirements for supporting programs (Shuttle-derived STS, HLLV, OTV, etc.).
- *Facilities (Plan 8)* - Location, size, support, community facilities, access, etc., to meet the manufacturing checkout and warehousing. also needed are plans for system ground test facilities. It may be important to plan major ground test facilities needed during the latter technology phase to coincide with sites suitable for expansion to Phase C/D facilities.
- *Specification Tree (Plan 12)* - Include as part of Systems Engineering and Integration, Plan 2.

As definition continues, another program plan consideration for the SPS is that covering computer software requirements. Typical areas of coverage would include manufacturing/test, launch and satellite operations, space operations, and supporting activities.

2.4 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 discussion to provide the applicable level of assessment based on the SPS concept definition at this time.

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

1. Program Management
   - SPS schedules were developed over the entire program through 2028, with emphasis on the 1979-1987 period. These schedules are developed to incorporate NASA, MSFC and DOE programmatic milestones applying to the DDT&E phase. On this basis, a series of SPS schedules showing design, development, technology production, operations, and commercialization phasing were developed and have been included in Plan 1 (Program Management).
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

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 1978-1987 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 POINT DESIGN PROGRAM REQUIREMENTS:

- Solar Photovoltaic CR-2 Concept Definition
- 30-Year Design Life with Maintenance
- 5-GW Constant Busbar Output at End of Life
- Satellite-DDT&E Configuration
- SPS Phase C/D DDT&E Program Coverage
- 1998 IOC for DDT&E SPS Operation
- State-of-the-Art Technology, 1986
- Technology Verification Period, 1978-1987
- Planning in Accordance with SPS Work Breakdown Structure
- 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

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SPS DDT&E PROGRAM PLANNING SUMMARY

PLAN	TITLE
1	PROGRAM MANAGEMENT

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
- Ground Station
- Space Assembly and Support Facility
- Heavy Life Launch Vehicle
- Space Transportation System
- Orbital Transfer Vehicles

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; such 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 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 listing of SPS 1978-2005 control milestones is represented in Table 1-1, and incorporates planning data from MSFC, NASA, and DOE sources

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

Table 1-1. SPS Program Milestones

MILESTONE DESCRIPTION	DATE	PHASES OF SPS WBS
SPS RECOMMENDED BASELINE CONCEPT DECISION	1978	ADVANCED STUDIES
CRITICAL COMPONENT/SUBSYST POINT DESIGN ANALYSIS COMPLETE	1980	ADVANCED STUDIES
PROTO SATELLITE FULL-SCALE DEVELOPMENT DECISION (LONG LEAD TRANSPORTATION & SUPPORT FACILITIES DEVELOPMENT)	END OF 1980	DESIGN, DEVELOPMENT, TEST, AND EVALUATION
INTEGRATED GROUND/SORTIE TEST PROGRAM START	1981	ADVANCED STUDIES
GRD RADIATION TEST FACILITY PROJECT COMPLETE	1981	ADVANCED STUDIES
SORTIE BASELINE SHUTTLE AVAILABLE	1982	ADVANCED STUDIES
FULL-SCALE FACILITIES & SUPPORT EQUIP DEVELOPMENT START	1982	DDT&E
25 KW POWER MODULE AVAILABLE	1983	ADVANCED STUDIES
ASSY SIMULATION FACILITY & EQUIPMENT PROJECT COMPLETE	1984	ADVANCED STUDIES
EXTENDED DURATION ORBITER AVAILABLE	1984	ADV. STUDIES/DDT&E
BEAM MAPPER/PILOT BEAM TRANSMITTER (GEOSAT) EXPERIMENTAL SATELLITE PROJECT OPERATIONAL	1986	ADVANCED STUDIES
MATERIAL/COMPONENT PILOT PRODUCTION FACILITIZATION AND EQUIPMENT DEVELOPMENT DECISION	1985	DDT&E
PROTO-AUTOMATED CONSTRUCTION EQUIPMENT PRELIMINARY DESIGN AND DEVELOPMENT COMPLETE	1985	DDT&E
GROUND/SORTIE COMPONENT AND SUBSYSTEM PERFORMANCE TEST AND EVALUATION PROGRAM COMPLETE	1987	ADVANCED STUDIES
COMMERCIAL PHASE FACILITIZATION DEVELOPMENT DECISION	END OF 1987	INVESTMENT
LOW-COST FWTO COMMERCIAL HLLV TRANSP SYST DEV DECISION	1988	INVESTMENT
SHUTTLE-DERIVED HLLV DEV COMPL & INIT OF FLEET UNIT AVAIL	1989	DDT&E
INITIAL SHUTTLE-DERIVED PERSONNEL CARRIER AVAILABLE	1989	DDT&E
ORBITAL FULL-SCALE STRUCTURAL ANTENNA FABRICATION AND ASSEMBLY DEMONSTRATION COMPLETE	1991	DDT&E
PROTOTYPE PRODUCTION (COMPONENTS/SUBSYST) OPERATIONS START	1990	DDT&E
LEO LOGISTICS & MAINTENANCE SUPPORT BASE OPERATIONAL	1989	DDT&E
LEO/GEO SPACE CONSTRUCTION FACILITY OPERATIONAL	1992	DDT&E
RECTENNA LAND IMPROVEMENT OPERATIONS START	1993	DDT&E
START LEO PRIMARY STRUCTURE FAB & ASSY OPERATIONS	1992	DDT&E
GW BUILDUP PLAN (RATE & TOTAL CAPACITY) DETERMINATION	1992	INVESTMENT
MATERIAL/COMPONENT COMMERCIAL PHASE PRODUCTION SUPPORT FACILITIZATION DECISION	1993	INVESTMENT
RECTENNA PANEL INSTALLATION OPERATIONS START	1994	DDT&E
LEO PROTO ORBITAL CONSTRUCTION OPERATIONS COMPLETE	1995	DDT&E
RECTENNA PROTO FAC EQUIP INSTALL & INTEG COMPL	1996	DDT&E
PROTO SATELLITE (1-GW CAP) GEO ASSY & INTEG COMPL	1996	DDT&E
PROTO SPS (1-GW CAP) OPERATIONAL DEMO COMPL	1997	DDT&E
COMMERCIAL IMPLEMENTATION PHASE	MID/END 1998	INVESTMENT
SATELLITE/RECTENNA 5-GW EXPANSION COMPLETE (IOC)	1998	DDT&E
15-GW/YR BUILDUP PLATEAU CAPABILITY (HIGH CASE)	2000	INVESTMENT
20-GW/YR BUILDUP PLATEAU CAPABILITY (HIGH CASE)	2005	INVESTMENT

SPS DDT&E PROGRAM PLANNING SUMMARY

PLAN	TITLE
1	PROGRAM MANAGEMENT

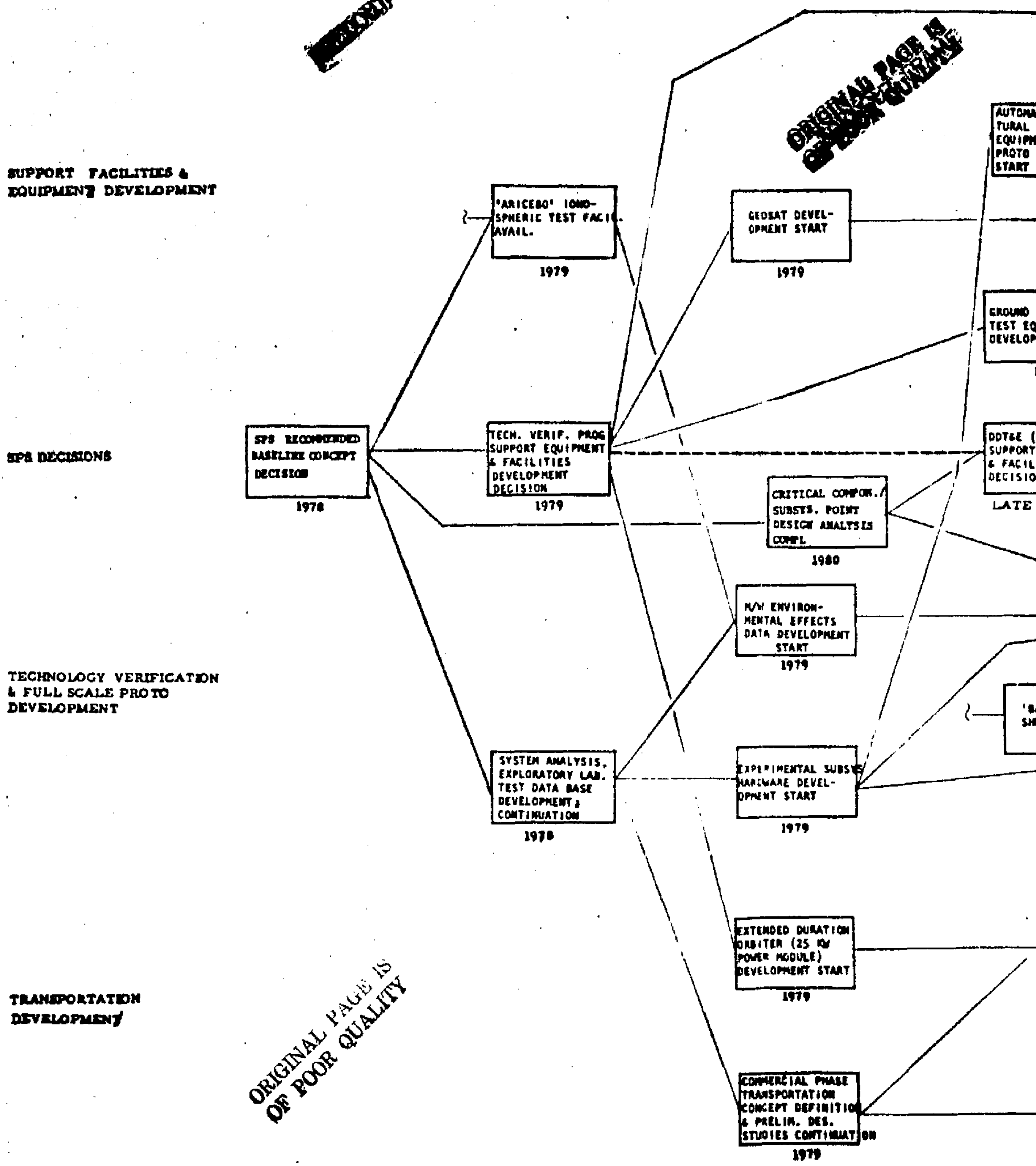
schedules/networks at all levels of the multi-faceted WBS. To provide an overall control of the scheduling activity, control milestones were established and maintained in a logic network of integrated program activities, as shown in Figure 1-1.

The network divides the program milestones into four major sub-categories which include technology verification and full-scale proto development, support facilities and equipment development, support transportation development, major programmatic development, and continuation decision points. These milestones logically support succeeding events in their own sub-categories and, in certain cases, logically support and impact succeeding milestone events in other sub-categories.

The central catalyst for development of the satellite power systems 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 development 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 the major satellite system development objectives.

To initiate and sustain these separate developmental subprograms, the decision milestone sequence was developed. Timely promulgation of these decisions will undoubtedly exercise overriding impact on the overall program progress. Further, justification for each of these decisions—for the most part—will be predicated on 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 manufacturing technology development for proto production of the GaAs solar cell blanket will be based upon results of an intensive lab, ground/sortie experimental development and test program effort being conducted through the mid 1980's. However, an integrated geosynchronous orbital test system program (utilizing the beam-mapper GEOSAT being developed on another subprogram) will provide the ultimate validity to the previously developed technical specification, and will not culminate until late 1987. Since initiation of a subprogram to develop a proto production specification and design/development of specialized equipment and facilities needed to produce this specification must start in late 1985 in order to support the proto satellite operational requirements of the early 1990's, a decision to develop proto production equipment and facilities contingent upon completion and evaluation of the Orbital Test Program would make a substantial delay in


SUPPORT FACILITIES & EQUIPMENT DEVELOPMENT
SPS DECISIONS
TECHNOLOGY VERIFICATION & FULL SCALE PROTO DEVELOPMENT
TRANSPORTATION DEVELOPMENT
SPS RECOMMENDED BASELINE CONCEPT DECISION
1978
'ARICEBO' IONOSPHERIC TEST FACIL. AVAIL.
1979
TECH. VERIF. PROG SUPPORT EQUIPMENT & FACILITIES DEVELOPMENT DECISION
1979
SYSTEM ANALYSIS, EXPLORATORY LAB. TEST DATA BASE DEVELOPMENT; CONTINUATION
1978
GEOSAT DEVELOPMENT START
1979
CRITICAL COMPON./SUBSYS. POINT DESIGN ANALYSIS COMPL
1980
M/W ENVIRONMENTAL EFFECTS DATA DEVELOPMENT START
1979
EXPERIMENTAL SUBSYS HARDWARE DEVELOPMENT START
1979
EXTENDED DURATION ORBITER (25 KW POWER MODULE) DEVELOPMENT START
1979
COMMERCIAL PHASE TRANSPORTATION CONCEPT DEFINITION & PRELIM. DES. STUDIES CONTINUATION
1979
LATE

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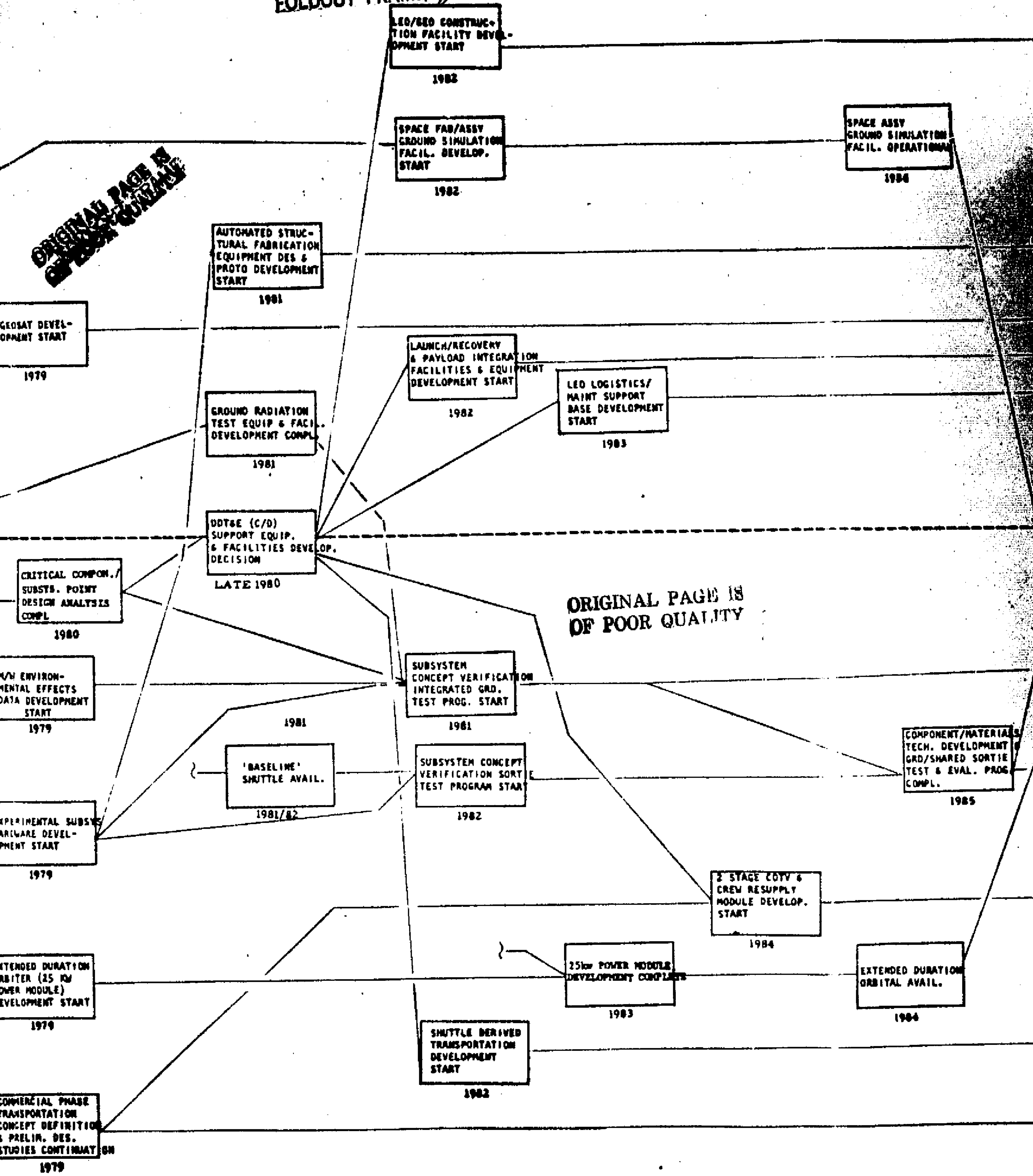

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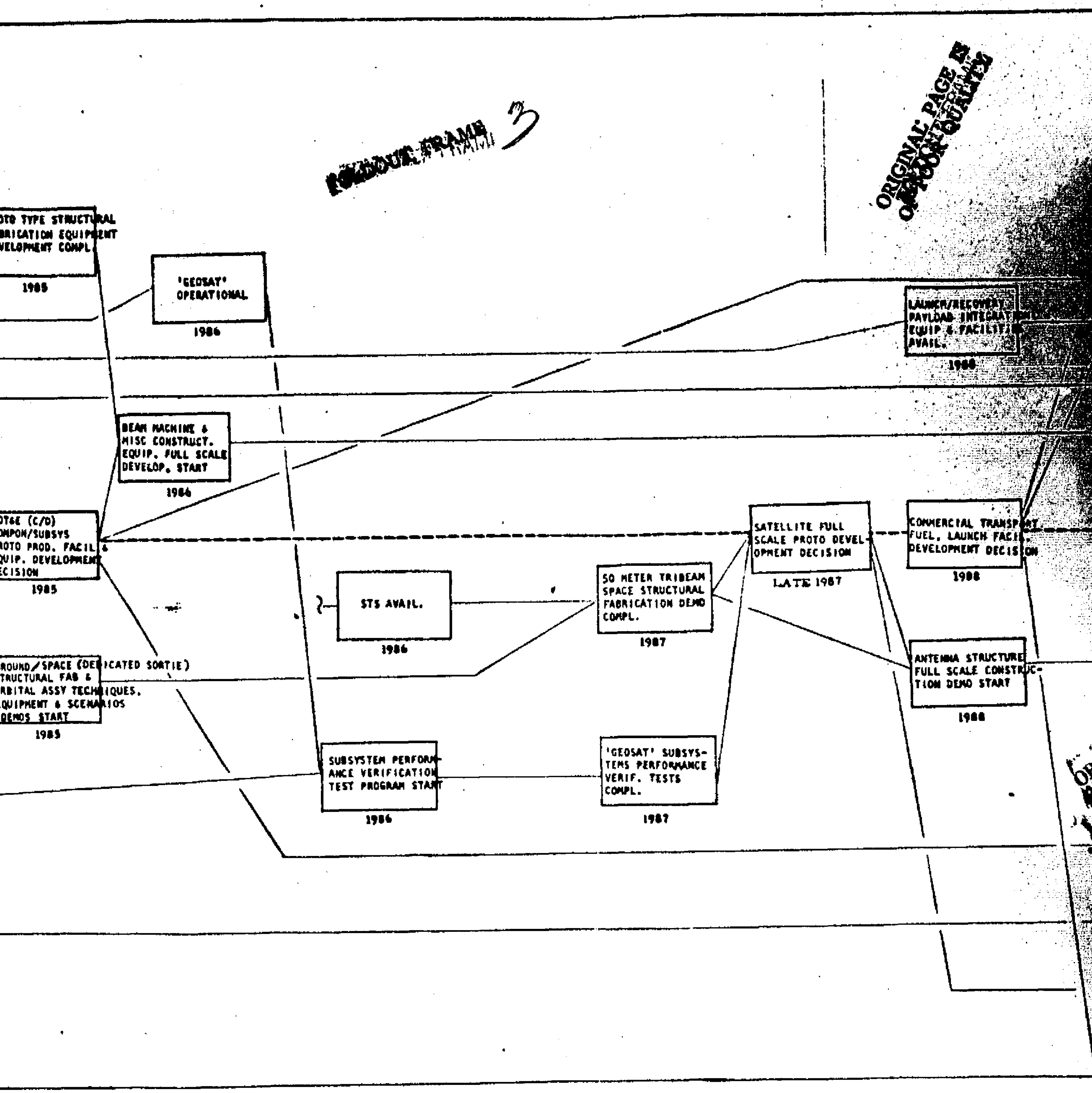

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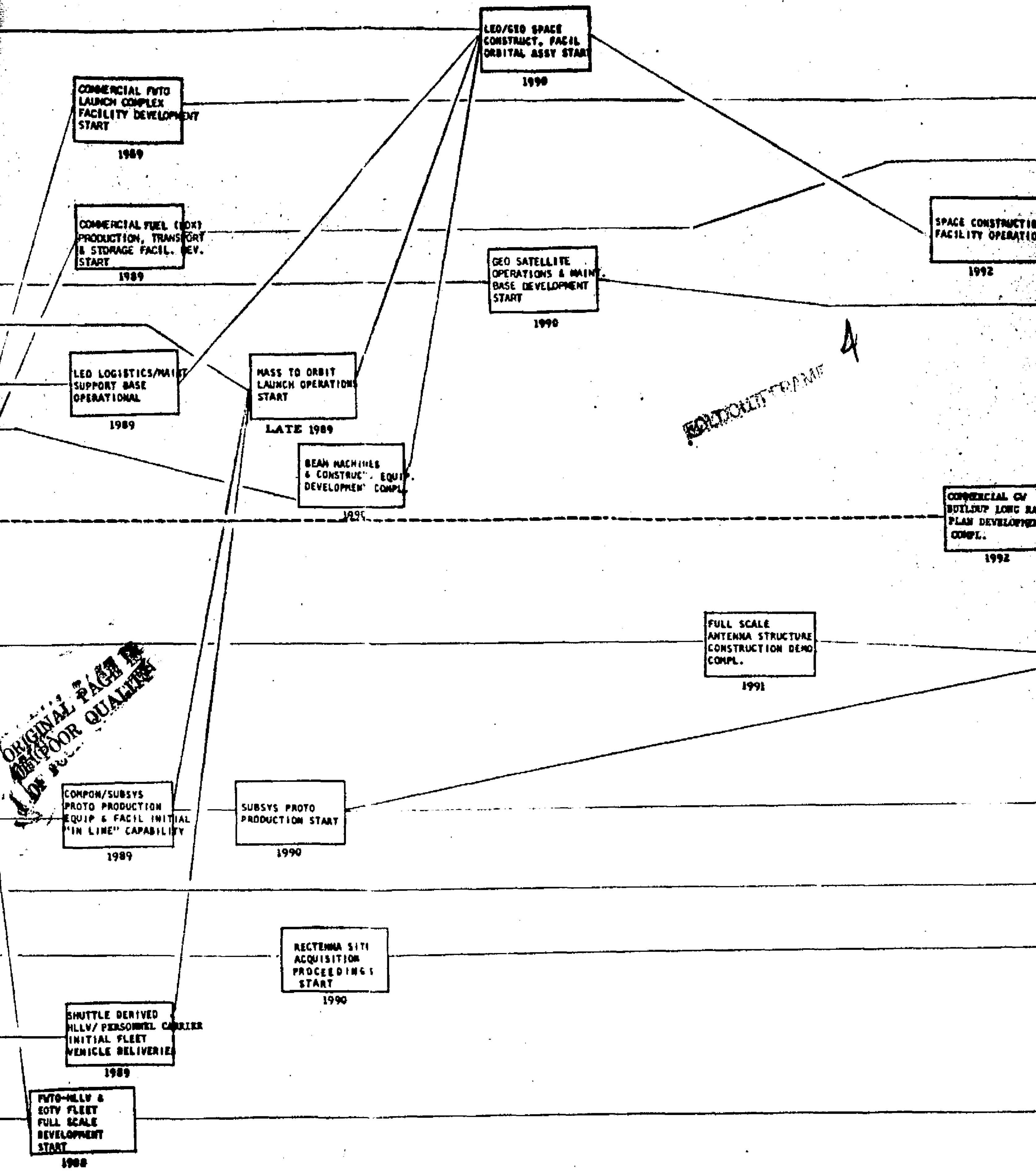
OTO TYPE STRUCTURAL
BRICATION EQUIPMENT
VELOPMENT COMPL.
1985
'GEOSAT' OPERATIONAL
1986
LAUNCH/RECOVERY PAYLOAD INTEGRATION EQUIP & FACILITIES AVAIL.
1988
BEAM MACHINE & MISC CONSTRUCT. EQUIP. FULL SCALE DEVELOP. START
1986
OT&E (C/D) COMPON/SUBSYS PROTO PROD. FACIL & EQUIP. DEVELOPMENT DECISION
1985
SATELLITE FULL SCALE PROTO DEVELOPMENT DECISION
LATE 1987
COMMERCIAL TRANSPORT FUEL, LAUNCH FACIL. DEVELOPMENT DECISION
1988
STS AVAIL.
1986
50 METER TRIBEAM SPACE STRUCTURAL FABRICATION DEMO COMPL.
1987
ROUND/SPACE (DEDICATED SORTIE) TRUCTURAL FAB & RBITAL ASSY TECHNIQUES, QUIPMENT & SCENARIOS DEMOS START
1985
ANTENNA STRUCTURE FULL SCALE CONSTRUCTION DEMO START
1988
SUBSYSTEM PERFORMANCE VERIFICATION TEST PROGRAM START
1986
'GEOSAT' SUBSYSTEMS PERFORMANCE VERIF. TESTS COMPL.
1987


LEO/GEO SPACE CONSTRUCT. FACIL ORBITAL ASSY START
1990
COMMERCIAL FVTO LAUNCH COMPLEX FACILITY DEVELOPMENT START
1989
COMMERCIAL FUEL (LOX) PRODUCTION, TRANSPORT & STORAGE FACIL. DEV. START
1989
SPACE CONSTRUCTI[...] FACILITY OPERATIO[...]
1992
GEO SATELLITE OPERATIONS & MAINT. BASE DEVELOPMENT START
1990
LEO LOGISTICS/MAINT SUPPORT BASE OPERATIONAL
1989
MASS TO ORBIT LAUNCH OPERATIONS START
LATE 1989
BEAM MACHINES & CONSTRUC. EQUIP. DEVELOPMENT COMPL.
1990
COMMERCIAL GW BUILDUP LONG RA[...] PLAN DEVELOPME[...] COMPL.
1992
FULL SCALE ANTENNA STRUCTURE CONSTRUCTION DEMO COMPL.
1991
COMPON/SUBSYS PROTO PRODUCTION EQUIP & FACIL INITIAL "IN LINE" CAPABILITY
1989
SUBSYS PROTO PRODUCTION START
1990
RECTENNA SITE ACQUISITION PROCEEDINGS START
1990
SHUTTLE DERIVED HLLV/ PERSONNEL CARRIER INITIAL FLEET VEHICLE DELIVERIES
1989
FVTO-HLLV & EOTV FLEET FULL SCALE DEVELOPMENT START
1988
4

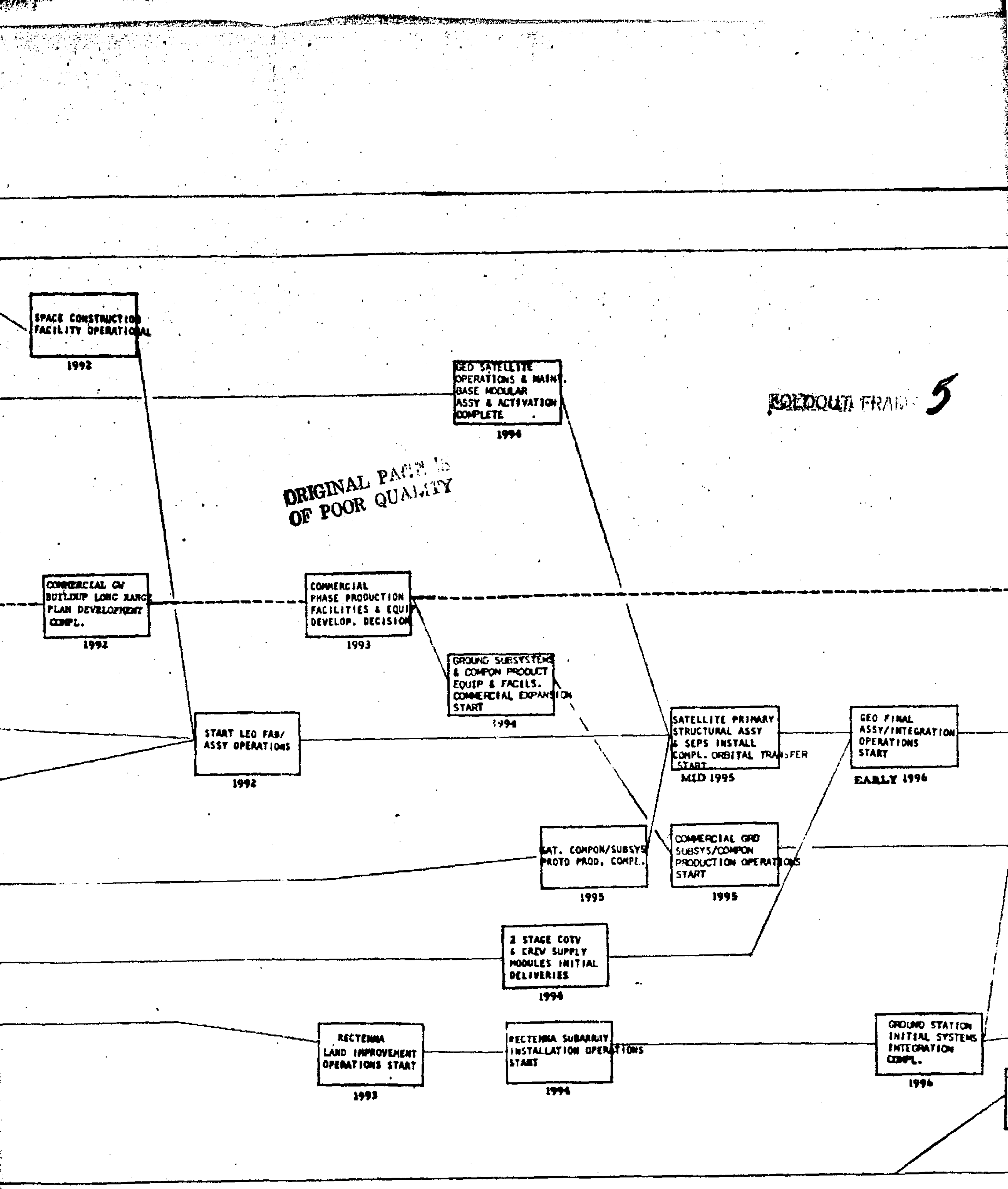


Figure 1-1. SPS Major Pr
Summary Logic N

Rockwell International
Space Division

SATELLITE POWER SYSTEMS
SPS
PROGRAMMATIC SCHEDULES

TITLE SPS MAJOR PROGRAM MILESTONE SUMMARY LOGIC NETWORK

Approval Responsibility ______________

Prepared by SPS Program Development ______________ date

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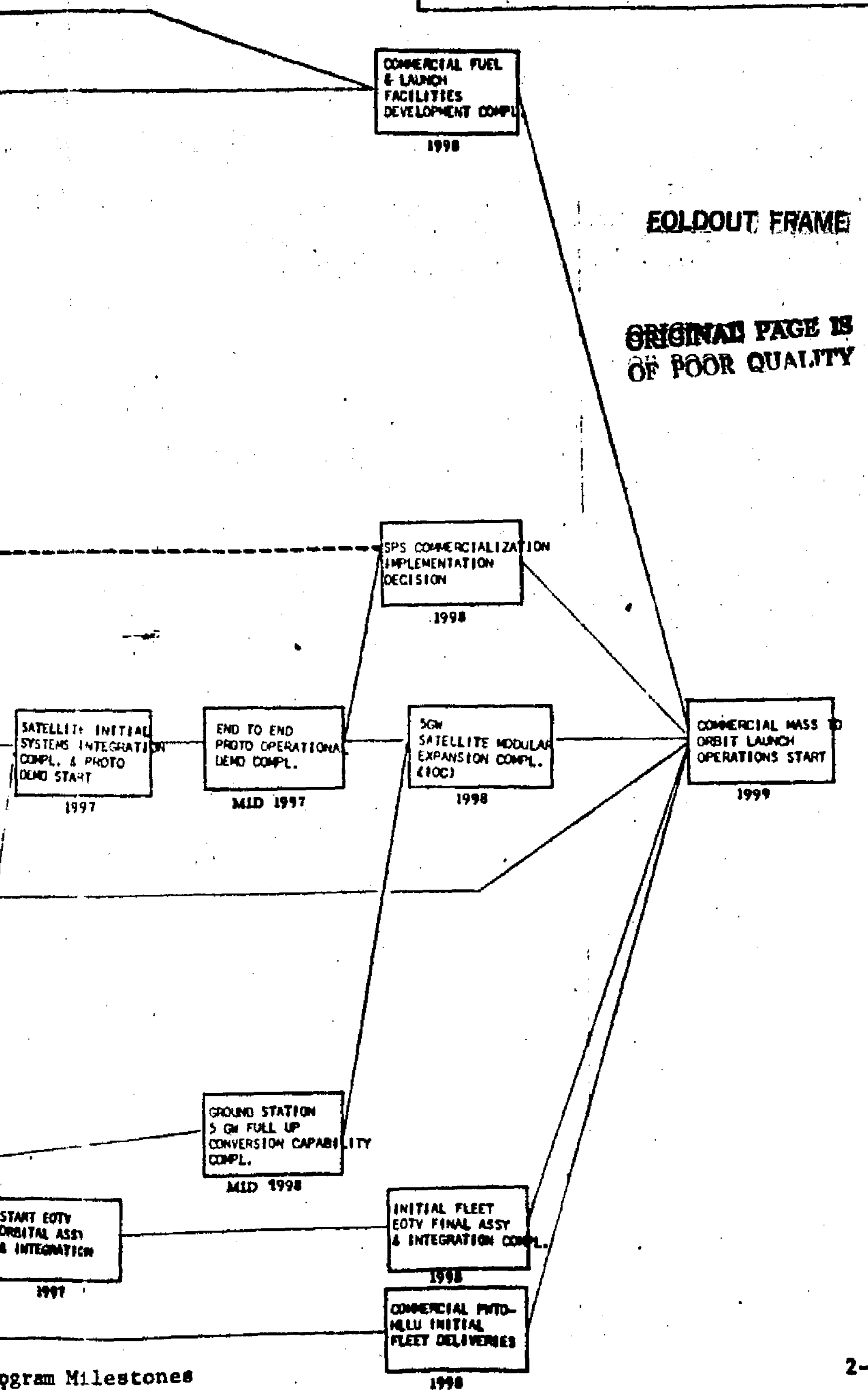


ogram Milestones
etwork

SPS DDT&E PROGRAM PLANNING SUMMARY

PLAN 1 | TITLE

PROGRAM MANAGEMENT

completion and test of the proto satellite system in 1997 highly probable. Thus, while proto production solar blanket development may well be able to incorporate improvements resulting from the Orbital System Test Program, a decision "to develop" cannot await the test program completion and evaluation.

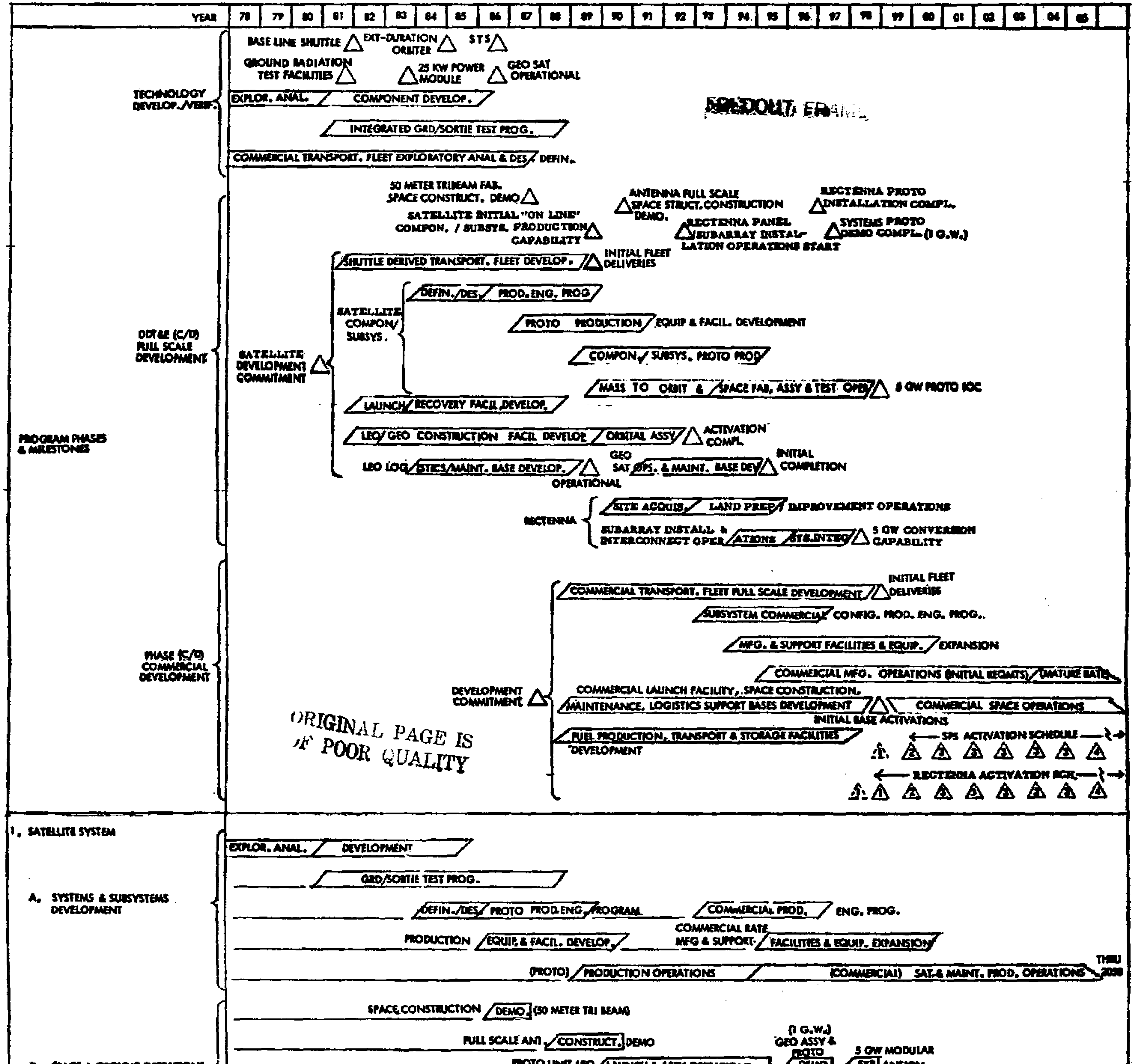
The SPS program, as a multi-faceted endeavor, will encompass major parallel supportive developmental efforts whose progress milestones have a very broad based interrelationship to each other and to the final end objective. Timely development implementation decisions in the several major program areas (contingent upon substantive achievement within its own parameters and tempered by progress evaluation in specifically established related areas) will be the pacing factors in development of this energy system.

To accommodate these inherent program conditions and still provide program visibility and cohesiveness of tasks and objectives, schedule exhibits have been organized into three primary phases:

1. Technology Development/Verification Program from 1978-1988.
2. DDT&E (Phase C/D) Full-Scale Development Program during the time period 1981 through 1998.
3. Commercial Development Program over the time period 1988 through 2028.

All three of these main program segments are presented on the SPS Summary Master Program Schedule (Figure 1-2) addressing the period 1978-2005. Technology activities fall into three sub-level phases of exploratory analysis (1978-1980), component development (1981-1986), and integrated ground/sortie test programs (1981-1988). The technology items scheduled during this period are elements of the satellite and ground station system, as detailed in the Technology Development Plan. Emphasis in each of these areas is intended to provide the necessary *proof of concept* essential to the DDT&E success of power conversion, microwave, power distribution, and structures systems designs.

The DDT&E, Phase C/D Full-Scale Development, will build on the technology program emphasizing space and ground segment component/subsystem developments and testing. The objective is to develop a fully integrated program activity that combines major technology advancements with other ground/space program elements that will evolve into a 1-GW SPS proto demonstration in 1997, leading to the full-scale demonstration of a 5-GW SPS in late 1998. This effort will involve other major program projects such as the Space Shuttle, orbital transportation systems, and space assembly/support facilities.



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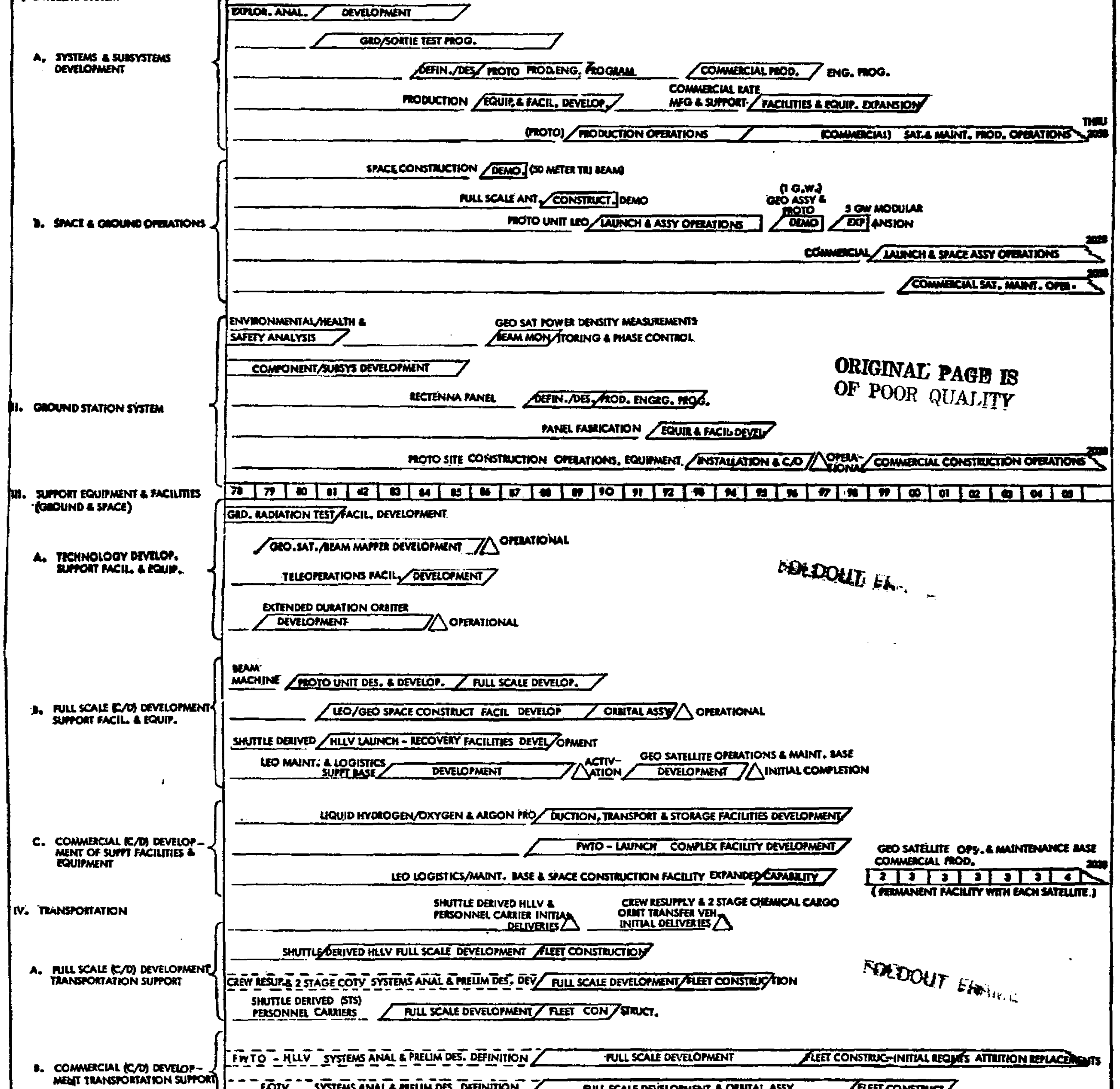
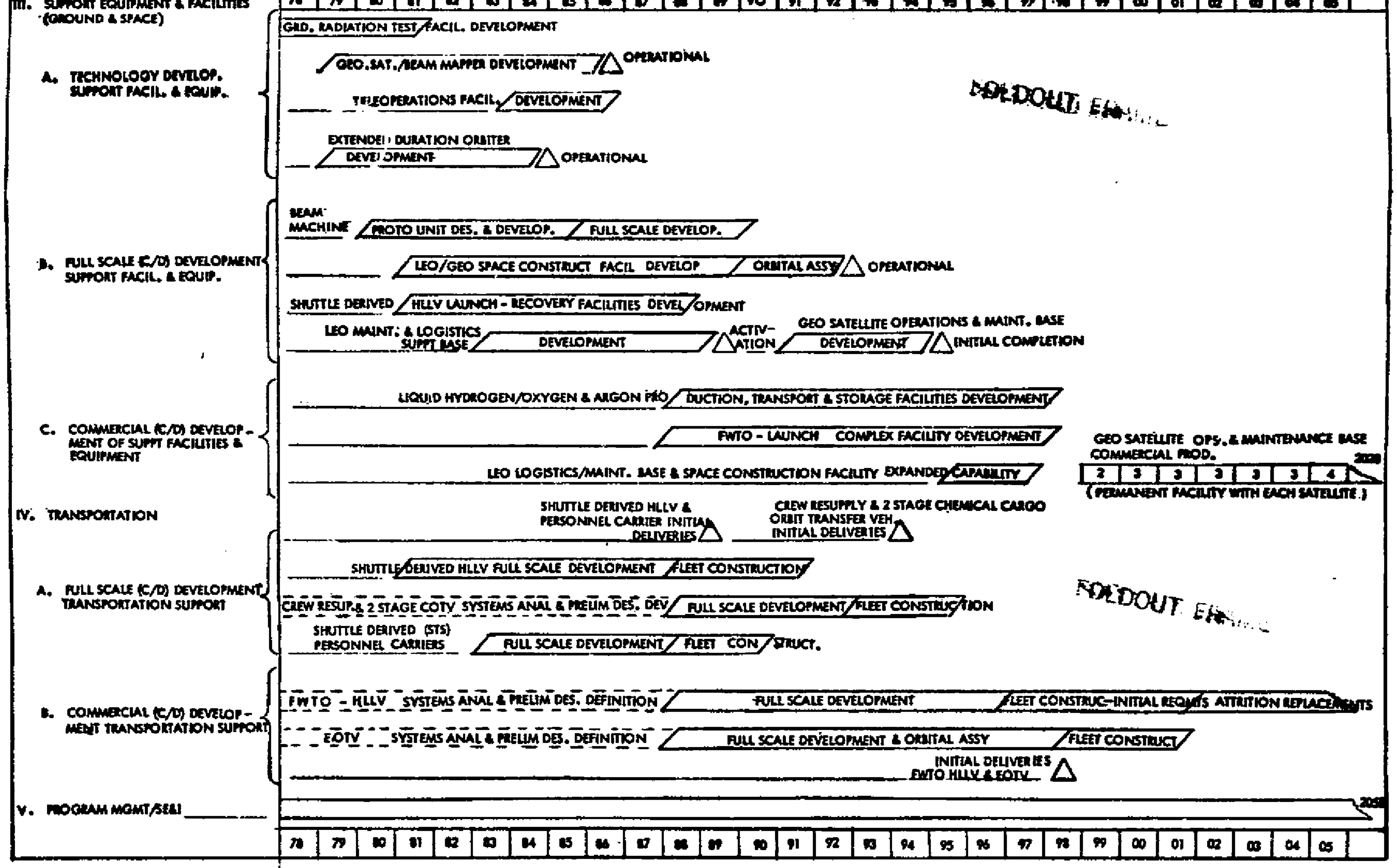

A. SYSTEMS & SUBSYSTEMS DEVELOPMENT
EXPLOR. ANAL. DEVELOPMENT
GRD/SORTIE TEST PROG.
DEFIN./DES. PROTO PROD.ENG. PROGRAM
COMMERCIAL PROD. ENG. PROG.
PRODUCTION EQUIP.& FACIL. DEVELOP.
COMMERCIAL RATE MFG & SUPPORT FACILITIES & EQUIP. EXPANSION
(PROTO) PRODUCTION OPERATIONS (COMMERCIAL) SAT.& MAINT. PROD. OPERATIONS THRU 2030
B. SPACE & GROUND OPERATIONS
SPACE CONSTRUCTION DEMO (50 METER TRI BEAM)
FULL SCALE ANT. CONSTRUCT. DEMO
(1 G.W.) GEO ASSY & PROTO DEMO
5 GW MODULAR EXPANSION
PROTO UNIT LEO LAUNCH & ASSY OPERATIONS
COMMERCIAL LAUNCH & SPACE ASSY OPERATIONS 2030
COMMERCIAL SAT. MAINT. OPER. 2030
II. GROUND STATION SYSTEM
ENVIRONMENTAL/HEALTH & SAFETY ANALYSIS
GEO SAT POWER DENSITY MEASUREMENTS
BEAM MONITORING & PHASE CONTROL
COMPONENT/SUBSYS DEVELOPMENT
RECTENNA PANEL DEFIN./DES. PROD. ENGRG. PROG.
PANEL FABRICATION EQUIP.& FACIL. DEVEL.
PROTO SITE CONSTRUCTION OPERATIONS, EQUIPMENT, INSTALLATION & C/O OPERATIONAL COMMERCIAL CONSTRUCTION OPERATIONS 2030
III. SUPPORT EQUIPMENT & FACILITIES (GROUND & SPACE)
78 79 80 81 82 83 84 85 86 87 88 89 90 91 92 93 94 95 96 97 98 99 00 01 02 03 04 05
A. TECHNOLOGY DEVELOP. SUPPORT FACIL. & EQUIP.
GRD. RADIATION TEST FACIL. DEVELOPMENT
GEO.SAT./BEAM MAPPER DEVELOPMENT OPERATIONAL
TELEOPERATIONS FACIL. DEVELOPMENT
EXTENDED DURATION ORBITER DEVELOPMENT OPERATIONAL
B. FULL SCALE (C/D) DEVELOPMENT SUPPORT FACIL. & EQUIP.
BEAM MACHINE PROTO UNIT DES. & DEVELOP. FULL SCALE DEVELOP.
LEO/GEO SPACE CONSTRUCT FACIL DEVELOP ORBITAL ASSY OPERATIONAL
SHUTTLE DERIVED HLLV LAUNCH - RECOVERY FACILITIES DEVELOPMENT
LEO MAINT. & LOGISTICS SUPPT BASE DEVELOPMENT ACTIVATION
GEO SATELLITE OPERATIONS & MAINT. BASE DEVELOPMENT INITIAL COMPLETION
C. COMMERCIAL (C/D) DEVELOPMENT OF SUPPT FACILITIES & EQUIPMENT
LIQUID HYDROGEN/OXYGEN & ARGON PRODUCTION, TRANSPORT & STORAGE FACILITIES DEVELOPMENT
PWTO - LAUNCH COMPLEX FACILITY DEVELOPMENT
LEO LOGISTICS/MAINT. BASE & SPACE CONSTRUCTION FACILITY EXPANDED CAPABILITY
GEO SATELLITE OPS.& MAINTENANCE BASE COMMERCIAL PROD.
2 3 3 3 3 3 4 2030
(PERMANENT FACILITY WITH EACH SATELLITE.)
IV. TRANSPORTATION
SHUTTLE DERIVED HLLV & PERSONNEL CARRIER INITIAL DELIVERIES
CREW RESUPPLY & 2 STAGE CHEMICAL CARGO ORBIT TRANSFER VEH. INITIAL DELIVERIES
A. FULL SCALE (C/D) DEVELOPMENT TRANSPORTATION SUPPORT
SHUTTLE DERIVED HLLV FULL SCALE DEVELOPMENT FLEET CONSTRUCTION
CREW RESUP.& 2 STAGE COTV SYSTEMS ANAL & PRELIM DES. DEV FULL SCALE DEVELOPMENT FLEET CONSTRUCTION
SHUTTLE DERIVED (STS) PERSONNEL CARRIERS FULL SCALE DEVELOPMENT FLEET CONSTRUCT.
B. COMMERCIAL (C/D) DEVELOPMENT TRANSPORTATION SUPPORT
FWTO - HLLV SYSTEMS ANAL & PRELIM DES. DEFINITION FULL SCALE DEVELOPMENT FLEET CONSTRUC- INITIAL REQMTS ATTRITION REPLACEMENTS
EOTV SYSTEMS ANAL & PRELIM DES. DEFINITION FULL SCALE DEVELOPMENT & ORBITAL ASSY FLEET CONSTRUCT



Rockwell International
Space Division

SATELLITE POWER SYSTEMS
SPS
PROGRAMMATIC SCHEDULES

TITLE SUMMARY MASTER PROGRAM SCHEDULE

Approval Responsibility ______

Prepared by SPS Program Development ______ date

Figure 1-2. Summary Master Program Schedule

SPS DDT&E PROGRAM PLANNING SUMMARY

PLAN 1 TITLE

PROGRAM MANAGEMENT

Commitments toward the SPS commercialization phase will be required in advance of the Initial Operating Capability (IOC) of the first commercial unit in 1999. Most critical is the Phase C/D commitment to the Heavy Lift Launch Vehicle (HLLV) in 1987 in order to accommodate the mass-to-orbit requirements of future SPS's and rectenna go-ahead. Other design development commitments scheduled at this same time include ground production/manufacturing operations, natural resources production, and further development of a program management and systems engineering/integration capability needed to meet SPS objectives.

A series of supporting schedules have been prepared to identify (1) system technology development tasks as shown on the Technology Development/Verification Schedule; (2) the production engineering, equipment/facilities development, and production operations as presented on the DDT&E (Phase C/D) Full-Scale Development Schedule; and (3) the "rate" production development tasks as shown on the Commercialization Schedule. By referring to the margin of these schedules, it will be possible to associate the WBS element, as shown in Figure 1-3, with the line to it, and to identify the major areas of a critical issue/concern as they apply to that particular element—such as power conversion, microwave, and power distribution. Each of these schedules are described in the following paragraphs:

1. *SPS Technology Development/Verification 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. Therefore, the schedule of Figure 1-4 addresses those key technology elements whose development is requisite to an overall SPS preliminary subsystem performance design and definition, plus development of the test equipment and facilities needed for direct support of 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/distribution, SPS structure, and transportation.

A summary of analyses, development, and test activities for MPTS technology advancement is illustrated. RF generation, beam control and waveguide testing/verification of concept will be the end result of these proposed tasks and technology developments.

Steps for the projected resolution of power conversion technology are presented for satellite components and subsystems, testing, and test equipment/facilities. The activities and their phasing address solar cell development, high-efficiency gallium recovery processes, solar blanket module development, and associated attention to the development of reflector (concentrator) technology. Array development and module testing are of particular interest. Power distribution technology advancement will focus on power conditioning,

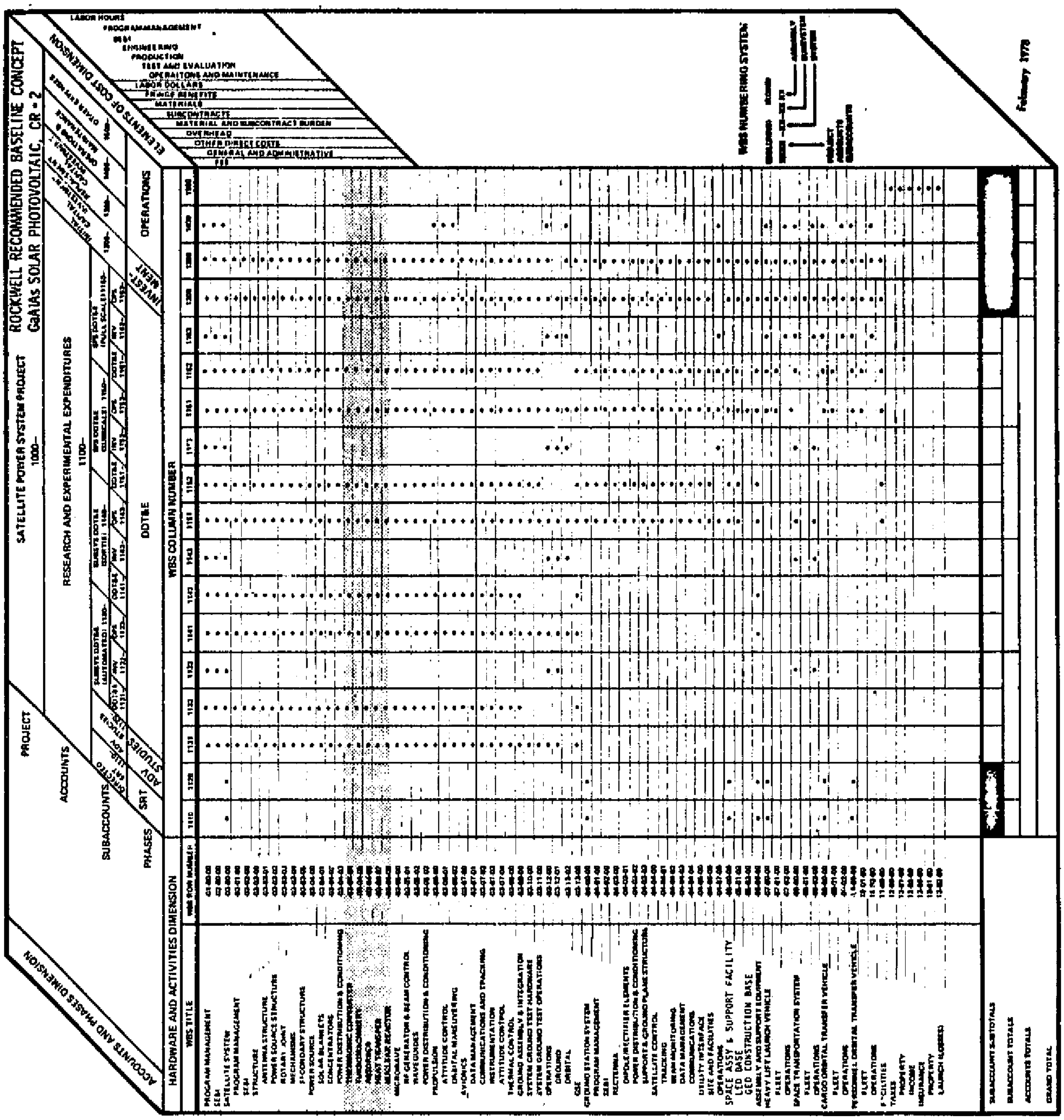
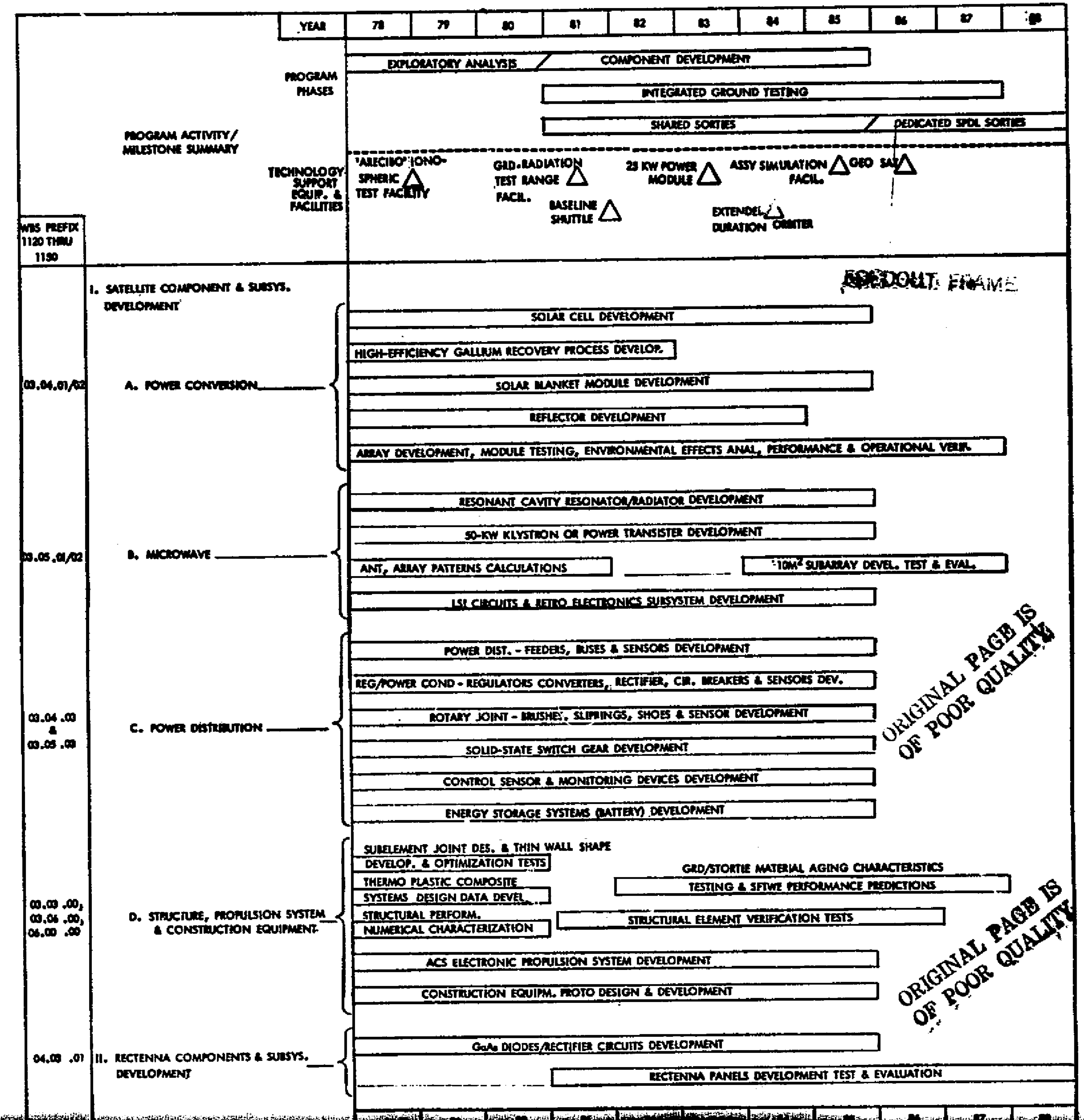


Figure 1-3. SPS Work Breakdown Structure Matrix


YEAR
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PROGRAM PHASES
EXPLORATORY ANALYSIS
COMPONENT DEVELOPMENT
INTEGRATED GROUND TESTING
SHARED SORTIES
DEDICATED SPDL SORTIES
PROGRAM ACTIVITY/ MILESTONE SUMMARY
TECHNOLOGY SUPPORT EQUIP. & FACILITIES
'ARECIBO' IONO-SPHERIC TEST FACILITY
GRD. RADIATION TEST RANGE FACIL.
BASELINE SHUTTLE
25 KW POWER MODULE
EXTENDED DURATION ORBITER
ASSY SIMULATION FACIL.
GEO SAT
WBS PREFIX 1120 THRU 1150
I. SATELLITE COMPONENT & SUBSYS. DEVELOPMENT
03.04.01/02
A. POWER CONVERSION
SOLAR CELL DEVELOPMENT
HIGH-EFFICIENCY GALLIUM RECOVERY PROCESS DEVELOP.
SOLAR BLANKET MODULE DEVELOPMENT
REFLECTOR DEVELOPMENT
ARRAY DEVELOPMENT, MODULE TESTING, ENVIRONMENTAL EFFECTS ANAL, PERFORMANCE & OPERATIONAL VERIF.
03.05.01/02
B. MICROWAVE
RESONANT CAVITY RESONATOR/RADIATOR DEVELOPMENT
50-KW KLYSTRON OR POWER TRANSISTER DEVELOPMENT
ANT, ARRAY PATTERNS CALCULATIONS
10M² SUBARRAY DEVEL. TEST & EVAL.
LSI CIRCUITS & RETRO ELECTRONICS SUBSYSTEM DEVELOPMENT
03.04.03 & 03.05.03
C. POWER DISTRIBUTION
POWER DIST. - FEEDERS, BUSES & SENSORS DEVELOPMENT
REG/POWER COND - REGULATORS CONVERTERS, RECTIFIER, CIR. BREAKERS & SENSORS DEV.
ROTARY JOINT - BRUSHES, SLIPRINGS, SHOES & SENSOR DEVELOPMENT
SOLID-STATE SWITCH GEAR DEVELOPMENT
CONTROL SENSOR & MONITORING DEVICES DEVELOPMENT
ENERGY STORAGE SYSTEMS (BATTERY) DEVELOPMENT
03.03.00, 03.06.00, 06.00.00
D. STRUCTURE, PROPULSION SYSTEM & CONSTRUCTION EQUIPMENT
SUBELEMENT JOINT DES. & THIN WALL SHAPE DEVELOP. & OPTIMIZATION TESTS
THERMO PLASTIC COMPOSITE SYSTEMS DESIGN DATA DEVEL.
STRUCTURAL PERFORM. NUMERICAL CHARACTERIZATION
GRD/SORTIE MATERIAL AGING CHARACTERISTICS TESTING & SFTWE PERFORMANCE PREDICTIONS
STRUCTURAL ELEMENT VERIFICATION TESTS
ACS ELECTRONIC PROPULSION SYSTEM DEVELOPMENT
CONSTRUCTION EQUIPM. PROTO DESIGN & DEVELOPMENT
04.03.01
II. RECTENNA COMPONENTS & SUBSYS. DEVELOPMENT
GaAs DIODES/RECTIFIER CIRCUITS DEVELOPMENT
RECTENNA PANELS DEVELOPMENT TEST & EVALUATION
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LSI CIRCUITS & RETRO ELECTRONICS SUBSYSTEM DEVELOPMENT

03.04 .03 & 03.05 .03 — C. POWER DISTRIBUTION
- POWER DIST. - FEEDERS, BUSES & SENSORS DEVELOPMENT
- REG/POWER COND - REGULATORS CONVERTERS, RECTIFIER, CIR. BREAKERS & SENSORS DEV.
- ROTARY JOINT - BRUSHES, SLIPRINGS, SHOES & SENSOR DEVELOPMENT
- SOLID-STATE SWITCH GEAR DEVELOPMENT
- CONTROL SENSOR & MONITORING DEVICES DEVELOPMENT
- ENERGY STORAGE SYSTEMS (BATTERY) DEVELOPMENT

03.03 .00, 03.06 .00, 06.00 .00 — D. STRUCTURE, PROPULSION SYSTEM & CONSTRUCTION EQUIPMENT
- SUBELEMENT JOINT DES. & THIN WALL SHAPE DEVELOP. & OPTIMIZATION TESTS
- GRD/SORTIE MATERIAL AGING CHARACTERISTICS TESTING & SFTWE PERFORMANCE PREDICTIONS
- THERMO PLASTIC COMPOSITE SYSTEMS DESIGN DATA DEVEL.
- STRUCTURAL PERFORM. NUMERICAL CHARACTERIZATION
- STRUCTURAL ELEMENT VERIFICATION TESTS
- ACS ELECTRONIC PROPULSION SYSTEM DEVELOPMENT
- CONSTRUCTION EQUIPM. PROTO DESIGN & DEVELOPMENT

04.03 .01 — II. RECTENNA COMPONENTS & SUBSYS. DEVELOPMENT
- GaAs DIODES/RECTIFIER CIRCUITS DEVELOPMENT
- RECTENNA PANELS DEVELOPMENT TEST & EVALUATION

78	79	80	81	82	83	84	85	86	87	88

III. INTEGRATED GRD/SORTIE TEST PROGRAM

03.04 .01/02 — A. POWER CONVERSION
- COMPONENT LAB TESTS
- GROUND REFLECTOR STRUC. SUPPT HIGH VOLT. ARRAY TESTS: DEPLOYMENT & REPAIR CONCEPT DEV.
- SORTIE CELL/REFLECTOR ENVIR EFFECTS TESTS SPACE MFG EXPMTS; HIGH-VOLTAGE PLASMA DISCHARGE CHARACTERISTICS

03.05 .01 — B. MICROWAVE
- IONOSPHERIC-ARICEBO TESTING
- 2 DIM ARRAY TESTS GRD/GRD NEAR-FIELD TESTS
- GEOSAT MICROWAVE TESTS

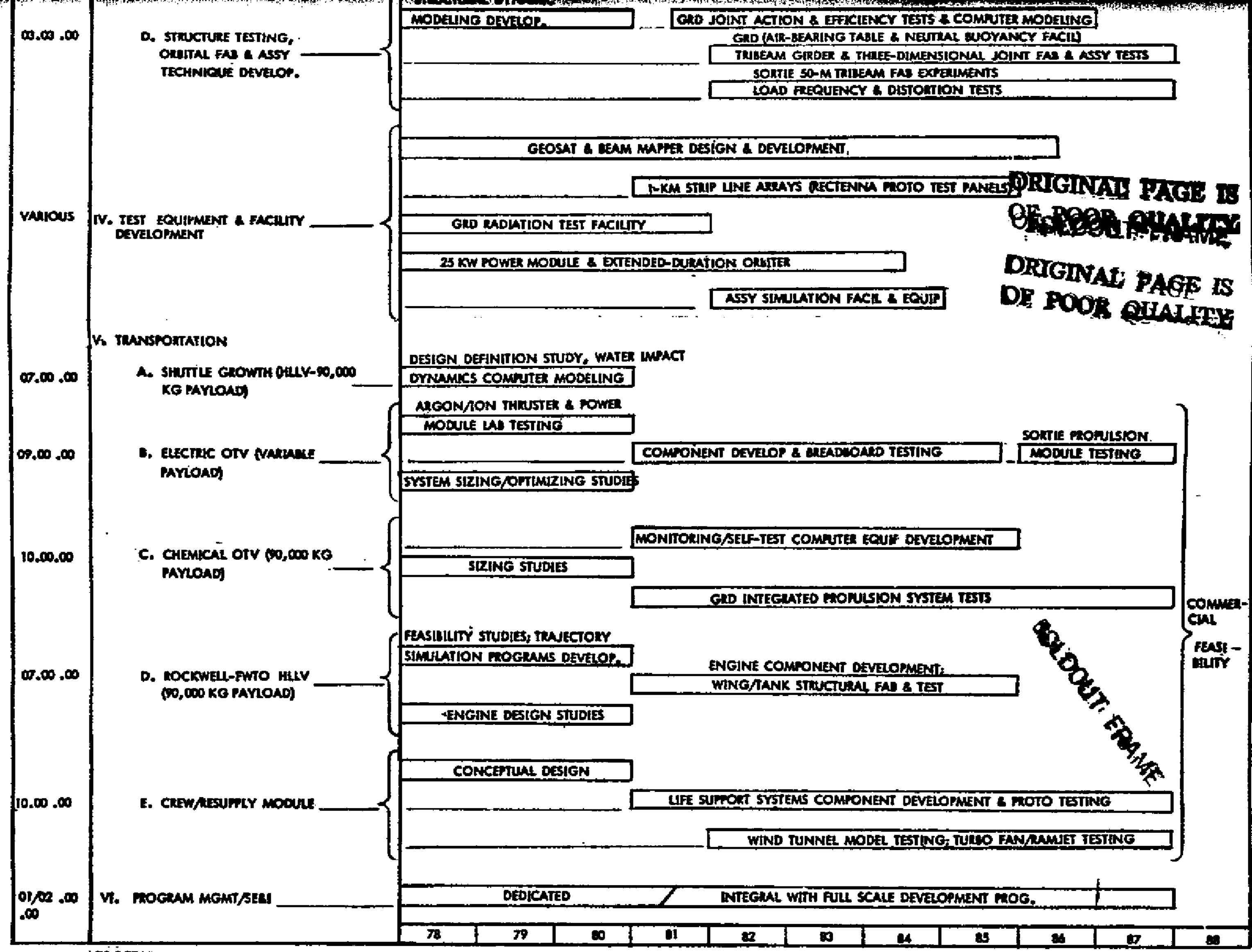
03.06 .03 — C. POWER DISTRIBUTION
- LAB TESTS - SPACE CHARGING, SUPERCONDUCTIVITY TESTS, EXPERIMENTAL JOINING TECHNIQUE
- GRD VERIF TESTS - ASSY & MAINT TECHNIQUE VERIF & PERFORM. VERIF.
- SORTIES - SPACE CHARGING EFFECTS; HIGH-VOLTAGE PLASMA LOSSES, POWER CABLE SUPERCONDUCTIVITY PERFORMANCE CHARACTERISTICS EVALUATION

03.03 .00 — D. STRUCTURE TESTING, ORBITAL FAB & ASSY TECHNIQUE DEVELOP.
- STRUCTURAL DYNAMIC MODELING DEVELOP.
- GRD JOINT ACTION & EFFICIENCY TESTS & COMPUTER MODELING
- GRD (AIR-BEARING TABLE & NEUTRAL BUOYANCY FACIL) TRIBEAM GIRDER & THREE-DIMENSIONAL JOINT FAB & ASSY TESTS
- SORTIE 50-M TRIBEAM FAB EXPERIMENTS LOAD FREQUENCY & DISTORTION TESTS

VARIOUS — IV. TEST EQUIPMENT & FACILITY DEVELOPMENT
- GEOSAT & BEAM MAPPER DESIGN & DEVELOPMENT.
- 1-KM STRIP LINE ARRAYS (RECTENNA PROTO TEST PANELS)
- GRD RADIATION TEST FACILITY
- 25 KW POWER MODULE & EXTENDED-DURATION ORBITER
- ASSY SIMULATION FACIL & EQUIP

V. TRANSPORTATION

07.00 .00 — A. SHUTTLE GROWTH (HLLV-90,000 KG PAYLOAD)
- DESIGN DEFINITION STUDY, WATER IMPACT DYNAMICS COMPUTER MODELING
- ARGON/ION THRUSTER & POWER MODULE LAB TESTING
- SORTIE PROPULSION.



GLOSSARY:

ROCKWELL - FWTO HLLV: HEAVY LIFT FIXED WING HORIZONTAL TAKE OFF & LANDING VEHICLE UTILIZED FOR TRANSPORT & DELIVERY OF CARGO & PERSONNEL TO LOW EARTH ORBIT.

EOTV: LARGE CAPACITY CARGO ORBITAL TRANSFER VEHICLE UTILIZING ELECTRIC ION/ARGON THRUSTERS POWERED BY GaAs SOLAR BLANKETS.

COTV: RAPID ORBITAL TRANSFER VEHICLE CHEMICALLY POWERED FOR USE IN TRANSPORT OF PRIORITY CARGO & PERSONNEL.

RETRO ELECTRONICS: SATELLITE MICROWAVE ANTENNA POINTING & PHASE CONTROL ELEC.

ACS: SATELLITE ATTITUDE CONTROL SYSTEM

LSI CIRCUITS: LARGE SCALE INTEGRATED CIRCUITS (REQUIRED FOR HIGH VOLTAGE APPLICATIONS)

Rockwell International
Space Division

SATELLITE POWER SYSTEMS
SPS
PROGRAMMATIC SCHEDULES

TITLE TECHNOLOGY DEVELOPMENT/VERIFICATION PROG.

Approval Responsibility ______

Prepared by SPS Program Development ______ date

Figure 1-4. Technology Development/Verification Program Schedule

SPS DDT&E PROGRAM PLANNING SUMMARY

PLAN 1	TITLE PROGRAM MANAGEMENT

regulating, brushes and slip rings, solid-state switch gear, and energy storage systems (battery) development.

Early analysis of structural materials, dynamic modeling, and supporting tests will provide confidence in the development of components, equipment, and fabrication techniques. Evolutionary growth of these basic projects (50-m tribeam jointing techniques, etc.) will support full-scale testing programs such as that for the microwave antenna.

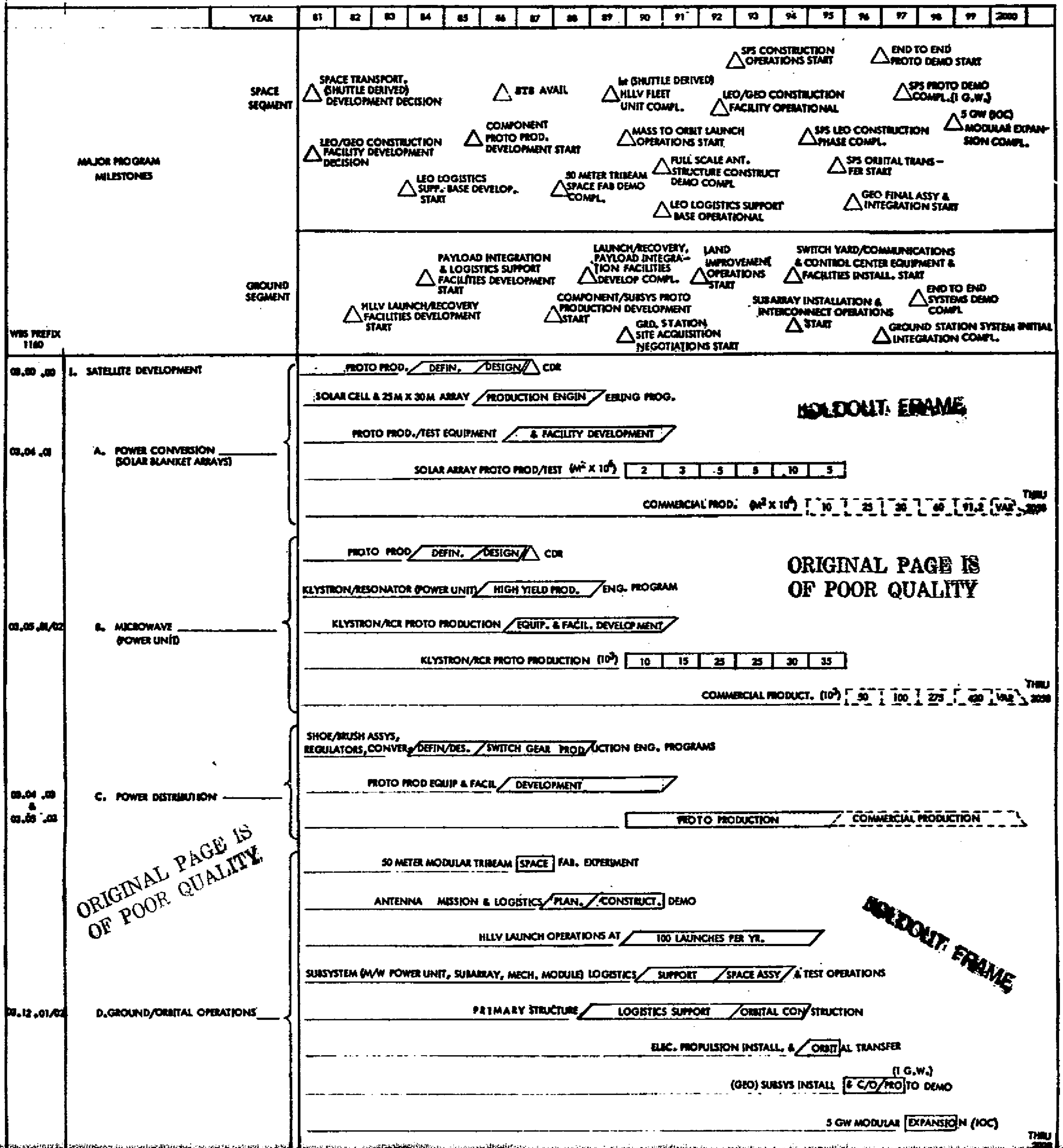
The transportation scope of the effort during this phase is primarily directed at providing preliminary design definition to those vehicles needed for specific missions further identified in subsequent program phases. The only transportation article developed during this period for direct project support use is the extended-duration orbiter which, measured against the total scope of this program phase, might be considered a minor effort.

2. *DDT&E (Phase C/D) 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 1-5 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 tasks involved in design and definition of subsystem proto production hardware (based upon data, specifications, and experimental hardware developed during the technology verification program phase); that manufacturing technology, equipment, and facilities can be developed; and that proto production operations can ultimately evolve. 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. Due to dictates of technology lead times and current state-of-the-art technology, transportation facilities/vehicles have currently been defined as "Shuttle-derived" technology for ground-to-LEO cargo and personnel applications, and with chemically powered vehicles for LEO-to-GEO usage, subject to further definition and analysis during subsequent end-to-end studies.

The DDT&E Phase C/D schedule supports both space segment and ground segment requirements. The space transportation [Shuttle-derived (SD)] and LEO/GEO construction facility development decisions of 1981 precede the 1982 design/development start of SD-HLLV launch/recovery facilities in order to support



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03.04.03 & 03.05.03 — C. POWER DISTRIBUTION

- SHOE/BRUSH ASSYS, REGULATORS, CONVER/ DEFIN/DES. / SWITCH GEAR PROD/UCTION ENG. PROGRAMS
- PROTO PROD EQUIP & FACIL / DEVELOPMENT /
- PROTO PRODUCTION / COMMERCIAL PRODUCTION

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03.12.01/02 — D. GROUND/ORBITAL OPERATIONS

- 50 METER MODULAR TRIBEAM SPACE FAB. EXPERIMENT
- ANTENNA MISSION & LOGISTICS / PLAN. / CONSTRUCT. DEMO
- HLLV LAUNCH OPERATIONS AT / 100 LAUNCHES PER YR. /
- SUBSYSTEM (M/W POWER UNIT, SUBARRAY, MECH. MODULE) LOGISTICS / SUPPORT / SPACE ASSY / & TEST OPERATIONS
- PRIMARY STRUCTURE / LOGISTICS SUPPORT / ORBITAL CON/STRUCTION
- ELEC. PROPULSION INSTALL. & / ORBIT/AL TRANSFER
- (GEO) SUBSYS INSTALL & C/O / PRO TO DEMO (1 G.W.)
- 5 GW MODULAR EXPANSIO N. (IOC)
- COMMERCIAL OPERATIONS / STARTUP / 2 / 3 / VAR. THRU 2028

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81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	2000

04.00.00 — II. GROUND STATION DEVELOPMENT

04.03.01 — A. RECTENNA M/W SUBARRAY CONVERTER PANELS

- RECTENNA PANEL PROTO PROD / DEFIN/DES / PRODUCT ENGRG. / PROGRAM
- 12.2 M LONG + VARIOUS WIDTH PANEL FABRICATION (4 TYPES) / EQUIP & FACIL. DEVEL/OPMENT
- LAMINATED PANEL FAB/ASSY OPERATIONS ($M^2 \times 10^6$) 10 / 30 / 40
- COMMERCIAL OPERATIONS ($M^2 \times 10^6$) 80 / 160 / 200 / VAR. THRU 2027

04.06.00 — B. SITE & FACILITIES

- SITE / ACQUISITION / LAND PREP/IMPROVE/MENT OPERATIONS

04.07.00 — C. OPERATIONS

- (PANEL/SUBARRAY STRUCTURE) SUBARRAY INSTALLATION & INTERCON/NECT OPERATIONS ≈ 436,018 PER SPS
- (POWER DISTRIB. & CONDITIONING/UTILITY INTERFACE) SWITCH YARD FACILITY / & EQUIP INSTA/LLATION & C/O
- (SATELLITE/RECTENNA COMMUNICATION & CONT.) COMMUNICATIONS & CONTROL CENTER FACIL. / & EQUIP. INST/ALL. & C/O
- SITE OPERATIONS PLAN/NING & LOGISTICS SUPP/ SYSTEM INTEGRATIO/N
- △ INITIAL CONVERSION CAPABILITY △ 5 GW CAPABILITY

III. SUPPORT EQUIP. & FACILITIES DEVELOPMENT

11.00.00 — A. FACILITIES

- (SHUTTLE DERIVED) HLLV LAUNCH/RECOVERY FACILITIES & SUPPORT EQUIP. DEVELOPMENT

05.00.00 — B. LEO/GEO CONSTRUCTION FACILITY

- ASSEMBLY FIXTURE, DEVELOPMENT, / LAUNCH OPER., OR/BITAL FAB & ASSY
- SPACE CONSTRUCTION BASE (320/640 MAN CREW) / DEVELOPMENT / ORBITAL ASSY / & ACTIVATION
- SUBSYSTEM SPACE ASSY & TEST EQUIP./FACIL / DEVELOPMENT / ACTIVATION / (I.E. M/W POWER UNIT, SUBARRAY, MECH. MODULE ASSY & TEST OPERATIONS.)

05.01/02.0 — C. SPACE REPAIR, MAINT. & LOGISTICS SUPPORT BASES

- LEO LOGISTICS & MAINT. SUP/PORT BASE, DEVELOPMENT / ORBITAL / ASSY & ACTIVATION
- GEO SATELLITE OPERATIONS & MAINT BASE / DEVELOPMENT / ORBITAL ASSY / ACTIVATION
- GEO SAT. OPER. & MAINT. BASE (20 MAN CREW - ONE PERMANENT FACILITY PER EACH SPS) 2 / 3 / VAR. COMMERCIAL FACILITY PRODUCTION THRU 2028

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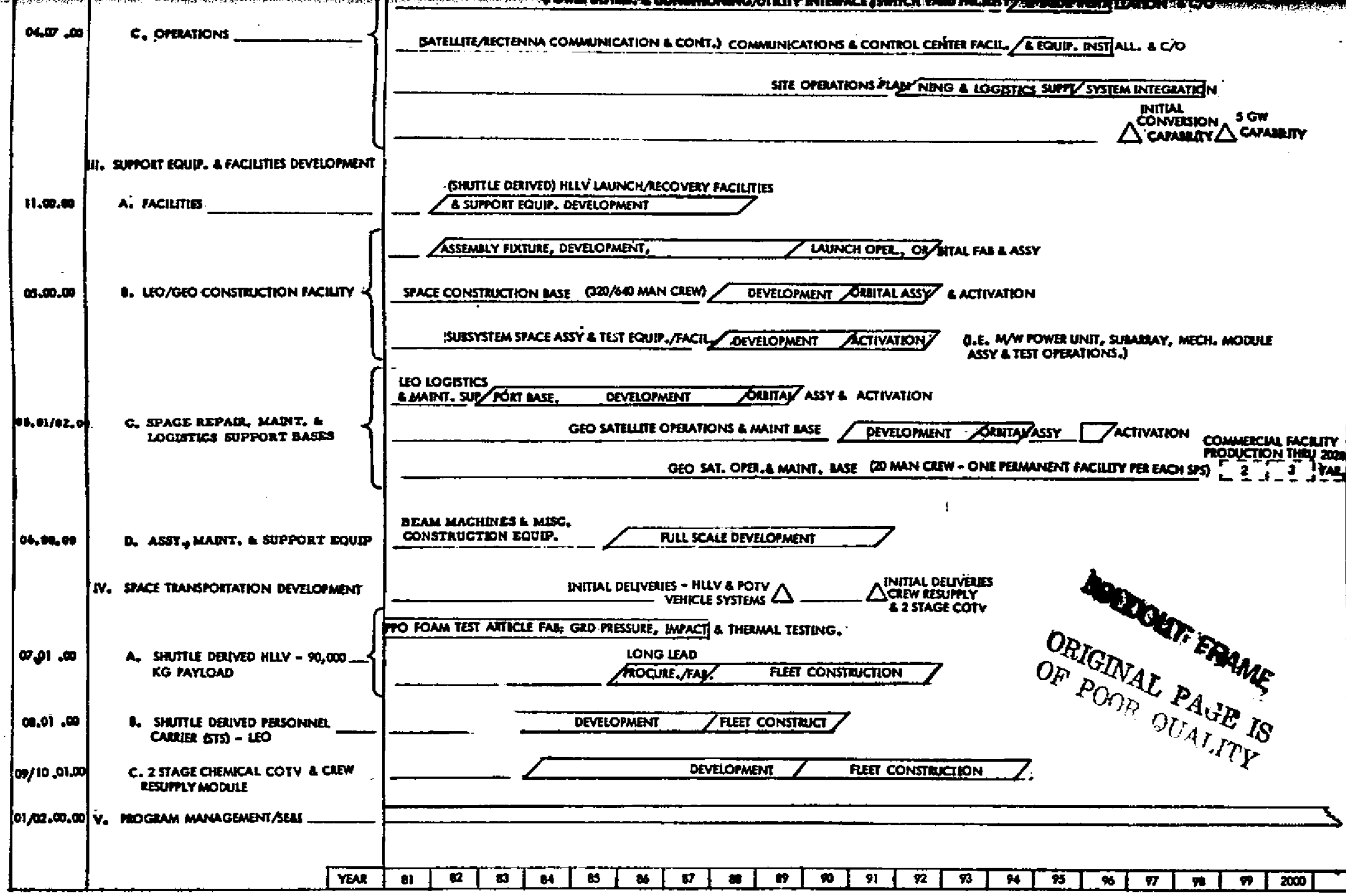

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GLOSSARY:

RECTENNA M/W SUBARRAY: A 12.24m X 14.69m RECEIVING/CONVERTING UNIT CONSISTING OF SEVERAL INTERCONNECTED, LAMINATED DIPOLE CONVERTER PANELS MOUNTED ON A STRUCTURAL ASSEMBLY. THE PANEL CONFIGURATION OF ANY PARTICULAR SUBARRAY UNIT IS DEPENDENT ON BEAM DENSITY CONVERSION CAPACITY REQUIRED.

PRODUCTION ENGINEERING PROGRAM: ALL EFFORT REQUIRED TO CONVERT EXPERIMENTAL DES HARDWARE INTO PRODUCTION HARDWARE SPECS & DES. INCLUDES TOOLING, TEST EQUIPMENT/ FACIL. DES. & DEV.; MFG. INSP., TEST METHODS DEVELOPMENT; MATERIALS// RESOURCES PLANNING & DEV.; Q.A., DESIGN TOCOST, RELIABILITY, PRODUCIBILITY ETC. SUPPORT FUNCTIONS.

DEVELOPMENT: ALL EFFORT REQUIRED TO CONVERT PRELIM. DES. ARTICLES INTO FULL SCALE OPERATIONAL HARDWARE UNITS.

RCR: RESONANT CAVITY RESONATOR-ANALOGOUS TO WAVE GUIDES UNDER WBS INTERPRETATION.

Rockwell International Space Division	SATELLITE POWER SYSTEMS SPS PROGRAMMATIC SCHEDULES
TITLE	DDT&E FULL SCALE DEVELOPMENT PROGRAM
Approval Responsibility	
Prepared by SPS Program Development	date

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Figure 1-5. DDT&E Full-Scale Development Program Schedule

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SPS DDT&E PROGRAM PLANNING SUMMARY

PLAN	TITLE
1	PROGRAM MANAGEMENT

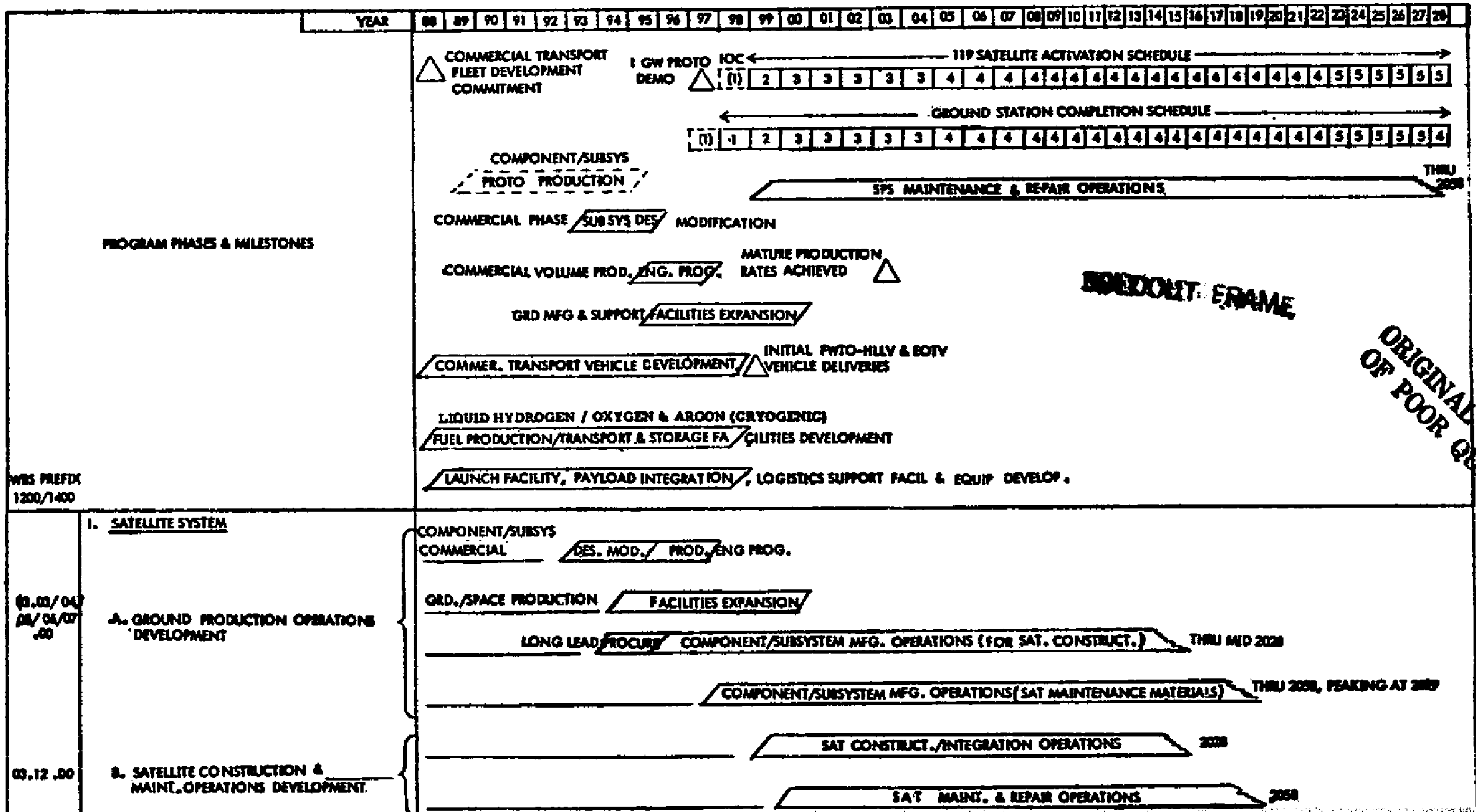
the SD vehicle availability and operational start of 1989; 5-GW SPS program developments will continue during this same period to develop production-level technology to produce solar cells/blankets, klystrons/RCR's, and other system/subsystem requirements for the 50-m modular tribeam space experiment, and hardware/software availability to initiate the projected 100 SD-HLLV launches per year starting in 1989. To support first-unit mass-to-orbit requirements in concert with the SPS build scenario, full-scale antenna construction is completed in 1990 along with supporting space logistics operations for test and a progressive prelude to the start of SPS construction operations in 1992. The completion of SPS LEO construction in 1994 will facilitate the transfer to GEO and preparations for the 1-GW proto demonstration test in 1997. In parallel with this integrated ground and space activity, ground station system activities—including rectenna site location/preparation and panel fabrication—have proceeded to install subarrays and satellite control elements for the 1-GW SPS test and end-to-end systems demonstration in late 1997. A modular expansion of space and ground segments will lead to the IOC of a 5-GW SPS by 1998.

3. *Commercial Development Program*

The objective of this program phase is to construct, operate, and maintain 120 5-GW satellite power systems, with a total terrestrial capability of 600 GW over a 30-year period (1998 through 2028), where the operation and maintenance portion extends from 1999 through 2058—or 30 years after activation of the last satellite. Primary emphasis is placed on the scheduling of facilities, equipment development, and preparation efforts required during the 1988-2028 time period to support large-scale ground/space construction and integration operations as shown in Figure 1-6.

The earliest development and capital intensive effort during this period will be centered on the availability of an economically viable transportation fleet (based on preliminary design and definition data and specifications developed during the technology verification programs) whose primary vehicle developments will be the horizontal fixed-wing takeoff heavy-lift launch vehicle (FWTC-HLLV) and the large-capacity solar electric powered orbital transfer vehicle (EOTV). A parallel supporting development will be in the creation of liquid-hydrogen/oxygen and argon fuel production, transportation and storage facilities needed to support the extensive requirements in mass to LEO, orbital transfer, and satellite stationkeeping operations. The commercial development schedule reiterates major program activities and milestone events occurring in each of the main WBS segments.

SPS
COMMERCIAL
DEVELOPMENT PROGRAM
SOLAR PHOTOVOLTAIC CR-2



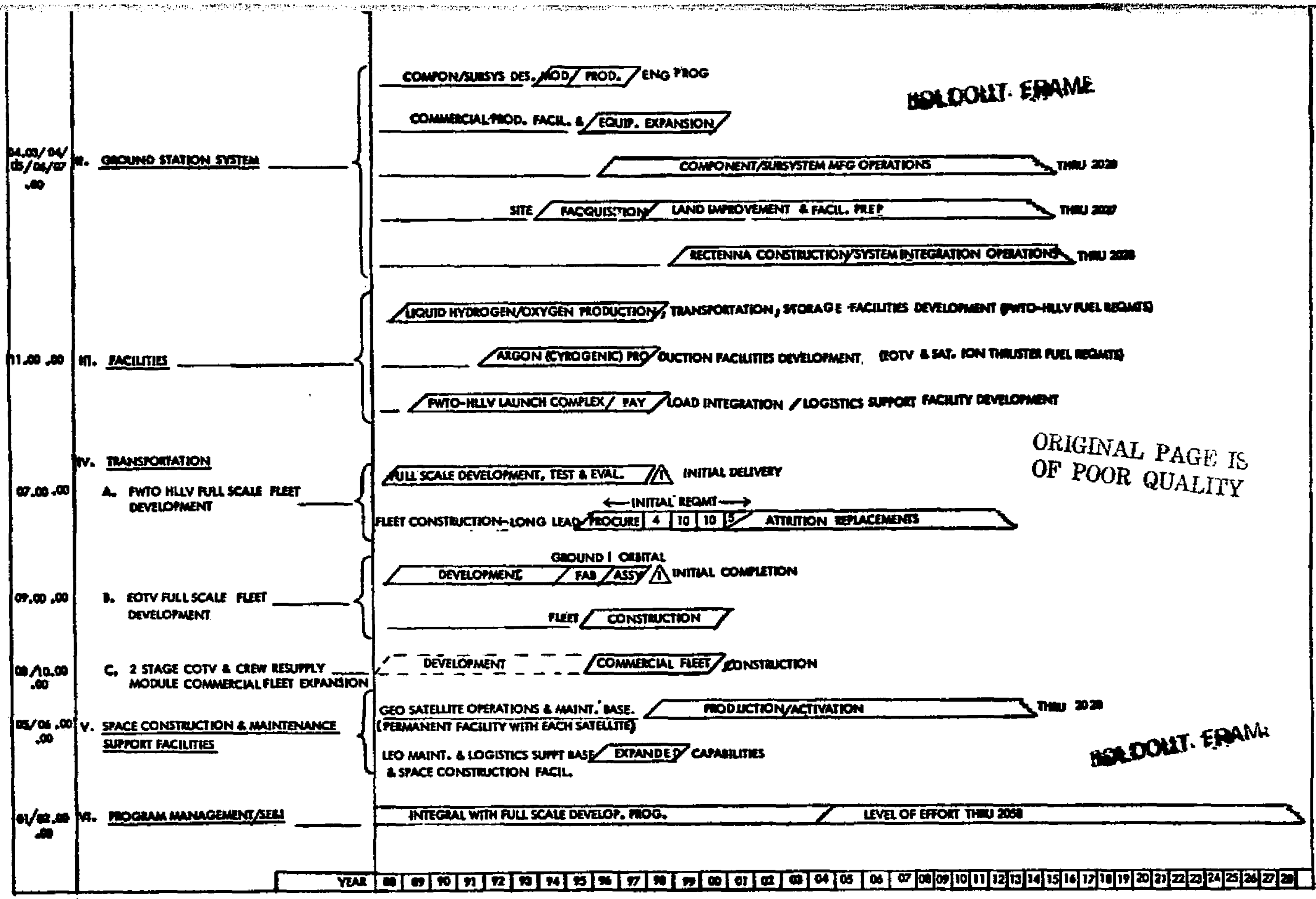


Figure 1-6. Commercial Development Program Schedule

Rockwell International Space Division	SATELLITE POWER SYSTEMS SPS PROGRAMMATIC SCHEDULES
TITLE	COMMERCIAL DEVELOPMENT PROGRAM
Approval Responsibility	
Prepared by SPS Program Development	date

SPS DDT&E PROGRAM PLANNING SUMMARY

PLAN	TITLE
1	PROGRAM MANAGEMENT

DDT&E Impact Sheets

The Program Management WBS element/Program Management Plan Intercept is mainly marked in the "C" category to indicate the summary level at which management coordination is performed. While Category C is used in most instances, certain plans such as Systems Testing are assigned to Category A—indicating a major commitment and one which can only take place at the systems integration level. The "Operations" line item (03-12-00) is assigned to Category C as a key part of the plan requiring long-term effort. Major system intercepts are marked "A" to indicate the critical interrelationship of long-range planning and funding requirements.

Prime objectives of make-or-buy decisions are to assure that maximum technological and economic benefits are accorded NASA through effective distribution of contract requirements between the contractor and outside subcontracting sources. The make-or-buy list will be developed from a hardware utilization list (HUL) that is prepared by the Engineering function and will reflect, by work breakdown structure element, all significant systems, subsystems, and major structures of each SPS configuration baseline. The same approach will be applied to each major system (i.e., satellite, STS, etc.).

Before make-or-buy determinations are made, technical and management resources and skills are carefully evaluated with emphasis on minimizing technical, schedule, and cost risks for both the contractor and NASA.

The make-or-buy list, with supporting rationale, will be presented to the Make-or-Buy Committee for evaluation. Conclusions and recommendations of the committee will be documented as required and submitted to NASA for approval. After approval, the make-or-buy list will be exhibited as a formal part of the contract. Thereafter, the decision to make or buy those items listed in the contract will only be changed with the concurrence of the contracting officer.

Make-or-buy assumptions are predicated on the fact that the prime contractor for the SPS would be one experienced in complex, manned space operations. The contractor would perform an overall systems management and coordinating role under NASA as the directing government agency. The contractor would also perform major tasks involving such things as development, assembly, and logistics. He would have a key role to play in development of supporting systems such as the STS or—at least—in coordinating interfaces with the SPS.

Due to the size of the overall SPS effort, a large number of capable contractors will be needed in performing substantial roles in the systems integration, development, and operational areas. Most likely, separate,

SPS DDT&E PROGRAM PLANNING SUMMARY

PLAN	TITLE
1	PROGRAM MANAGEMENT

Individual system contracts would be let for all major systems. These contractors would normally be from the aerospace industry or from among large companies in other segments of industry, as most appropriate. For example, the large number and type of electrical and electronic equipment would be developed and procured within that industry. Such items as solar blankets and high-voltage power conditioning and distribution equipment would require long-term commitment and extensive facilities which could best be built up within the existing industry.

In discussions with large suppliers of materials (such as plastic foam and film), the feasibility of setting up new plants on site to produce such items as dipole modules for the rectenna was indicated.

The broad cross-section of industry which must be involved in the SPS precludes application of the normal decision-making criteria for make or buy. Most hardware, software, and services would be bought from sources outside of the prime contractor/system-integrator organization; hence, these would be "buy" items. From the standpoint of dollars, however, a substantial portion of the resources of major systems suppliers would be expected to be retained within their respective organizations for the procurement of "make" items.

Table 1-2 addresses the main items of "impact" as currently identified in the Program Management area.

Table 1-2.

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

Plan No.: 1 **Title:** PROGRAM MANAGEMENT PLAN

WBS Element	Impact	Category
03-00-00 SATELLITE SYSTEM	The items listed on this Impact Sheet are major system elements which are an integral part of the SPS or on which the SPS critically depends. While some of these elements may be developed for multiple project application, they will—for the time being—remain entirely within the SPS work breakdown structure. Each of the systems or projects listed will be an undertaking not unlike the satellite in magnitude, and will require a fully developed set of program plans. No attempt has been made to provide detailed definition at this time since baseline concepts remain to be selected and defined.	A
04-00-00 GROUND STATION SYSTEM		A
05-00-00 SPACE STATION PROJECT		A
06-00-00 ASSEMBLY AND SUPPORT EQUIPMENT		A
07-00-00 HLLV		A
08-00-00 STS		A
09-00-00 COTV		A
10-00-00 POTV		A
11-00-00 FACILITIES		

SPS DDT&E PROGRAM PLANNING SUMMARY

PLAN	TITLE
2	SYSTEMS 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 & Operations Monitoring
- SPS Cost/Economics

RESOURCE CONSIDERATIONS:

- Technical and Management Personnel
  - Engineering Management
  - Safety
  - Reliability
  - Maintainability
  - Support Management
- Support Materials/Equipment & 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, ICDs, 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. This data will form the basis for establishing long range budgeting for economic projections.

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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 & Design Requirements
  - Structural Elements - Joining & Stiffening
  - Beam Machine Development
  - Solar Blanket Design Efficiency & Reliability
  - Microwave Reliability & 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, 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

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SPS DDT&E PROGRAM PLANNING SUMMARY

PLAN	TITLE
3	DESIGN AND DEVELOPMENT

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 starting in the late 1980's. This is equivalent to the goal for entire U.S. production in 1986. However, this production is almost entirely planned for low cost silicon cells not GaAs, to say nothing of thin-film production. Risk assessment under this plan would be a basis for implementing major developmental effort on GaAs to provide thin-film, high efficiency cells.

Secondly, development programs must be identified, planned and carried out to assure that proof-of-concept will actually take place as scheduled. This effort will not include resolution of key issues or research activities which have presumably 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. The 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
03-00-00 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
03-03-00 Structure	The methods of designing the prototype structure will evolve as smaller structural platforms (i.e., GEOSAT) for demonstration projects are designed and developed during Phase C. 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 prototype are included under 06-00-00. Capability for producing large structures in space must be developed.	B
03-03-03 Rotary Joint	Special consideration must be given to design and development to provide high reliability for all moving parts. Parts replacement must be considered. (Slip-rings are part of 03-04-03.)	B
03-04-03 Mechanisms	Same comment as 03-03-03.	B
03-04-00 Power Source	Design and development must address the integrated power source at this level although most hardware-related effort will be at a lower or higher level. The power source is among the most critical subsystems requiring extensive development and long lead time, primarily at levels 03-04-01 and 03.	A
03-04-01 Solar Blankets	Design and development of the solar blanket will be, perhaps, themost 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

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Table 3-1.

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

(Cont.)

Plan No.: 3 **Title:** DESIGN AND DEVELOPMENT

WBS Element	Impact	Category
03-05-00 Microwave	Design and development of regulators, switch gear, circuit breakers, klystrons, etc., cathode structure will be extensive to assure high efficiency and reliability. Considerable investigations of alternate PDC subsystem and component approaches is foreseen. Not as large in magnitude as 03-04-00 but just as critical. Similar comments apply.	A
03-05-01 Generator & Beam Control	This level is called out to emphasize the need to consider beam control which must be taken into account as a critical item during design and development.	B
03-11-00 Ground Test Operations	Comprehensive. Includes design of all STE and facilities not included elsewhere. This would not cover solar blanket checkout with associated test equipment and facilities design which are not systems level tests.	B
03-12-01 Ground	Major planning effort required on ground to support orbital assembly and close-out but not operatins and maintenance.	B
03-12-02 Orbital	Comprehensive. Covers all orbital operations associated with SPS including assembly, checkout, operations and maintenance. These concepts will have major influence on design and development.	A
04-03-00 Rectenna	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.	C
04-03-01 Dipole/Rectifier Elements	Design must permit mass production at minimum cost. Consider on-site fabrication of dipole panels	B
04-03-02 Power Distr. & Conditioning	Similar comments apply as to 03-04-03 except that weight, reliability, etc., are perhaps, not as critical.	B

Table 3-1.

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

Plan No.: 3 **Title:** DESIGN AND DEVELOPMENT

WBS Element	Impact	Category
04-05-00 Utility Interface	As the ultimate user the impact of the utilities on SPS design will be considerable. The utilities will have requirements for regulation and reliability for example. 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.	A
05-00-00 Space Station	Major supporting program. ICD's must be considered throughout design and development. Concerns include life support, logistics, docking, flight control, personnel/cargo transfer, etc.	A
06-00-00 Assembly & Support Equip.	Design and development of satellite assembly and support equipment is a comprehensive task involving such items as assembly fixtures, beam machines, teleoperators, etc. This is one of the most critical areas of development.	A
07-00-00 HLLV	Major parallel program. Will support prototype after IOC. Therefore ICD's must be considered throughout design.	B
08-00-00 STS	Major supporting program. ICD's must be considered throughout design and development. Expect design to evolve closely from Space Shuttle.	B
09-00-00 COTV	Major supporting program. ICD's must be considered throughout design and development.	B
10-00-00 POTV	Major supporting program. ICD's must be considered throughout design and development.	B

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 - $30.6 \times 10^6 m^2$ per Satellite
  - Power Distribution and Control
  - Rotary Joint
  - Microwave Power
  - Rectenna
  - Space Transportation
- System & Subsystem Verification Test Requirements
- System Test Hardware/Software Definition
- Unique Test Facilities - Ground & Space

RESOURCE CONSIDERATIONS:

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

DISCUSSION:

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

- Development
- Production
- Qualification
- Verification
- Operations

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SPS DDT&E PROGRAM PLANNING SUMMARY

PLAN	TITLE
4	SYSTEMS TESTING

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 pointing 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.

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.

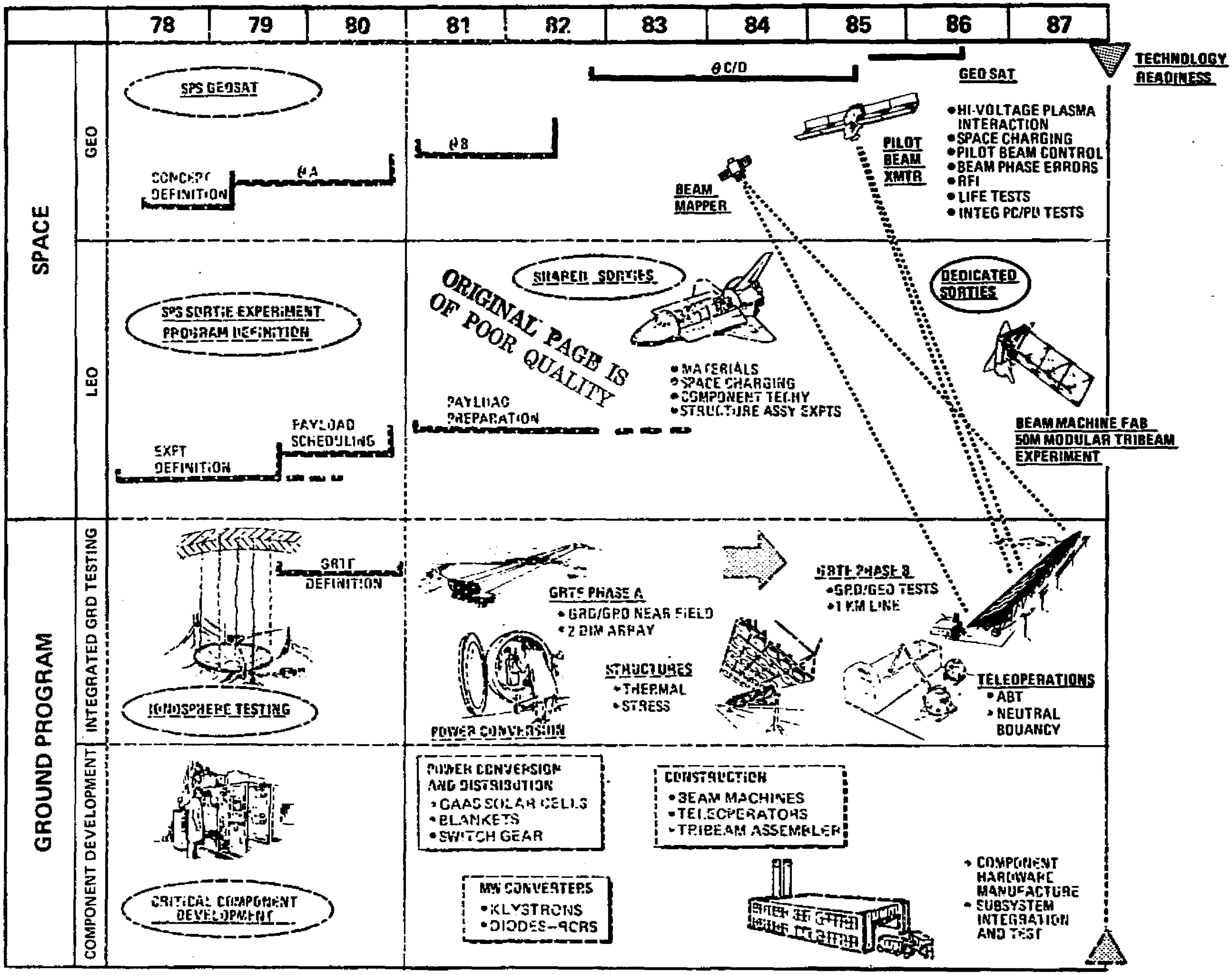

Figure 4-1. SPS Technology Advancement Plan Elements

Table 4-1.

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

Plan No.: 4 **Title:** SYSTEMS TESTING

WBS Element	Impact	Category
01-00-00 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
03-00-00 Satellite System	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. Are there stability, control, switching, etc., tests which must be performed at this level without ground station interface?	A
03-03-03 Rotary Joint	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
03-03-04 Mechanisms	Same comment as above.	B

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

(Cont.)

Plan No.: 4 **Title:** SYSTEMS TESTING

WBS Element	Impact	Category
03-04-00 Power Source	Similar questions arise as under 03-00-00: What is the testing concept and sequence? For test purposes will the smallest unit be a single blanket (say, 800 square meters)? How will the concentrators (flat mirrors for CR-2) be integrated? Will power source modules include switch gear, regulators, etc., for testing purposes? This element is part of the 03-00-00 level.	
03-04-01 Solar Blankets	Prototype plus EOTV and spares will require approximately 31×10^6 m^2 of solar blankets starting in 1993 for delivery and installation thru 1996. Buildup will require average production of 5.2×10^6 m^2/yr for 6 years starting in 1990. Testing will require ten or more "blimp hanger" size test stands capable of testing 800 m^2 blankets on 3-shift basis. Testing of each solar blanket would be done on test stands adjacent to the factory. These stands would each have solar spectrum simulation capability. Power requirements would be 800 kW minimum per test stand. Test stands will be located at factory sites.	A
03-04-03 Power Distribution & Cond.	High rate, high voltage (45 kV) testing of equipment will be involved. Questions: What special problems and requirements are involved in high voltage testing of regulators and switch gear (40,000 sets if using 800 m^2 blankets) and dc/dc converters (14,000 units to drive 140,000 klystrons).	A
03-05-00 Microwave	Verification tests must satisfy beam control and interlock capability relative to safety concerns. However, testing will be covered at the 03-00-00 level.	
03-05-01 RF Generation & Beam Control	High rate, high voltage testing at component level for klystrons, driver amplifiers, etc.	B

Table 4-1.

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

(Cont.)

Plan No.: 4 **Title:** SYSTEMS TESTING

WBS Element	Impact	Category
03-05-03 Power Distribution & Conditioning	High rate, high voltage testing of conduction network at subsystem level and at component level of switch gear, conditioning electronics.	B
03-11-00 Systems Ground Test Operations	Comprehensive. Includes all ground systems tests involving two or more subsystems for purposes of qualification and development. Does not include component tests such as solar blankets, klystrons, etc. Does not include flight hardware.	A
04-03-00 Rectenna	Tests must verify 436,818 dipole subarrays plus distribution and conditioning system up to utility interface. 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
04-05-00 Utility Interface	Utility must be prepared to accept interim and incremental power as part of systems testing.	B
04-07-00 Operations	SPS test operations.	B
11-00-00 Facilities	Large facilities will be required for systems tests, particularly those in conjunction with the power source and STS.	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 C/O 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 fall-out 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

Plan No.: 5 **Title:** GROUND SUPPORT EQUIPMENT (GSE) DESIGN AND DEVELOPMENT

WBS Element	Impact	Category
03-04-01 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.	B
04-03-00 Rectenna	Checkout, maintenance, repair and replacement of large number of dipole panels in place may require special support equipment exclusive of test gear.	C
07-00-00 HLLV	Major system program/major support equipment.	C
08-00-00 STS	Major system program/major support equipment.	C
09-00-00 COTV	Major system program/relatively minor support equipment.	C
10-00-00 POTV	Major system program/relatively minor support equipment.	C
11-00-00 Facilities	Heavy investment required for solar blanket and high voltage testing.	C
	NOTE: Although GSE will represent a substantial investment neither the resource allocation, 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 - 30.6×10^6 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

SPS DDT&E PROGRAM PLANNING SUMMARY

PLAN	TITLE
6	MANUFACTURING PLAN

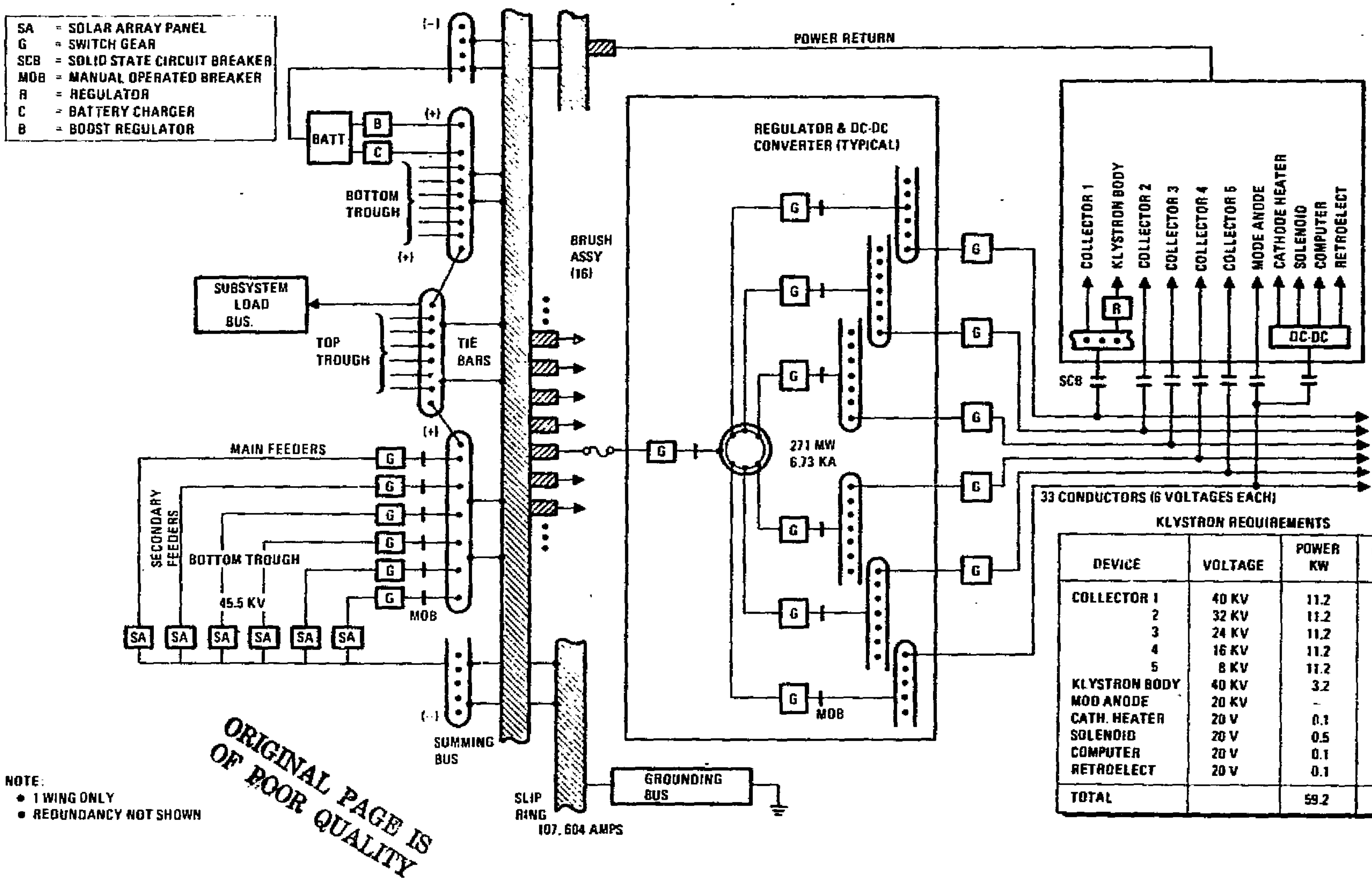
DISCUSSION:

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.

Development of high production, thin film, GaAs technology is probably the most critical item and will require a long term, well-funded program. Most of the current U.S. program under direction of DOE is aimed at providing a total production capability of silicon cells exceeding 500 MW/year by 1986.[1] 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 Space Operations, Plan No. 10.) Such items as beam machine complexes, templatas, 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 Space Operations Plan No. 10. "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.

[1] Ref: Photovoltaic Conversion Program, Summary Report, ERDA 76-161, November 1976



KLYSTRON REQUIREMENTS

DEVICE	VOLTAGE	POWER KW	REGUL-ATION
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%
CATH. HEATER	20 V	0.1	1%
SOLENOID	20 V	0.5	1%
COMPUTER	20 V	0.1	1%
RETROELECT	20 V	0.1	1%
TOTAL		59.2	

Figure 6-1. SPS PD&C Simplified Block Diagram

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SPS DDT&E PROGRAM PLANNING SUMMARY

PLAN	TITLE
6	MANUFACTURING PLAN

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 proto production will peak at 1666 m^2 per hour in 1994 and will need to increase to 15,000 m^2 per hour by the year 2000, and over 20,000 m^2 per hour by the year 2004, 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.

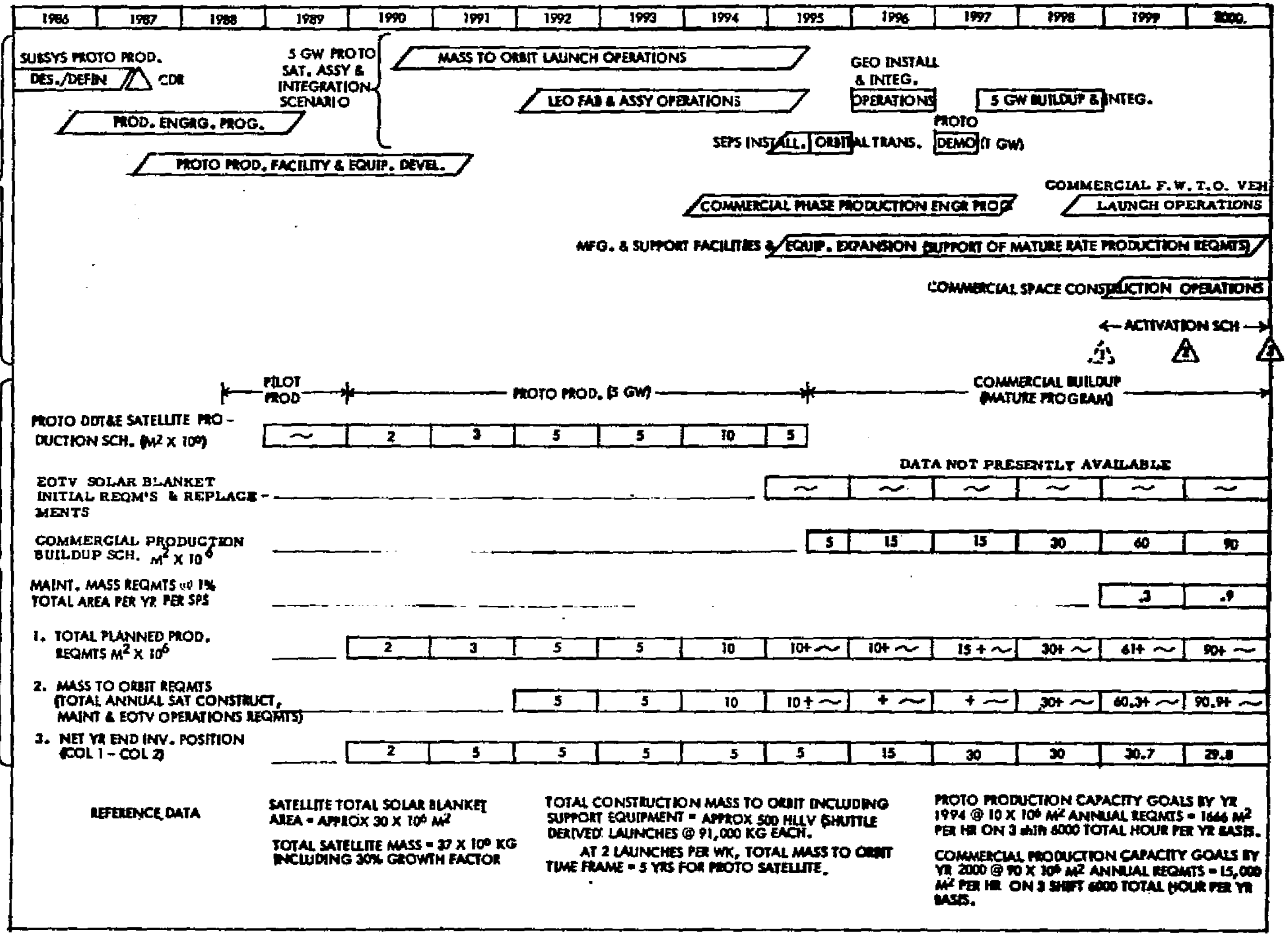

Figure 6-2. SPS Solar Blanket Requirements

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

Plan No.: 6 **Title:** MANUFACTURING PLAN

WBS Element	Impact	Category
03-00-00 Satellite System	Once point design is firm an overall satellite manufacturing plan must be provided in detail.	B
03-04-01 Solar Blankets	For the prototype SPS alone a 30.6×10^6 m^2 area of solar blankets is required. Starting in 1988 it is suggested that a production rate be developed per Figure 6-2 to support prototype and follow-on production. Average production during the period 1990-1995 would be 5.2×10^6 m^2 per year. The development of GaAs solar blankets meeting production, reliability, efficiency and weight goals is probably the major SPS technical challenge.	A
03-04-03 Power Distribution & Conditioning	Problems relate to the large quantity of high voltage, highly reliable components which must be produced. Figure 6-1 provides 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 (136,000-3.2 kW size), switch gears (7700 in 12 mW to 271 mW size) and dc/dc converters (32-271 mW size and 136,000-800 W size) sets will be involved. Plus system complexity with IMS control for array regulation, load control, and associated interfaces.	A
03-05-00 Microwave	Comments similar to the above apply to the MWPTS. In line with a decision to fabricate microwave resonant cavity radiators of 10 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 10 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, 6,993 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 No. 10, Space Operations.	B

Table 6-1.

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

(Cont.)

Plan No.: 6 **Title:** MANUFACTURING PLAN

WBS Element	Impact	Category
03-05-01 RF Gen. & Beam Control	Same comments as 03-04-03, however does not include regulators. Conductor problems will be resolved under 03-04-03. Method for high rate producibility of cathode structure/permanent magnet focusing will be required.	B
03-05-02 Waveguides	See Microwave Resonant Cavity Resonators 03-05-00.	B
03-05-03 Power Distribution & Conditioning	Similar comments to 03-04-03 and 03-05-01.	B
03-10-00 System Ground Test Hardware	Test articles for all components and subsystems will be built for qualification testing. This does not include flight or operational hardware.	B
04-03-01 Dipole/Rectifier Elements	Similar technology could be used as for element 03-04-01. 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 5,000,000 multi-layered panels of 4 types (78.5×10^6 m^2 per site), averaging 1.2m W x 12m long, assembled into 436,818 subarrays.	A
04-03-02 Power Distribution & Conditioning	Similar problem to 03-04-03 in terms of components and junctions, however, of lesser magnitude in technology. Includes switch gear, multiple junctions and converters.	B
04-03-03 Support & Ground Plane 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.	B

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

(Cont.)

Plan No.: 6 **Title:** MANUFACTURING PLAN

WBS Element	Impact	Category
05-00-00 Space Station		
06-00-00 Assembly & Support Equip.	Includes all special support equipment (teleoperators, beam machines, etc.) to assemble, checkout and maintain the satellite system.	A
07-00-00 HLLV	Each requires a separate manufacturing plan as part of the individual program effort.	
08-00-00 STS	(same as above)	
09-00-00 COTV	(same as above)	
10-00-00 POTV	(same as above)	
11-00-00 Facilities	Manufacturing requirements, particularly for solar blankets, power conditioning and distribution components and rectenna modules will require extensive facilities.	

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-I) 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-I)
- Reliability Assurance Requirements - NHB 5300.4 (ID-I)
- Systems Safety Requirements - NHB 5300.4 (ID-I)

RESOURCE CONSIDERATIONS:

- Technical and Management Personnel
- Support Equipment/Facilities & 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 Station, Space Station, Satellite). The plans, reflecting NHB 5300.4 (ID-I) 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.

SPS DDT&E PROGRAM PLANNING SUMMARY

PLAN	TITLE
7	PRODUCT ASSURANCE

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 endeavour. Due to the large size of the satellite rapid means of transportating 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 7-1.
SPS DDT&E Program Planning Considerations (Phase C/D)
Impact Sheet

Plan No.: 7 **Title:** PRODUCT ASSURANCE

WBS Element	Impact	Category
01-00-00 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
03-00-00 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
03-04-00 Power Source	System safety and reliability will be addressed at the 03-00-00 level since inspection, M/R, etc., must be performed on equipment with the photovoltaics (03-04-01) and concentrators (03-04-02) operating in combination.	C
03-04-01 Solar Blankets	15,000 square meters or more of solar blankets will be produced each day with associated checkout, and inspection and repair. This element includes product assurance considerations on the ground and in orbit.	C
03-05-01 RF Generation & Beam Control	Verification of pointing accuracy and interlock capability will be essential to public acceptance of SPS.	A
03-05-02 Waveguide	Quality assurance considerations relating to producing zero defects waveguide assemblies in orbit.	B
03-06-00 Propulsion	Safety aspects of fueling and performance M&R, etc., of multiple thrusters.	C
04-03-00 Rectenna	Problems similar to 03-04-00.	C

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 & Operations Facilities Requirements
  - Ground Support Requirements
- Requirements for Major/Critical New Facilities
  - Financial & Organizational Concept Financing

    Space Segment
    Ground Segment
- Scheduled Availability Requirements

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 and warehousing of equipment, such as those related to power generation and transmission (Table 8-1). The same will apply to major systems such as STS and HLLV which must include launch, recovery and refurbishment facilities.

Table 8-1.
SPS DDT&E Program Planning Considerations (Phase C/D)
Impact Sheet

Plan No.: 8 **Title:** FACILITIES

WBS Element	Impact	Category
01-00-00 Program Mgmt.	Top level planning function, major cost commitment required in subordinate areas indicated.	A
03-04-01 Solar Blankets	Production, test, storage facilities.	A
03-04-03 Pwr. Distr. & Cond.	Production and high voltage test facilities.	A
03-05-01 RF Generator & Beam Control	Production and high voltage test facilities.	B
03-05-03 Pwr. Distr. & Cond.	Production and high voltage test facilities.	B
04-03-00 Rectenna	Production facilities for approximately 500,000 dipole panels (78.5×10^6 m^2).	A
04-06-00 Site and Facilities	Includes all land, site preparation, buildings, access and utilities interface for rectenna and other elements of ground station. Site may encompass over 150 square kilometers. Several thousand workers must be accommodated during construction, reducing to 500-1000 when the site is placed into operation.	A
11-00-00 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

SPS DDT&E PROGRAM PLANNING SUMMARY

PLAN	TITLE
8	FACILITIES

A summary of the presently foreseen special facilities and equipment development needed to support the primary proto satellite development objective is shown in Figure 8-1. The schedule is WBS oriented and includes time phasing not only of the production of satellite and ground station components, but development of space transport facilities/equipment and space construction, maintenance, and logistics support bases. The program time phasing of these elements can be coordinated by referring to program milestone header listing in which they support.

SPS
DDT&E (PHASE C/D)
FACILITIES DEVELOPMENT SCHEDULE
SOLAR PHOTOVOLTAIC CR-2

Rockwell International
Space Division

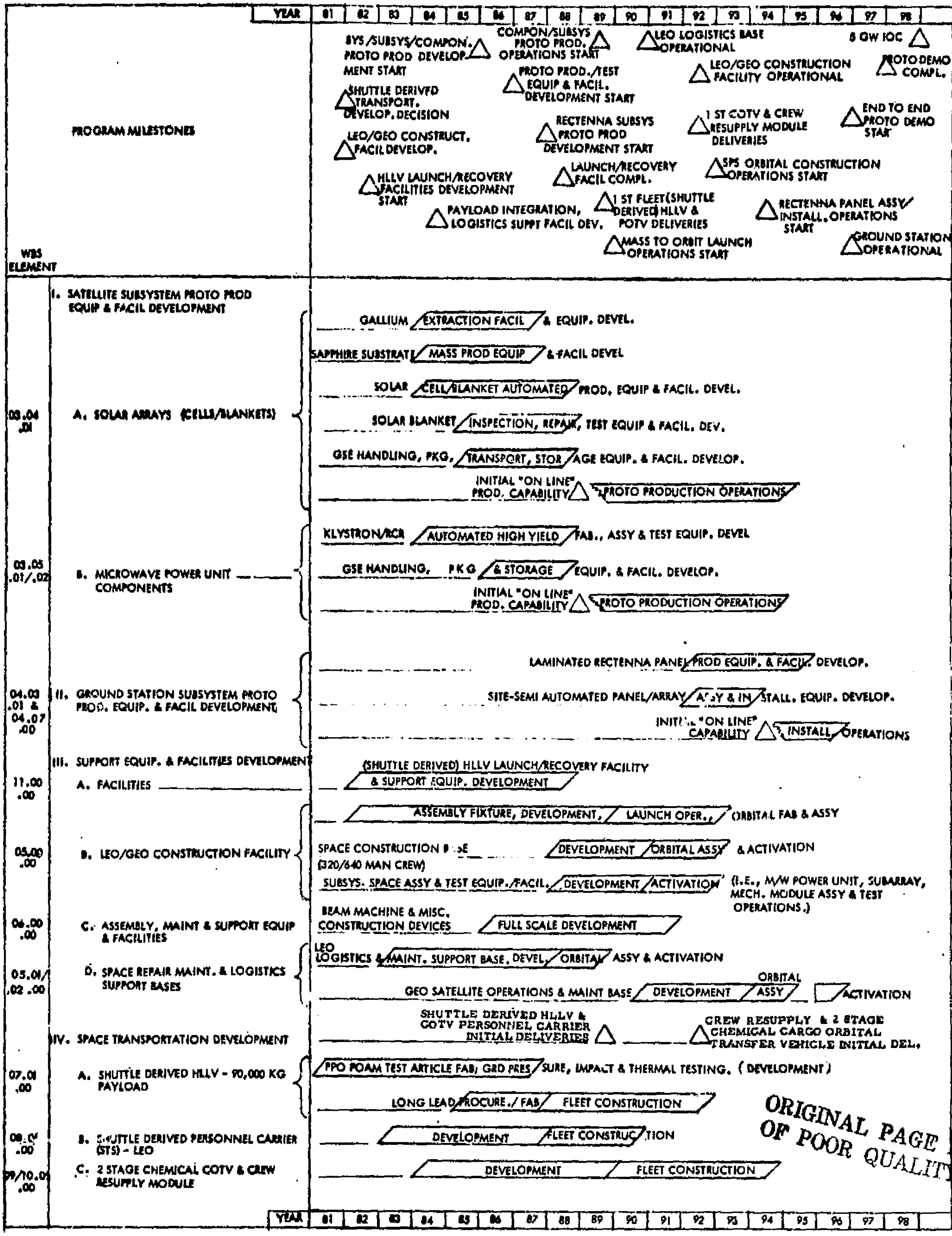

Figure 8-1. Facilities Development Schedule

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

Plan No.: 9a **Title:** GROUND OPERATIONS - GROUND INTEGRATION

WBS Element	Impact	Category
03-09-00 Ground Assembly & Integration	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

Rockwell International
Space Division

SPS DDT&E PROGRAM PLANNING SUMMARY

PLAN 9b — TITLE: 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 full 5 GW rectenna site will; for example, contain close to half a million dipole panels (12.24 meters wide by 14.69 meters 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

Plan No.: 9b **Title:** Ground Operations - Maintenance and Refurbishment

WBS Element	Impact	Category
04-07-00 Operations	Maintenance and refurbishment will cover all areas of ground stations including 436,818 dipole subarrays and all associated power conditioning, distribution and interface equipment.	B

SPS DDT&E PROGRAM PLANNING SUMMARY

PLAN 9c | TITLE

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 prototype 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 towards 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 No. 10, Space Operations. Table 9c-1 lists potential concerns in the logistics area.

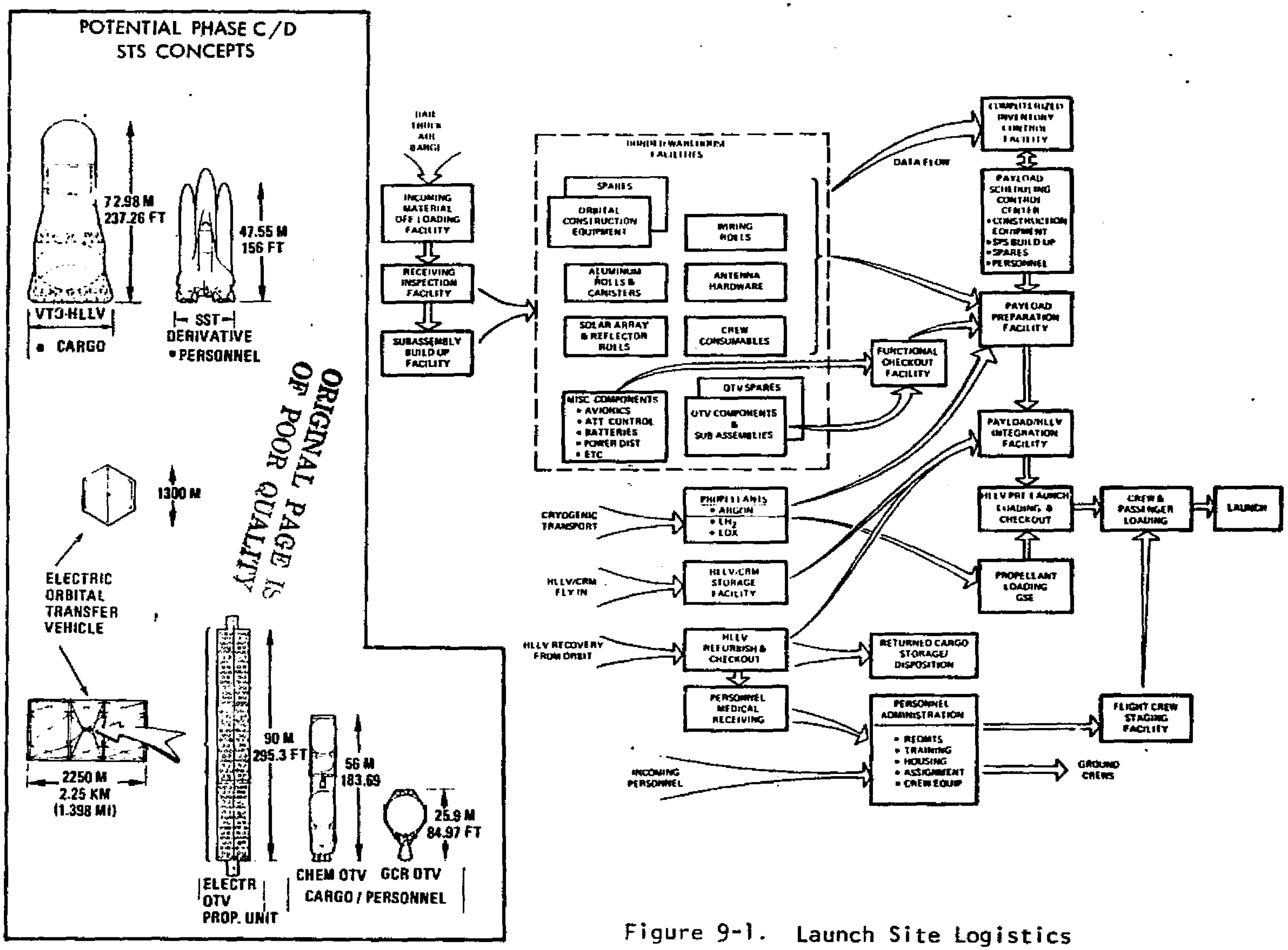

Figure 9-1. Launch Site Logistics

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

Plan No.: 9c **Title:** GROUND OPERATIONS - LOGISTICS

WBS Element	Impact	Category
01-00-00 Program Management		B
03-12-00 Operations, Ground	Manpower, training and support for space operations.	B
04-07-00 Operations	Manpower, training and support for ground station operations, maintenance and refurbishment.	B

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 covers 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)

SPS DDT&E PROGRAM PLANNING SUMMARY

PLAN	TITLE
10	SPACE OPERATIONS

- Maintenance and Refurbishment
- Interstation/Interorbital Transportation
- Product Assurance (Including Safety)
- Ground Support (i.e., operations, not logistics/facilities planning and operation, not construction)

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 as unique facets of the Space Operations Plan.

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

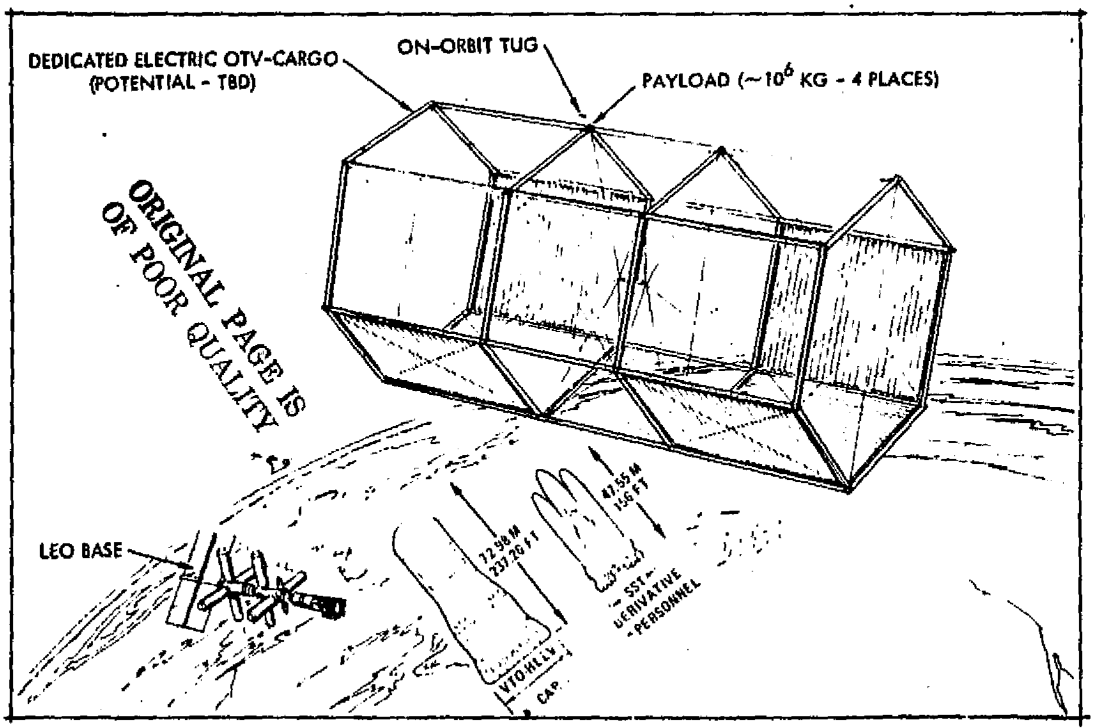

Figure 10-1. Potential Phase C/D Transportation System Concept

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

Plan No.: 10 **Title:** SPACE OPERATIONS

WBS Element	Impact	Category
01-00-00 Program Management	Summary planning functions integrating all major flight and supporting ground systems.	A
03-00-00 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
03-03-00 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 10-2. The resulting manufacturing sequence provides for full construction in a total elapsed time of 90 days and requires supporting several hundred men in orbit. The prototype, on the other hand, will be assembled in stages and will permit wide flexibility in sequencing and rate of assembly. Considerable study will be required to identify an optimum approach to prototype 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
03-12-02 Operations, Orbital	Along with development of the solar blankets (03-04-01) requirement to develop capability for larger scale, routine operations involving assembly, checkout, maintenance, etc., in orbit represents the greatest challenge to SPS.	A

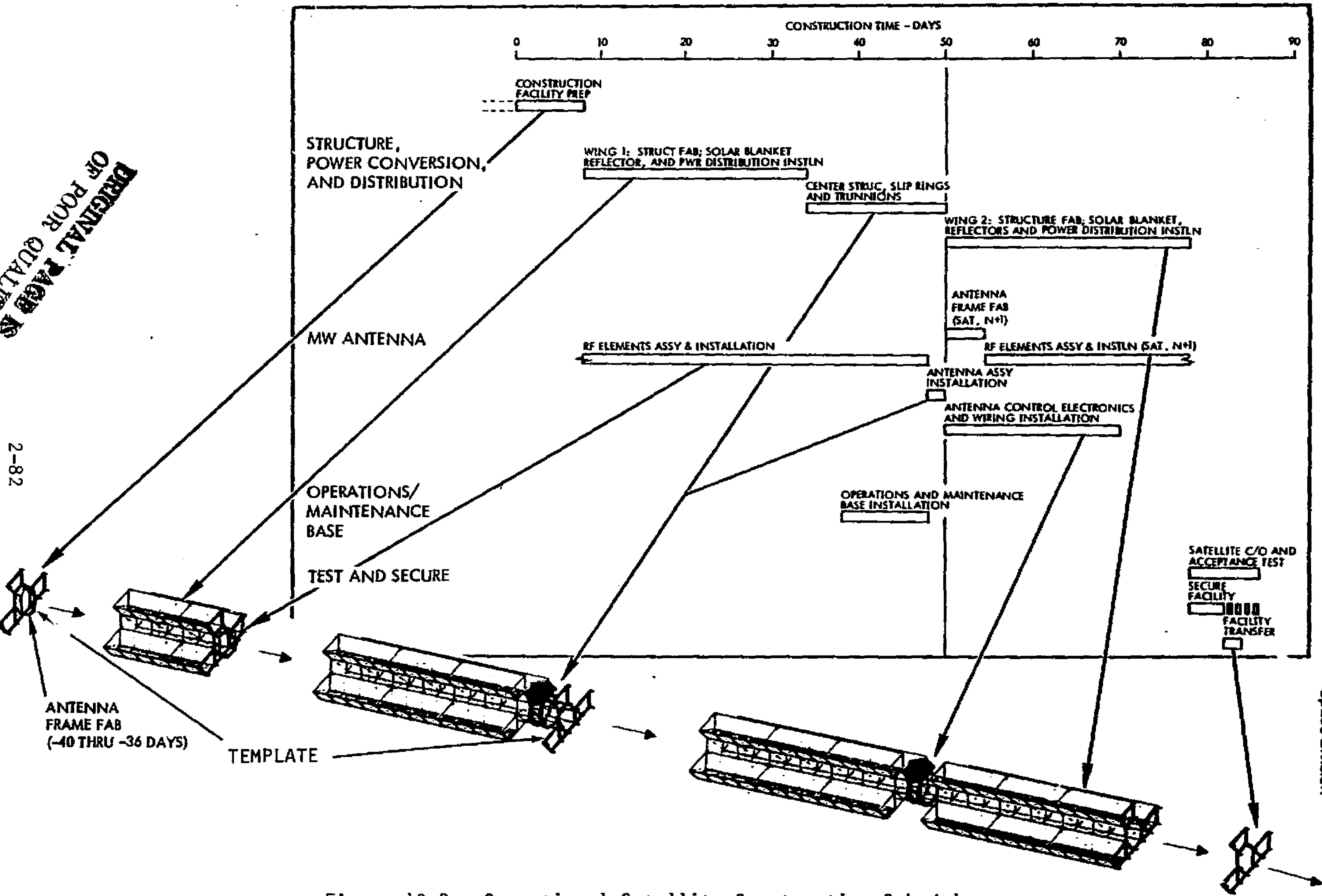

Figure 10-2. Operational Satellite Construction Schedule

SPS DDT&E PROGRAM PLANNING SUMMARY

PLAN 11 | TITLE: LAUNCH OPERATIONS

PROGRAM PLAN DESCRIPTIONS:

This plan shall address all the activities associated with launch operations. Launch operations covers 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

Plan No.: 11 **Title:** LAUNCH OPERATIONS

WBS Element	Impact	Category
01-00-00 Program Management	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 800 launches of a Shuttle - derived HLLV will be required to support prototype assembly over the period 1991 through 1996. This is an average of almost 2 launches per week.	B
03-12-01 Operations, Ground	See level 01-00-00.	A
11-00-00 Facilities	Facilities requirements to support STS operations.	A

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 on top.

SPS POINT DESIGN PROGRAM REQUIREMENTS:

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

RESOURCE CONSIDERATIONS:

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

DISCUSSION:

This plan might be incorporated under Plan No. 1 or No. 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 RESOURCE AVAILABILITY ANALYSES

PROGRAM PLAN DESCRIPTION:

This plan shall assess the degree and rate of consumption of critical materials, the degree of utilization of material extraction and production plants, and the sensitivity of this consumption toward meeting the program objectives, major milestones, and the initial operational capability of planned satellites.

SPS POINT DESIGN PROGRAM REQUIREMENTS:

- Solar Photovoltaic CR-2 Concept Definition
  - Satellite System Definitions
    Solar Blankets
  - Ground Station System Definitions
  - Space Transportation System Definition
  - Facilities Requirements
- SPS Programmatic Definition
- Resource Requirements

RESOURCE CONSIDERATIONS:

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

DISCUSSION:

On a national level a major impact on resources is not foreseen as a result of the Phase C/D DDT&E effort. For the SPS to be practical, however, long range plans must assure that resources to support the operational phase will be available and that the overall SPS concept is environmentally acceptable. Such factors as the following must be considered:

- Gallium availability
- Land availability
- Atmospheric effects (launch vehicle exhaust)
- Socioeconomic effects
- Noise pollution
- Space availability and allocation
- Ionospheric effects
- Terrestrial effects of MW transmission

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3.0 SPS ECONOMIC ANALYSIS

3.1 INTRODUCTION

This section of the report addresses results and conclusions of SPS cost analyses, trades and sensitivities, economic evaluations, and risk assessments that focused on system/subsystem and assembly levels of the WBS. Within this framework, the cost/economics were established at a level consistent with the depth of technical definitions of the study. A preceding section described the approaches taken to complete the tasks on SPS costs, economics, and risk assessment.

3.2 COST EFFECTIVENESS

As the study progressed, certain observations were made concerning cost perspectives of major hardware and activities of the SPS program. Cost drivers began to emerge and an increased emphasis was given where cost benefits could contribute to the confidence level of identified final system costs. Of all the SPS items studied, the satellite power source and microwave systems, and the ground station system rectenna accounted for a majority of the costs in the individual areas. Technical definitions during the study of SPS space transportation elements also indicate areas of significant cost that will require analysis after further technical assessments.

3.2.1 PHOTOVOLTAIC COSTING APPROACH

The following activities were undertaken to establish confidence in the cost data developed for the various elements of the solar photovoltaic satellite concept:

- Completed detail review and study of NASA/MSFC CER's and supporting data. CER's (cost estimating relationships) were constantly reviewed and analyzed with the technical staff—especially on items where cost trades or grass root analyses indicated the need to confirm cost estimates.
- Conducted a correlation of CER's on the Si design based on the cost of known Si space solar cell panels.
- Determined the cost of large 10^6 m^2 arrays to verify the CER for Si array.
- Compared the complexity of manufacturing of Si and GaAlAs cells and factored results into CER for GaAlAs solar cell arrays.
- Normalized cell costs based on mass production and automated assembly techniques for post-1985 time period.

- Established grass roots cost analysis for arrays and reflectors. Determined cost of raw materials, processes, and projected component costs.

- Estimated reduction in raw material cost as a function of production volume and factored in component costs. At regular intervals, system/subsystem cost assessments were subjected to ERB (Engineering Review Board) meetings with the program manager, task leader, and cognizant engineer under the direction of Program Development. These agendas treated comparative costs, vendor quotes, materials costs unique to the scope of SPS requirements, and scaling/complexity factor evaluations.

- Conducted studies on solar cell efficiency to obtain economic benefit.

A comparison of GaAlAs cell manufacture with Si cell manufacture was reviewed. In reviewing the manufacturing process, there are actually fewer steps required to produce a GaAlAs cell and a mass production mode would offset the higher cost of the raw materials for the GaAlAs cell.

The junction thicknesses for the GaAlAs cells are much thinner than for Si and, therefore, the through-put of the manufacturing plant will be much higher. Using the metal-oxide-chemical vapor deposition (MO-CVD) process, good dimensional control can be obtained, and the CVD process lends itself readily to a continuous process flow operation. In discussions with one solar cell manufacturer, it was stated that they are planning to reschedule and modernize their manufacturing line and would predict that in five years the majority of their production will be GaAlAs cells.

Mass production of cells for Si cells are projected for the post-1985 time period to result in cell processing cost of $\$17/m^2$, and processing of blankets of another $\$17/m^2$. Mass production of GaAlAs cells was estimated to also result in processing costs of $\$17/m^2$ for the cells and the blankets. Therefore, the only major difference between the GaAs cell and Si cell will be the cost of the raw materials. Present day costs of the GaAs cell materials are tabulated below:

	Cost ($/kg)
Ga	500
As	150
Sapphire (Al_2O_3)	325 (semiconductor grade)

As shown below, the cost of raw materials (at today's prices) in the cell design for SPS is $\$37.60/m^2$.

Ga	$\$6.78/m^2$
As	1.95
Al_2O_2	25.87
Blanket material	3.00
	$\$37.60/m^2$

As the requirements for the raw materials increase, the prices should decrease and volume discounts can be negotiated and obtained. It is interesting to note that although Ga is the highest priced material, it is the sapphire substrate that has major impact on the total raw material costs. It is possible that with large-quantity buying that the cost of the Ga, As, and blanket material could be reduced by 50 percent of their present-day cost.

The sapphire substrate should be given special consideration to reduce its price. Volume production and increased use of the material will certainly reduce its cost. Also, it would be advantageous to reduce the sapphire thickness (if possible) from 20 μm to 15 μm, and this would reduce its price by 25 percent on a square-meter basis.

The solar cell blankets result in one third of the cost of the average commercial phase SPS satellite. An investigation was conducted to understand the cost makeup of the solar array and to try to reduce the array costs. The first approach was to clearly understand the cost of each element of the array and to develop a *grass roots* cost model for raw material costs and processing costs; an average array cost of approximately $\$60/m^2$ was obtained for the 120 satellites of the SPS program.

The second approach for cost reduction was to employ solar concentrators to replace the high-cost solar arrays with low-cost reflective membranes.

For the SPS point design, a concentration ratio (CR) of 2 was used. As the CR is increased, the cost of the array and satellite will decrease to the point where the complexity of assembly and increased reflector area and structural penalty negate the saving. Also, if the CR exceeds approximately 5, then an active cooling system is required for the array and additional weight and cost penalties are incurred.

A grass-roots determination of concentrator costs at CR-2 was completed. Figure 3.2-1 shows the cost of material and processing of Kapton-Type H where approximately 50 percent of the cost is material. Today's cost of 1-mil Kapton is $22¢/ft^2$, and another $10¢/ft^2$ is added for aluminized coating on the concentrator. Early in-house projections (represented by the dashed lines at 15¢ and 24¢, respectively) were subsequently adjusted to acknowledge detail discussions with DuPont and National Metallization. The results of the discussions established 0.5-mil Kapton at $22¢/ft^2$, with 2¢ for the coating, to make a total of $\$2.58/m^2$. There is the potential that the Kapton material cost may be reduced further, from $22¢/ft^2$ to $15¢/ft^2$, but it is a function of such variables as production rate, plant location, transportation cost, specification requirements, investment capital, etc.

The third approach to reduce the array cost would result from improved GaAlAs cell operation and resistance to the space environment for UV and ionized radiation. The point design GaAlAs cell used in the SPS is rated at 20 percent efficiency at AMO and 28°C.

There is now some preliminary work being done on cascaded solar cells which may obtain 25 percent, or more, efficiency. The Air Force has recently issued an RFP in this area for the development of a cascaded cell. An increase in cell efficiency to 25 percent, from the point design efficiency of 20 percent, would result in a significant savings in cost, weight, and solar area compared with the current SPS point design.

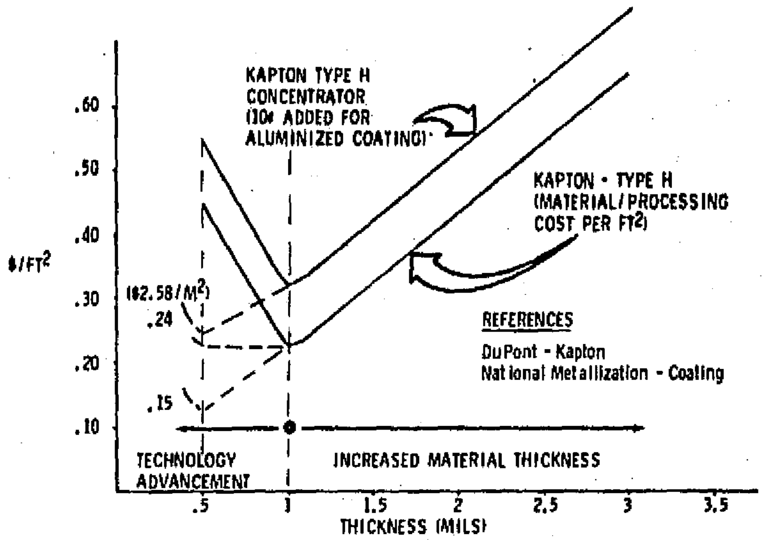

Figure 3.2-1. Photovoltaic Concentrator
(Grass Roots Determination)

3.2.2 PHOTOVOLTAIC SYSTEM COMPARISONS

Tradeoff studies as to weight, deployed area, and cost of photovoltaics were performed to define in more detail the baseline point design. The areas, weights, and costs of the solar cell, reflector, array conductor, and structure as a function of efficiency and launch costs of $10 to $60/kg to GEO were calculated. The weight and cost of the combined subsystems as a function of efficiency are shown in Figure 3.2-2. As the distribution efficiency increases,

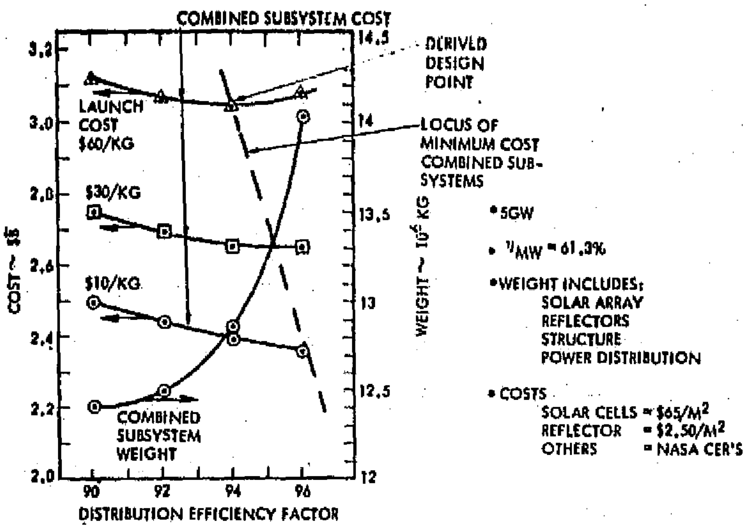

Figure 3.2-2. Photovoltaic Parametric Cost and Weight Comparisons

the solar blanket and reflector size decrease, the struct ra weight decreases, and the conductor weights increase. The result is that ov... l system weight increases monotonically as the distribution efficiency increases. The cost curves, however, reach a minimum--depending on launch costs--and then increase again with efficiency. The locus line for the minimum cost is shown in the curve, and for the SPS photovoltaic point design configuration, the nominal distribution efficiency was selected to be 94 percent for the range of launch costs of $40/kg to $80/kg to GEO.

3.2.3 RECTENNA COST ANALYSIS

Each rectenna farm area of 10×13 km contains 814 rows of rectenna panels tilted 40 degrees to the horizontal, providing an active intercept area of 78.54×10^6 m^2. Since an individual panel is 12.24×14.69 m, some 436,818 panels will have to be assembled on site and erected. Several rectenna panel design concepts have been considered, and the element of cost has played an important part in all design definitions. Table 3.2-1 summarizes a grass-roots determination that was completed on the bow-tie dipole panel design, which incorporates both technical and economic advantages for the rectenna design.

Table 3.2-1. Rectenna Bow-Tie Dipole Panel Cost Data

5-GW GAUSSIAN BEAM

Total panel area = 845×10^6 ft^2 (78.5×10^6 m^2)/436,818 panels

	Item	Factor	Total
Foam - 0.0931 lb/ft^2 ($0.872/lb) 845×10^6 ft^2	$68.6×10^6$	4	$274.4×10^6$
Copper-Clad Mylar - 3 layers 3 ($0.0175/$ft^2$) 845×10^6 ft^2	44.27×10^6	4	177.1×10^6
Etching - 2 layers 2 ($0.0087/$ft^2$) 845×10^6 ft^2	14.77×10^6	4	59.1×10^6
Bonding - 4 layers 4 ($0.0262/$ft^2$) 845×10^6 ft^2	88.55×10^6	4	354.2×10^6
	TOTAL		$864.8×10^6$
			[$1.02/$ft^2$ ($11.02/$m^2$)]

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NOTES -

- Projected 1985 technology in 1977 dollars
- Factor includes diode rectifier and estimating margin

3.3 SPS COST ANALYSIS

This section summarizes the cost data developed during the study. It includes costing ground rules and assumptions, costing methodology, cost breakdown summaries, and cost by fiscal year.

3.3.1 COSTING GROUND RULES AND ASSUMPTIONS

The following major ground rules and assumptions were considered in developing data during the study:

- All cost estimates are in constant mid-1977 dollars.
- Costs are reported by WBS level in terms of:
  - Development cost through TFU (theoretical first unit)
  - Initial capital investment cost per satellite (Satellites TFU and 2 through 120)
  - Replacement capital investment (RCI) cost, and operations and maintenance (O&M) cost per satellite per year. (Assumed SPS operational lifetime of 30 years with maintenance)
- Assumed 1985 technology base and resources supply/demand conditions.
- Assumed 90 percent launch vehicle load factor in calculating cost of mass flow to LEO.
- A 30-percent satellite mass contingency is reflected in only those satellite costs with mass-dependent cost calculations.

3.3.2 COSTING METHODOLOGY

The SPS cost estimates were developed parametrically utilizing a computer cost model. The purpose of the computer cost model is to provide an analytical tool to support the systems analysis process by assessing the cost implications of various SPS system design decisions. While the cost estimating relationships (CER's) 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 cost estimates. What is desirable at this stage, in order to aid in the determination of preferred concepts, is to have the capability to predict the direction and relative magnitude of cost impacts that will be brought about by design decisions.

The satellite system and ground station system costs were developed utilizing the NASA/MSFC SPS computer cost model with certain CER variations. Costing of the remaining WBS elements such as the space station elements, launch vehicles, orbital vehicles, space equipment, facilities, and taxes and insurance utilized the MSFC cost model, but with slight modifications in some areas in order to exercise a more simplified direct function. Therefore, much of the following discussion and the CER rationale and descriptions provided in Appendix B are based upon that developed by MSFC for the computer cost model.

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 by the CER's and by the cost equations for 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 cost for each type of cost.

The DDT&E equation (CD) estimates the cost of the design, development test and evaluation, non-recurring (excluding ground test hardware), ground test operations, program management (PM), and systems engineering and integration (SE&I). Program management and SE&I are shown as separate line items in the WBS at project level and at system level. Separate factors are provided for calculating the project and system program management and SE&I costs. In view of the gross nature of the level of information currently available on the ground test hardware and the ground test operations, the cost of these two WBS items has been assumed to be the equivalent of one-half the satellite system TFU cost.

The appropriate inputs for the DDT&E CER's are the applicable total system mass, area or power. A development factor is provided in the equation (DF) 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 three different forms—CLRM, CTFU, and CIPS. The CLRM (cost of lowest repeating module) equation requires that the point 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. It automatically takes into account the progress over production quantities required when calculating CIPS. In some ICI cost equations, such as avionics —display and control and space station elements—the appropriate input for the CLRM cost calculation is the total mass per satellite/module. In these cases, the cost equation calculates the value of one LRM and exercises this LRM value in the normal manner as the TFU value is used to calculate IPS.

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 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 initial investment 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 reflected in the following WBS items:

03-06-00	Propulsion
03-12-00	Satellite System Operations
04-07-00	Ground Station System Operations
07-02-00	STS/HLLV Operations
08-02-00	IOV Operations
09-02-00	COTV Operations
10-02-00	POTV Operations

The cost methodology seeks to account for five separate effects which influence SPS cost; these are 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, cost per unit of size will decrease. The slope 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 based to manned spacecraft specification levels using factors from the RCA Price Model.[1] From that model, an average cost factor to adjust MILSPEC 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

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

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.

As required by the costing ground rules and assumptions, all CER's are in terms of 1977 dollars. The study did assume 1985 technology and 1985 supply/demand conditons which, in some cases, resulted in differential (non-general) price inflation or deflation between 1977 and 1985 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.

3.3.3 COST ESTIMATES

Tables 3.3-1 and 3.3-2 summarize cost data developed during the study. Table 3.3-1 reflects the SPS project-related development cost (CD) through the first full 5-GW satellite (TFU) including space transportation fleets (HLLV and OTV's); initial space assembly and support requirements; and the facilities needed to establish the SPS operational capability. This means that the TFU cost includes elements with a lifetime capability of building more than one SPS system. Table 3.3-2 summarizes the investment cost per satellite (CIPS) and the replacement capital investment cost (CRCI)/operations and maintenance cost (CO&M) per satellite per year. Figure 3.3-1 shows a comparison of the cost relationship of the summary WBS elements for each of the above. Additional cost data are provided in Appendix B by lower level WBS elements within each program phase.

Table 3.3-1. Satellite Power System Project Development Cost
(Millions of $)

5GW PHOTOVOLTAIC CR=2

WBS #	DESCRIPTION	DDT&E	DEVELOPMENT TFU	TOTAL
01-00-00	PROGRAM MANAGEMENT	341.399	262.384	603.783
02-00-00	SE&I	1625.710	514.479	2140.189
03-00-00	SATELLITE SYSTEM	10483.742	5750.535	16234.277
04-00-00	GROUND STATION SYSTEM, GSS	132.364	2624.531	2756.896
05-00-00	SPACE STATION	9198.422	8807.328	18005.750
06-00-00	ASSEMBLY & SUPPORT EQPT.	582.300	749.731	1332.031
07-00-00	STS - HLLV	7921.199	2991.271	10912.469
08-00-00	INTRA ORBIT VEHICLE	97.900	97.916	195.816
09-00-00	CARGO ORBITAL TRANSFER VEHICLE	394.383	1328.299	1722.682
10-00-00	PERSONNEL ORBITAL TRANSFER VEHICLE	493.900	124.357	618.257
11-00-00	FACILITIES	3210.000	3250.000	6460.000
12-00-00	TAXES	0.0	0.0	0.0
13-00-00	INSURANCE	0.0	0.0	0.0
	TOTAL	34481.305	26500.816	60982.121

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Table 3.3-2. Satellite Power System Project Average Cost
(Millions of $)

5GW PHOTOVOLTAIC CR=2

WBS #	DESCRIPTION	INV PER SAT	** OPS COST PER SAT PER YEAR ** FCI	O&M	TOTAL OPS	TOTAL
01-00-00	PROGRAM MANAGEMENT	100.710	1.160	16.069	17.229	117.939
02-00-00	SE&I	197.471	2.274	31.508	33.782	231.253
03-00-00	SATELLITE SYSTEM	4951.836	52.375	29.592	81.967	5033.801
04-00-00	GROUND STATION SYSTEM, GSS	2574.820	11.700	0.217	11.917	2586.736
05-00-00	SPACE STATION	886.378	47.104	0.0	47.104	933.481
06-00-00	ASSEMBLY & SUPPORT EQPT.	15.843	0.003	0.0	0.003	15.846
07-00-00	STS - HLLV	1294.925	0.0	1485.000	1485.000	2779.925
08-00-00	INTRA ORBIT VEHICLE	14.167	0.263	1.500	1.763	15.930
09-00-00	CARGO ORBITAL TRANSFER VEHICLE	58.822	0.446	21.300	21.746	80.568
10-00-00	PERSONNEL ORBITAL TRANSFER VEHICLE	10.121	0.127	0.450	0.577	10.698
11-00-00	FACILITIES	66.607	1.667	0.0	1.667	68.333
12-00-00	TAXES	0.0	0.0	36.047	36.047	36.047
13-00-00	INSURANCE	0.0	0.0	1.287	1.287	1.287
	TOTAL	10171.730	117.118	1622.969	1740.088	11911.816

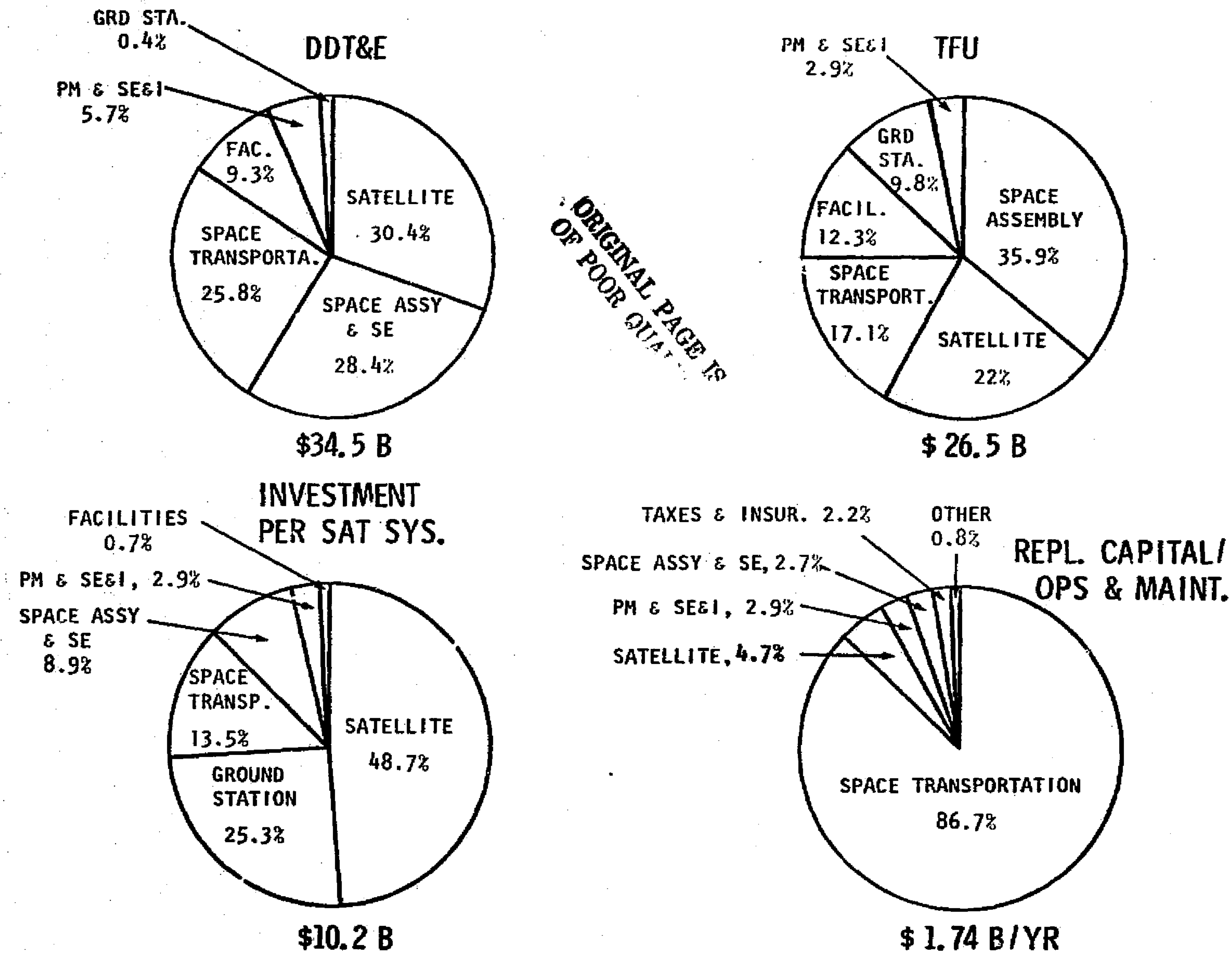

Figure 3.3-1. SPS WBS Cost Relationship

Development Cost (DDT&E)

The DDT&E phase consists of the one-time effort associated with designing, development, 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 analysis, 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 a 1-GW SPS prototype demonstration satellite which, following demonstrations, will be upgraded to the full 5-GW satellite (TFU). Also included are the analysis 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.

The total project development cost through the first full 5 GW satellite (TFU) system is $60.982 billion (DDT&E is $34.481 B and TFU is $26.501 B). Table 3.3-1 identifies the main areas of cost by WBS category. Figure 3.3-1 reflects this relationship within DDT&E and TFU cost areas. The satellite portion of the DDT&E cost is $10.483 billion. Cost to develop the space assembly and support equipment is $9.780 billion; and the space transportation DDT&E is $8.907 billion.

The TFU cost breakdown shown in Table 3.3-1 and Figure 3.3-1, reflects a somewhat different makeup of costs when compared to DDT&E costs. TFU estimates at $26.5 B include the full dollar assessment for the initial satellite and ground station buildup including space transportation fleets (HLLV's and OTV's); initial space assembly and support equipment requirements; and the facilities needed to establish a 5 GW SPS operational capability. This means that the TFU cost includes elements with a lifetime capability of servicing/building more than one SPS system. In this regard, analysis will show that space assembly and support equipment represent the largest portion of total TFU costs - $9.557 B. Satellite system costs are $5.750 B; space transportation - $4.542 B; and ground facilities at $3.250 B. In the space assembly and support equipment TFU costing, the LEO/GEO satellite construction base makes up 84% of the total space assembly and support equipment estimate.

The more detailed DDT&E cost breakdowns provided in Appendix B show that the structure, ground test hardware, and ground test operations make up the largest portion of the satellite system DDT&E cost at about 25% of the total for each. The power source system accounts for only 3.2%; the microwave antenna, 2.5%; attitude control and avionics, less than 1.0%; and thermal control, .4%.

costing of DDT&E for the space station 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.

The development factor was determined by engineering and, in general, was estimated to be 20 percent--with a few exceptions. This means that it was determined by engineering that the appropriate DDT&E cost necessary to develop the total subsystem would equate to the cost of 20 percent of the total subsystem mass, area, or power per satellite. In some cases, it was determined that the factor should be slightly higher. The development factor for attitude control was estimated to be 30 percent; for the microwave antenna, 40 percent; and for the antenna structure, 50 percent. Some of the avionics component development factors are less than 20 percent. The computer cost data tables included in Appendix B reflect the application of the development factor (DF) for each satellite subsystem.

Investment and Operations

Table 3.3-2 reflects the investment and operations cost data developed during the study. 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. 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 120. This total average cost of $10.172 billion (Figure 3.3-1) includes $4.952 billion for the satellite; $2.575 billion for the ground station (rectenna); $1.378 for space transportation; and $.902 billion for space assembly and support equipment. The total average (investment) cost per 5 GW satellite yields an investment of $2034/kW.

SPS Replacement capital and operations/maintenance phases have been combined and are estimated at an annual cost of $1.740 billion or $52.202 billion over the 30 year operational period. Space transportation requirements comprise 86.7% of these costs.

Appendix B provides additional detailed cost data on investment and operations costs.

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3.3.4 SPS COST BY FISCAL YEAR

Table 3.3-3 summarizes the full-scale DDT&E and incremental cost build-up of the 5 GW TFU by year from 1980 through the year 1998. The time period is reflected in terms of consecutive years (1 through 19), beginning in 1980.

Table 3.3-3. DDT&E Plus TFU Cost by Year

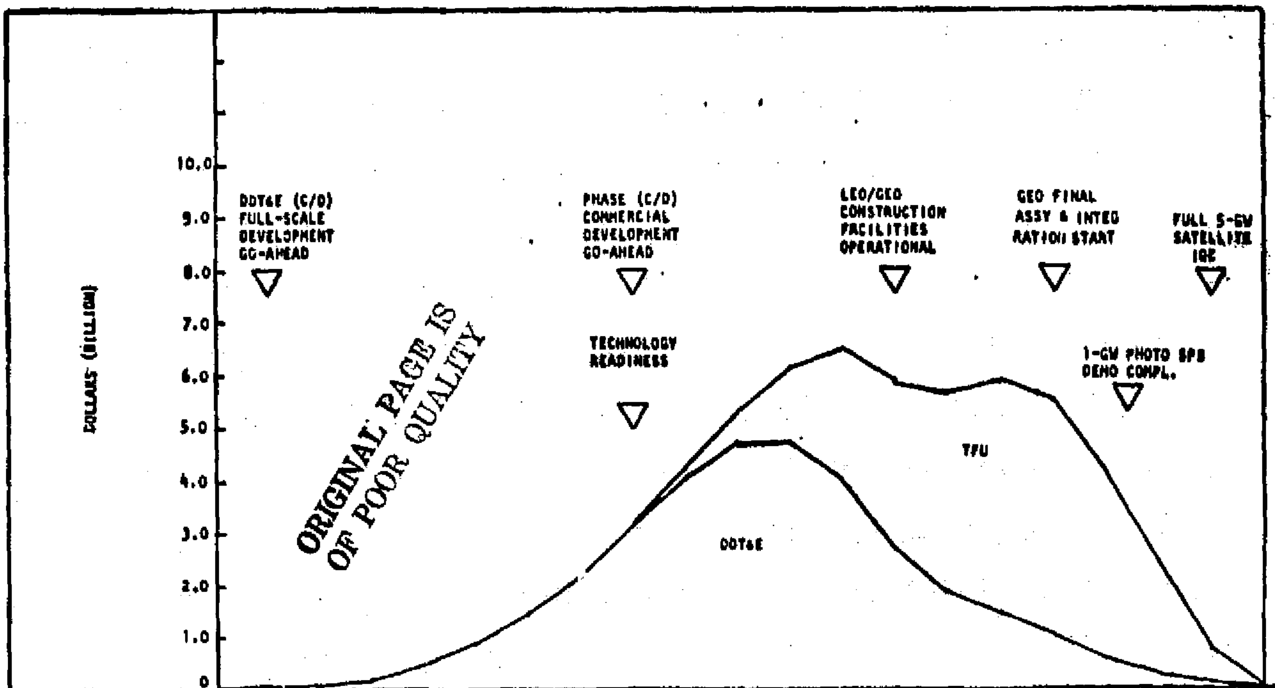
YEAR	01 PL	02 SENI	03 SAT	04 GSS	05 SS	06 AASE	07 HLLV	08 TOV	09 COTV	10 POTV	11 FTI	TOTAL
1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
3	0.17	0.83	11.36	0.03	0.0	0.0	0.0	0.0	0.0	0.0	0.0	12.39
4	1.17	5.55	73.17	0.14	0.0	0.0	0.0	0.0	0.0	0.0	0.0	80.02
5	3.02	10.37	179.76	4.06	5.20	0.33	14.73	0.0	0.0	0.0	0.0	217.42
6	5.56	26.56	414.11	1.07	52.56	3.33	92.56	0.0	0.0	0.0	0.0	595.76
7	8.05	41.37	461.37	1.78	180.05	11.44	220.73	0.0	0.0	0.0	0.0	926.43
8	12.16	58.01	660.32	3.21	403.47	25.54	373.73	0.0	0.0	0.0	0.0	1484.47
9	15.09	75.67	743.16	4.73	710.31	44.97	528.88	0.0	0.0	0.0	80.91	2205.08
10	20.56	93.49	850.61	6.49	1075.02	67.47	666.30	0.0	0.0	0.0	423.71	3201.84
11	20.93	112.99	969.15	6.40	1449.93	101.56	777.92	0.0	0.0	8.10	779.38	4237.00
12	39.65	140.24	1153.26	10.35	1900.11	172.59	983.10	0.0	9.96	44.56	914.12	5327.96
13	50.66	171.21	1368.27	12.17	2251.52	241.86	1145.55	0.0	52.06	88.41	759.03	6140.76
14	60.20	199.77	1666.76	13.75	2282.09	206.60	1261.73	4.63	95.76	118.37	432.14	6291.18
15	66.86	270.89	1678.17	57.88	1775.44	216.66	1274.98	24.74	112.31	125.35	331.61	5867.70
16	69.56	230.55	1661.37	251.93	1335.50	131.59	1102.70	41.68	190.18	103.34	496.53	5715.13
17	67.66	225.62	1570.73	466.33	1310.60	48.26	996.38	26.65	465.46	55.52	601.09	5922.71
18	60.72	204.77	1335.02	634.12	1279.50	0.0	741.56	7.38	547.40	26.73	617.00	5454.21
19	48.75	166.55	984.52	632.76	1036.06	0.0	457.86	31.78	249.57	24.52	534.51	4166.89
20	32.10	111.31	543.36	464.15	673.31	0.0	198.95	40.35	0.0	17.20	362.32	2443.06
21	11.43	40.27	151.79	166.49	232.47	0.0	32.59	18.40	0.0	6.16	127.66	784.76
22	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
23	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	603.70	2140.19	16236.25	2756.90	16005.73	1332.03	10912.45	195.81	1722.68	618.26	6460.00	60982.04

A spreading function curve (ojive) was used in the time-phasing of costs within the various system categories of the SPS WBS. A 50/40 cost spreading function was used as it was the most representative of the low-level buildup during the technology verification phase, and the most realistic for the time period associated with development engineering, design, testing, and evaluation necessary to determine viable subsystem designs for solar power conversion, microwave power transmission, ground station system, and space transportation. As for the TFU cost spread by fiscal year, the 50/40 distribution supports a low, front-end buildup which provides for early incorporation of test results into the full-scale operational hardware within the scheduled milestones. The HLLV transportation system (07) element reflects time-phased dollars that also include the DDT&E costs projected for the low-cost transportation vehicle (FWTO—Fixed Wing-to-Orbit) vehicle required for the implementation of the commercial investment phase of the SPS program.

A relatively low profile prevails through the early 1980's, reflecting the activity of the technology verification program. The fiscal costs then rapidly expand through the mid-/late-1980's as the need for developing proto production technology, equipment, and facilities grow and the operations for hardware buildup proceed in support of early launch, ground operations, and space construction tasks. Fiscal costs peak during the early/mid-1990's, reflecting a peak simultaneous with ground production, launch, and full-up space activity. The mid-/late-1990's focus on (1) the 1-GW proto unit test program, (2) GEO integration and evolution to the 5-GW satellite, (3) ground station integration, and (4) SPS system tests and proto demonstration operations.

Figure 3.3-2 graphically displays the funding requirements and peak year distributions for DDT&E and TFU. DDT&E cost peaks at just over $4.7 billion during the years 10 through 11 (1989-1990). This time period corresponds to the activation time of the space construction base, orbital support equipment, and satellite construction fixtures. The FTU costs peak at nearly $4.5 billion in years 15 and 16 (1994-1995), which is the time period associated with construction, assembly, and test of the first full 5-GW satellite.

Cost by fiscal year for the investment, replacement capital, and operational phases covering Units 2 through 120 are presented in the next section on financial and operational concepts of the SPS program for the period of 1999 through the year 2028.



YEAR	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	TOTAL DOLLARS (BILLIONS)
	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	[illegible]	1994	1995	1996	1997	1998	1999	
DDT&E	.012	.080	.218	.496	.926	1.485	2.205	3.203	4.151	4.737	4.742	4.012	2.794	1.896	1.481	1.043	.666	.287	.047	0	34.481
TFU								.001	.086	.591	1.399	2.280	3.073	3.819	4.442	4.411	3.500	2.156	.743	0	26.501
TOTAL	.012	.080	.218	.496	.926	1.485	2.205	3.204	4.237	5.328	6.141	6.292	5.867	5.715	5.923	5.454	4.166	2.443	.790	0	60.982

Figure 3.3-2. Cost by Fiscal Year

3.4 FINANCIAL AND OPERATIONAL CONCEPTS

This section of the report summarizes the evolution of a recommended concept for the funding and organizational alignment of the SPS program; provides specific information on a workable funding concept; and proposes an organizational structure for the operational space and ground segments. The work leading to these conclusions involved a period of preliminary definition of some six concepts and their variations; an expansion of these concepts and the development of scenario elements; identification of two preferred approaches (concepts); and the definition and finalization of the recommended/selected concept for achieving the best partnership between industry, utilities, and the federal government for a satellite power system program of great cost magnitude and economic impact. Detail information and supporting analyses on the various SPS concepts studied are presented in Appendix C of this Volume VII - SPS Program Plan and Economic Analysis.

3.4.1 GUIDELINES, GROUND RULES, AND ASSUMPTIONS

Pertinent background material and resource information was analyzed to form study guidelines, ground rules, and basic assumptions relative to projects of applicable size and scope that would involve the participation of government, electric utility industry, and general industry. From this analysis, several important premises were established:

- Financial and operational success of the projected satellite power system will stem, in part, from relevant space projects (space transportation systems, Spacelab, space industrialization programs, etc.).
- Investments in satellite power systems (space and ground segments) would be made after successful demonstration projects have been accomplished under government DDT&E funding of the first fully operational 5 GW system.
- Utilities will form regional consortia to provide funds for satellite power systems offering electrical power on a basis comparable to similar capability and overall costs in competitive power generation.
- Industrial firms will form consortia to provide funds that present a comparable cost basis for similar capabilities on earth with the added benefits of improved quality, reliability, performance, life, and producibility.

General assumptions and ground rules have been established for the SPS organizational entities, as proposed, based on the following considerations: (1) current views of the economic environment, total U.S. energy consumption and projection, and government funding levels that offer the opportunity to present and sell a well-conceived SPS program; (2) the impact of an SPS type program upon estimated Department of Energy, NASA, and other Governmental funding levels through 1995, and beyond, warrants the consideration of a selected financial and operational concept over other considered concepts/ options; (3) space industrialization projects by the Government - NASA, and U.S. industry are necessary activities and should precede or parallel the SPS operational development; (4) utilities, via consortia funding participation, will be interested and willing to invest in the SPS following demonstrated economic and operational feasibility; and (5) funding data and market/ investment data for government, utilities, and industry can be utilized for deriving investment participation between government, utilities, and general industry. In addition, a basic ground rule was established whereby the SPS will be a national corporation--with varying roles, investments, and ownership participation by the government, electric utilities, general industry, or the public; and that a considered approach would be developed for each contemplated, acceptable operational and financial arrangement.

3.4.2 RECOMMENDED SPS ORGANIZATIONAL AND FUNDING CONCEPT FOR THE SPS PROGRAM

Of the six basic financial and operational concepts considered, investigated, and evaluated (see Appendix C for details), a single concept is recommended from the results of organizational studies and economic determinations involving revenues, profitability, investments/costs funding and operational effectiveness. The evolution of this work is summarized in the following statements of SPS concept formation and funding as it deals with the single recommended concept:

Organizational Roles - SPS Investment and Operations Phase

- A national SPS Space Segment Corporation or Authority (Federally-owned) would be created by an Act of Congress (public law) to undertake the space segment. The scope of activities/responsibilities of the space segment would include the satellite, space assembly and support facility, launch, and space transportation systems.
- SPS Ground Segment Utility Consortia Corporation(s) would be formed geographically, to undertake the operation of ground station/rectenna system(s) after SPS DDT&E. Ground segment responsibilities include rectenna sites and utility interface.

Funding Arrangements - SPS Investment and Operations Phase

- The National SPS Space Segment Corporation is required to become financially self-supporting within ten years of operation. This would occur from funds/revenues provided by utilities or utility consortia purchasing electric power from the National SPS Space Segment Corporation; cash flow; and capital obtained via bond issues.
- The SPS Ground Segment Utility Consortia Corporation(s) would undertake funding of all operational rectenna installations. Funds would be obtained via the equity positions taken by utilities through the issuance of stock and/or long term debt based on the degree of participation in this organizational entity.

3.4.3 SATELLITE POWER SYSTEMS ORGANIZATIONAL CONSIDERATIONS

Figure 3.4-1 illustrates intra- and inter-program relationships of a workable funding concept for a National Satellite Power System Program. It shows the coordination and funding responsibilities based on the basic assumptions for government funding and for utility consortia funding. The program coordination roles are explicit for each. It assumes that the entire program would be fully coordinated with the utility industry and considers the planning necessary in evolving private sector plans, financial resources and motivations. Initially, in the DDT&E phase, the National SPS Space Segment Corporation assumes full responsibility, but would receive electric utility participation in research and development of transmission, land management, systems control methodologies, and related applications of the SPS system power generation and transmission subsystems on operational utility grids and integration of all these into an optimally structured and managed system via the DDT&E Receiving Antenna Site. Co-sponsorship of research by both the utility industry and the equipment manufacturers would be anticipated and encouraged. Relationships will be established and documented with the Office of the Assistant Administrator for Environment and Safety for support in the areas of biomedical and environmental research, environmental control technology, and operational safety.

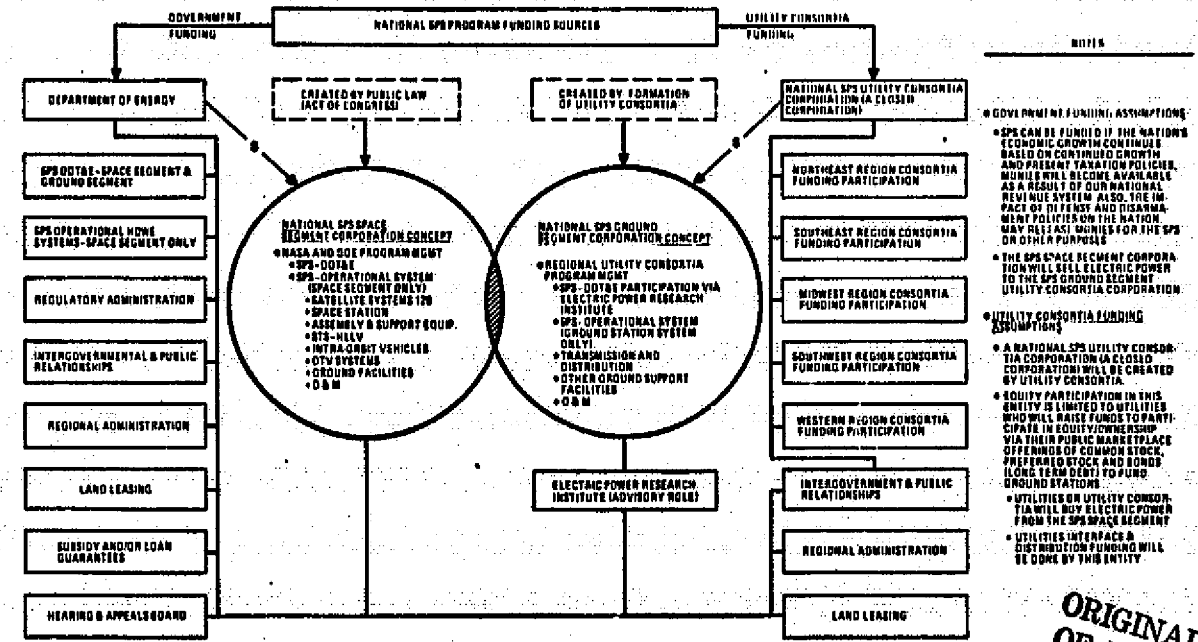


Figure 3.4-1. A Workable Funding Concept for a National Satellite Power System Program

Figure 3.4-2 depicts a possible organizational structure/concept for a (Federalized) National Satellite Power System, Space Segment Corporation. The creation of such an entity by public law, is an immense undertaking. The analysis of this large-scale technical development indicated that the Space Segment should be continued under Government sponsorship. The Ground

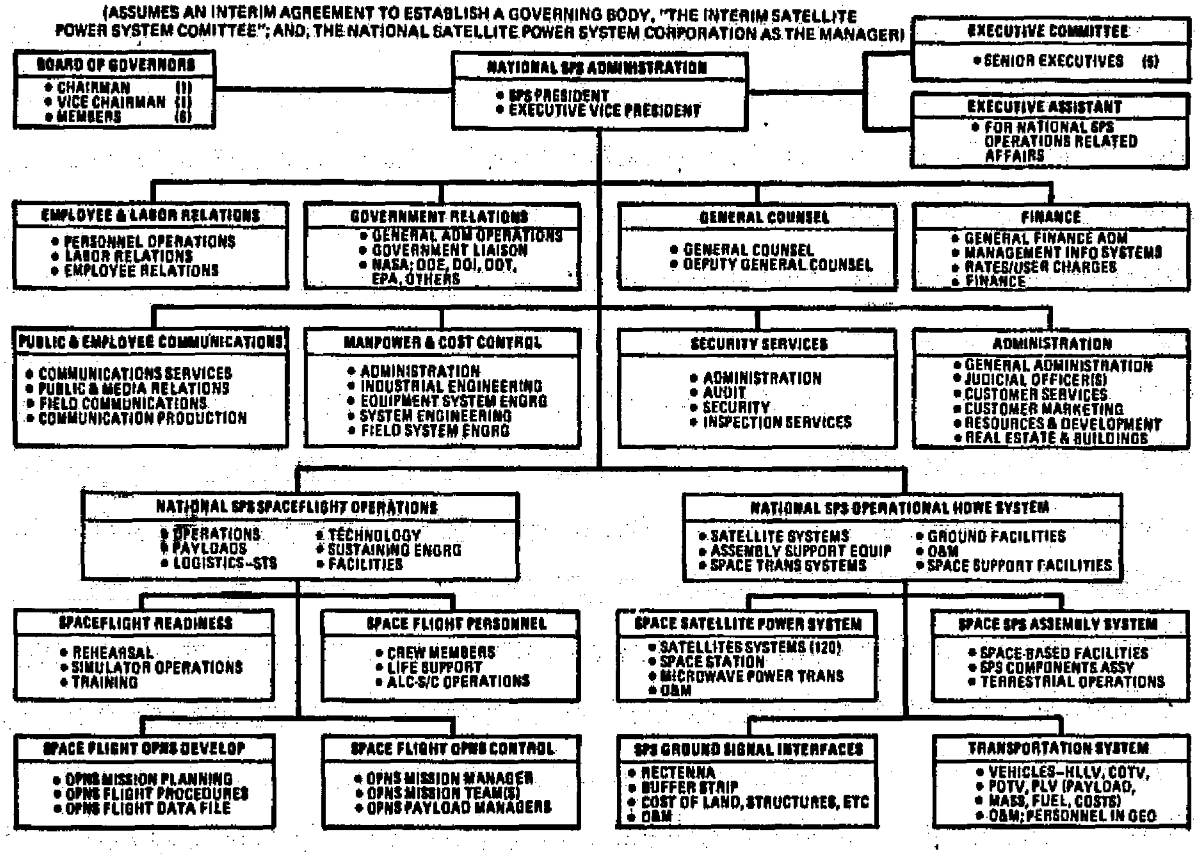


Figure 3.4-2. A (Federalized) National Satellite Power System, Space Segment Corporation/Organizational Concept

Segment should be funded and operated by utility consortia. Obviously, the issues of ownership and control between the Space Segment and Ground Segment are both delicate and difficult. These attributes, if they applied at all, would apply to the Space Segment of the system. This is a creditable rationale. Rectenna sites located within a regional consortia on state or federal land would belong to the utility consortia of that geographical area with the problem of land ownership or use to be worked out. All details are considered workable as to ownership, allocation of shares/equity, voting rights, management, conditions for new utility entrants, etc.

Figure 3.4-3, shows a potential National SPS Ground Segment Utility Consortia arrangement for obtaining funding. The funding of this large entity concept is an immense opportunity/problem for the nation's utilities; however, it is not an impossible one. Based on their current investment outlays, the nation's investor-owned utilities are expected to spend about $122 billion on construction of power-generating plants in the period 1978-1983, according to data put out by the Edison Electric Institute. It is estimated that approximately $73 billion will be raised through outside financing, with the remainder obtained via common equity. In 1976, utilities spent $17 billion on new electricity plants and equipment. About $11.5 billion of the $17 billion was raised externally. Figure 3.4-3 shows the participation aspects of various consortia in the National SPS Ground Segment Utility Consortia Corporation and sources of funds, including other possible participants.

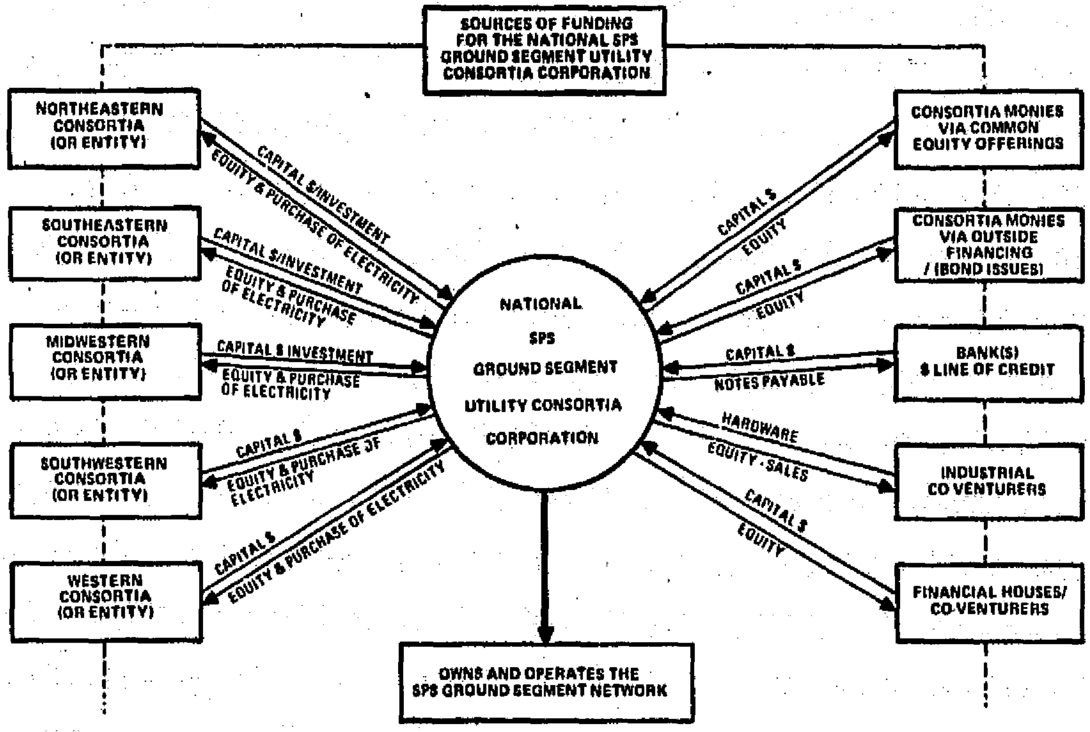


Figure 3.4-3. Potential National SPS Ground Segment Utility Consortia/Arrangement

The first move in organizing such a National SPS Ground Segment Utility Consortia Corporation would stem from policy guidance for new-legislation by the President of the U.S. leading to a public law announcing the creation of the National SPS Space Segment Corporation and providing for affirmative formulation of a new organizational and business entity for SPS space operations and providing the policy guidance for the utility industry participation and response for the practical business considerations of the utilities industry; that is, public policy favoring the formation of regional consortia for SPS Ground Systems based on recognizable, prospective benefits, with the provisions that SPS Space Segment Electricity would be available on a timely basis and that Ground Segment facilities will be suitable for use. That is, satisfactory in quality and offering reasonable costs in the light of alternative power generation systems.

3.4.4 GENERAL EVALUATION OF FINANCIAL AND OPERATIONAL RESULTS

Income statements for the SPS National Space Segment Corporation and the SPS - Ground Segment Utility Consortia Corporation were developed on the basis of 30 and 40 mills per kWh. Although the income statement for the ground segment corporation is satisfactory at 30 mills per kWh for return on revenues, return on investment, and cash flow analysis; an evaluation of financial performance and the overall requirements of the space and ground segment corporations proved unsatisfactory for the National SPS Space Segment Corporation. Further analysis and evaluation established that a cash flow sufficient to finance of up to 70% of its investment requirements should be established.

Accordingly, it was found that the Space Segment Corporation could sell electric power to the SPS - Ground Segment Corporation at a rate of 27 mills per kWh, making the 40 mills per kWh at the busbar acceptable. Therefore, a summary exhibit of SPS financial and operational data are furnished in this summary section on the basis of 40 mills per kWh. The full analysis of 30 and 40 mills per kWh is presented in Appendix C.

On the basis of 40 mills per kWh, a summary of SPS revenues and income was developed as shown in Table 3.4-1. An evaluation of assets employed statements and return on assets employed for the SPS Ground Segment Utility Consortia was conducted in support of the overall 30 and 40 mills per kWh analysis. In addition, comparisons were developed with and without an investment tax credit. This overall evaluation favored the 40 mills per kWh and permitted acceptable percent returns on assets employed for the space segment entity. Investment and return on investment analyses at 40 mills per kWh are shown in Figure 3.4-4 for the SPS Ground Segment and in Figure 3.4-5 for the National SPS Space Segment.

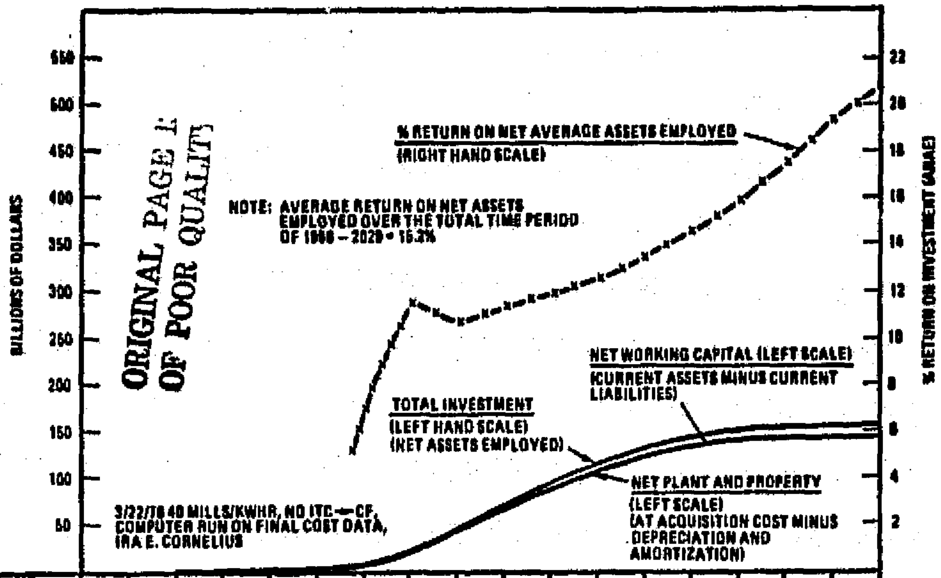
Return on revenues/sales is an important financial performance parameter; however, it must also be related to other financial performance factors, e.g., return on investment (average net assets employed) and cash flow performance.

Table 3.4-1. Summary of SPS Revenues and Income at 40 Mill per Kilowatt Hour

SPS GROUND SEGMENT UTILITY CONSORTIA—INCOME STATEMENT FOR THE YEARS 1991 - 2029	
REVENUE FROM SALE OF ELECTRICITY	($ BILLIONS)
TOTAL OPERATING REVENUES (SALES + OTHER)	3,183.379
ANNUAL kWh SALES (000's)	79,584.424
CENTS PER kWh	4¢
OPERATING COSTS	
PURCHASED POWER FROM SPS SPACE SEGMENT CORP.	2,109.911
OPERATIONS & MAINTENANCE	11.341
DEPRECIATION & AMORTIZATION	167.127
INTERIM REPLACEMENT EXPENSE	20.246
PROPERTY INSURANCE	2.340
STATE & LOCAL TAXES	65.490
INTEREST COSTS	191.003
INCOME TAXES	120.968
INVESTMENT TAX CREDIT & OTHER	(30.799)
TOTAL OPERATING COSTS	2,657.627
OPERATING INCOME	525.752
OTHER INCOME	-0-
INCOME BEFORE R&D EXPENSE	525.752
R&D EXPENSE	TBD
TOTAL INCOME ON REVENUES	525.752
RETURN ON REVENUES (%)	16.52

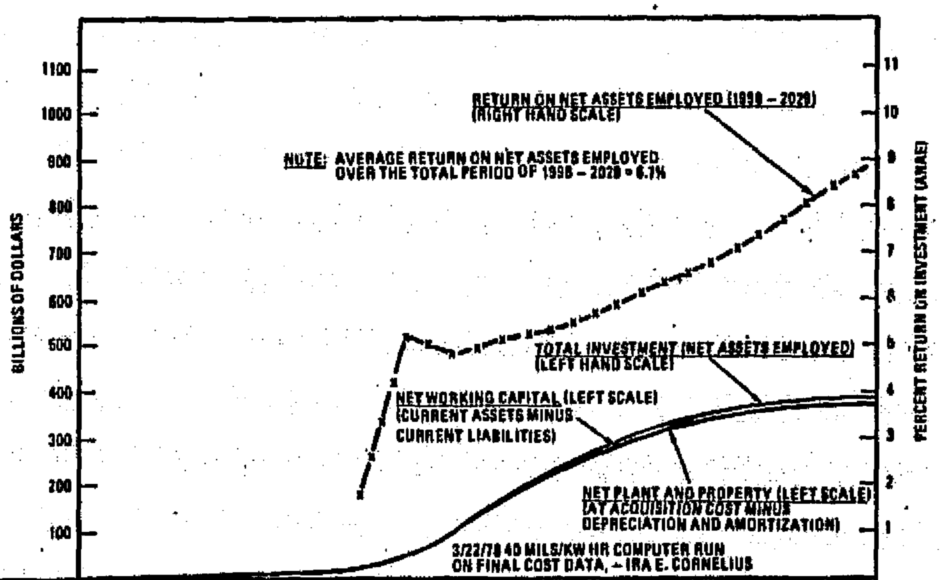
SPS SPACE SEGMENT CORPORATION (FEDERALLY OWNED)—INCOME STATEMENT FOR THE YEARS 1991 - 2029	
POWER SALES AND REVENUES	($ BILLIONS)
TOTAL POWER REVENUES (ELECTRIC UTILITIES + OTHER)	2,109.911
ANNUAL kWh SALES (000's)	79,584.562
CENTS PER kWh	2.7¢
OPERATING COSTS	
POWER PRODUCTION	659.111
SATELLITE INTERIM REPLACEMENT	91.212
SATELLITE SYSTEM OPERATIONS & MAINTENANCE	54.841
SPACE STATION INTERIM REPLACEMENT	76.671
SPACE ASSY & SUPPORT EQUIPMENT EXPENSE	7.378
HLLV INTERIM REPLACEMENT	9.817
HLLV OPERATIONS & MAINTENANCE	40.990
INTRA-ORBIT VEHICLE INTERIM REPLACEMENT	0.449
INTRA-ORBIT VEHICLE OPERATIONS & MAINTENANCE	0.004
COTV INTERIM REPLACEMENT EXPENSE	0.527
POTV INTERIM REPLACEMENT EXPENSE	0.153
POTV OPERATIONS & MAINTENANCE	0.818
FACILITIES INTERIM REPLACEMENT	3.291
DEPRECIATION & AMORTIZATION	385.739
PAYMENTS IN LIEU OF TAXES	73.783
SOCIAL SECURITY TAXES	21.840
TOTAL OPERATING COSTS	1,426.624
OPERATING INCOME	683.287
OTHER INCOME	TBD
INCOME BEFORE R&D	683.287
R&D EXPENSE	TBD
INCOME BEFORE INTEREST	683.287
INTEREST EXPENSES	(118.053)
TOTAL INCOME ON REVENUES	565.234
RETURN ON REVENUES (%)	26.79

NOTE: NUMBERS SHOWN HAVE BEEN MADE TO ADD PRECISELY AND THEREFORE MAY NOT AGREE EXACTLY ON THE LAST TWO DIGITS WITH THE COMPUTER PRINTOUTS DUE TO COMPUTER ROUNDING OF DATA INPUTS.



NO. OF OPERATIONAL UNITS	–	–	–	–	–	1	6	15	26	38	50	62	74	86	98	110	120
% RETURN ON INVESTMENT (INCOME ÷ ANAE)						7.8	11.4	10.5	11.2	11.8	12.6	13.5	14.6	15.9	17.5	19.4	20.7
TOTAL INVESTMENT (NET ASSETS EMPLOYED – $B)	–0–	–0–	0.082	0.574	1.438	4.268	18.799	42.476	67.880	91.779	111.636	127.637	139.896	148.489	153.467	154.871	158.822
NET WORKING CAPITAL ($B)	–0–	–0–	0.001	0.005	0.015	0.140	0.841	2.102	3.645	5.326	7.008	8.690	10.372	12.054	13.736	15.418	16.819
NET PLANT & PROPERTY ($B)	–0–	–0–	0.081	0.569	1.423	4.128	17.958	64.235	40.373	86.453	104.628	118.947	129.524	136.436	139.731	139.463	141.803
SELECTED YEARS	1988	1989	1991	1993	1995	1998	2000	2003	2006	2009	2012	2015	2018	2021	2024	2027	2029

Figure 3.4-4. SPS Ground Segment Utility Consortia Corporation Concept - Investment and Return on Investment (At 40 Mills per Kilowatt Hour, Excludes Investment Tax Credit)



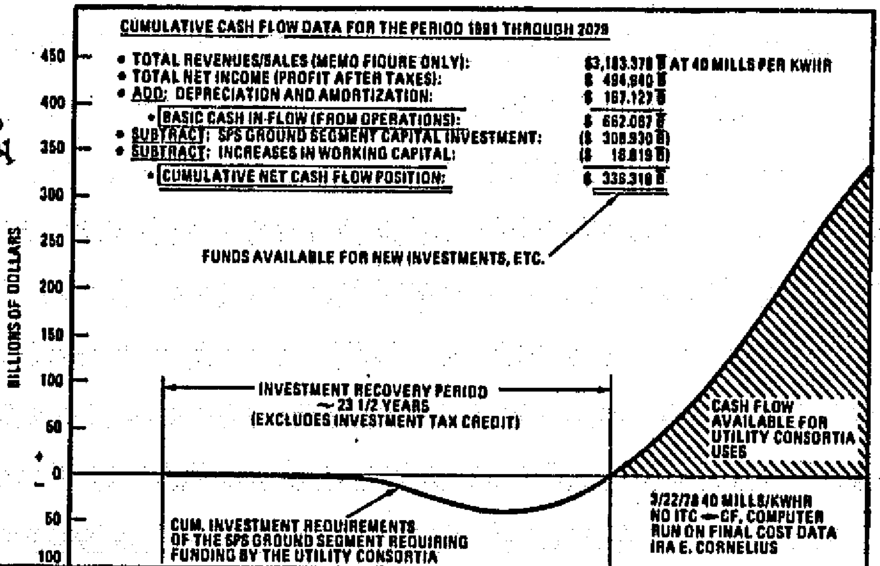
NO. OF OPERATIONAL UNITS	–	–	–	–	–	1	6	15	26	38	50	62	74	86	98	110	120
% RETURN ON INVESTMENT (INCOME ÷ ANAE)			–0–	–0–	–0–	1.8	6.2	4.8	5.1	5.3	5.7	6.1	6.5	7.0	7.7	8.4	8.9
TOTAL INVESTMENT (NAE - $B)	0.166	0.476	1.758	4.288	8.700	19.477	45.556	102.961	164.677	223.000	271.847	311.894	342.815	365.409	379.610	386.504	396.364
NET WORKING CAPITAL ($B)	0.001	0.002	0.004	0.017	0.030	0.081	0.487	1.219	2.113	3.089	4.064	5.039	6.014	6.981	7.965	8.941	9.754
NET PROPERTY ($B)	0.166	0.474	1.754	4.271	8.670	19.396	45.068	101.742	162.564	219.911	267.783	306.855	336.801	358.418	371.645	376.563	386.610
SELECTED YEARS	1988	1989	1991	1993	1995	1998	2000	2003	2006	2009	2012	2015	2018	2021	2024	2027	2029

Figure 3.4-5. National SPS Space Segment Corporation Concept (Federally-Owned) - Investment and Return on Investment (At 40 Mills per Kilowatt Hour)

Return on average net assets is considered the most important parameter for appraisal of financial performance. It measures the effectiveness of the assets employed in generating income and is an important criterion in measuring the effectiveness of management. However, it too, like return on revenues must be further understood and interpreted by relating it to asset turnover and to cash flow. The ability of an organizational entity to substantially finance its expansion out of self generated funds is an important element in any financial evaluation.

3.4.5 CASH FLOW PERFORMANCE SUMMARIES AND INVESTMENT RECOVERY SCHEDULES

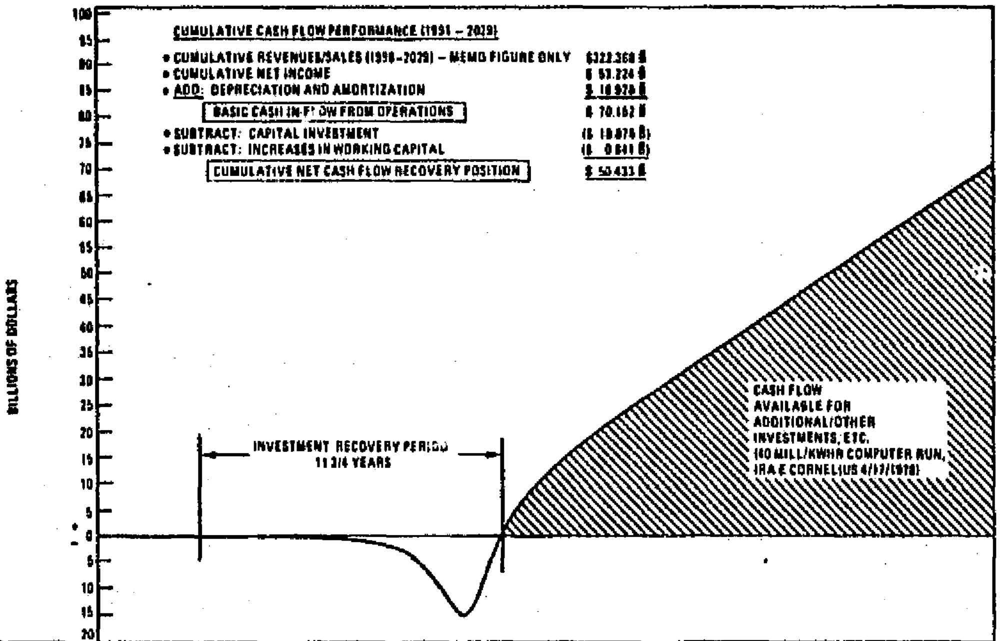
SPS Ground Segment Utility Consortia cumulative cash flow and investment schedule at 40 mills per kWh (without investment tax credit) results in a maximum cumulative cash outlay of $37.383 billion in the year 2006. Investment recovery occurs in the year 2015 as compared with the first SPS operational 5 GW capability at 1998. Positive cash flows of $336.318 billion are provided through the year 2029 (Figure 3.4-6). Evaluation of the cash flow performances based on 30 mills and 40 mills per kWh provide suitable performances for the SPS Ground Segment Consortia in all cases considered. However, the factors resulting in these acceptable performances must also permit acceptable cash flow performance levels for the SPS Space Segment entity with its greater investment requirements.



NO. OF OPERATIONAL RECTENNAS	–	–	–	–	–	1	6	15	28	38	50	62	74	86	98	110	120
CUMULATIVE NET CASH FLOW ($B)	–0–	–0–	(0.083)	(0.570)	(1.447)	(4.007)	(16.098)	(29.958)	(37.383)	(33.498)	(15.763)	15.634	60.579	118.997	190.836	276.056	336.318
SELECTED YEARS	1988	1989	1991	1993	1995	1998	2000	2003	2006	2009	2012	2015	2018	2021	2024	2027	2029

Figure 3.4-6. SPS Ground Segment Utility Consortia Corporation Concept - Cumulative Cash Flow and Investment Recovery Schedule At 40 Mills per kWh (Excludes Investment Tax Credit)

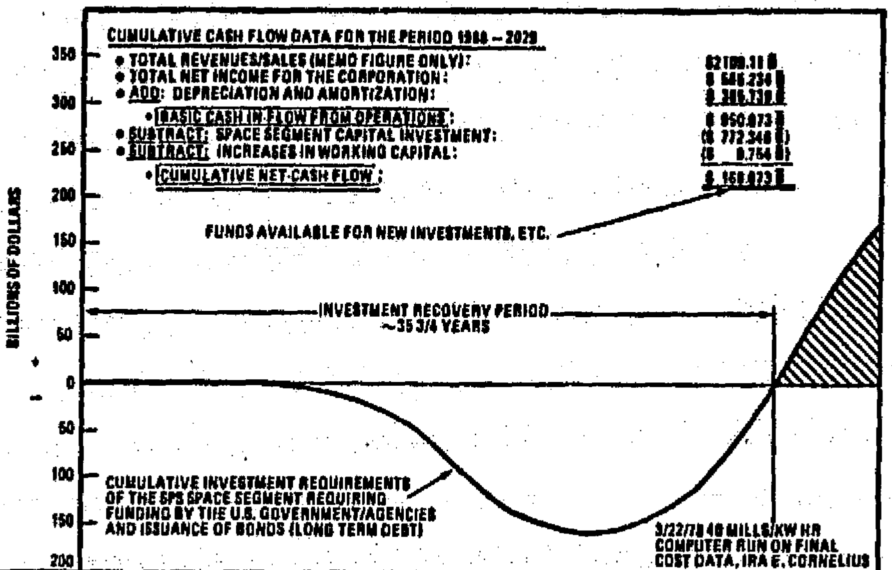
A special analysis was undertaken to show a cumulative cash flow performance summary and investment recovery schedule based on a single geographical utility consortia with a requirement for six SPS ground segment installations (Figure 3.4-7). Since there are no further capital investments after the installation of six operational rectenna sites (with an operational life of 30 years) the revenues/sales become an annual constant; net working capital also becomes an annual constant; and cash flow results in an investment recovery being accomplished in 11-3/4 years overall.



NO. OF OPERATIONAL UNITS	–	–	–	–	–	1	3	6	6	6	6	6	6	6	6	6	6
	–	–															
CUM. NET CASH FLOW	–	–	(0.043)	(0.579)	(2.016)	(3.950)	(15.918)	10.684	14.646	24.392	31.256	38.120	44.984	51.848	58.717	65.676	70.152
SELECTED YEARS	1987	1989	1991	1993	1995	1998	2000	2003	2006	2009	2012	2015	2018	2021	2024	2027	2029

Figure 3.4-7. Cash Flow Summary Data for an SPS-Ground Segment Utility Consortia Corporation Based on a Utility Consortia Formed for Six Rectenna Operational Sites (Data Based on 40 Mills per Kilowatt-Hour)

The SPS Space Segment cash flow and investment schedule based on 40 mills per kWh (a cost of 27 mills per kWh to the SPS Ground Segment Utility Consortia) and 120 Satellite Systems, achieves investment recovery in approximately 35-3/4 years or 26 years after the first SPS satellite operational capability of 1998. Maximum cumulative cash outlay is $162.349 billion, occurring in the year 2012 (Figure 3.4-8). Investment recovery occurs in the third quarter of the year 2024. This cash flow performance and investment recovery is considered acceptable on the basis of the size of the investment, the return on investment, and the return on sales/revenues.



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NO. OF OPERATIONAL UNITS	–	–	–	–	–	1	6	16	26	38	50	62	74	86	98	110	120
CUMULATIVE NET CASH FLOW ($B)	(0.166)	(0.476)	(1.759)	(4.293)	(8.709)	(19.179)	(42.458)	(88.865)	(129.949)	(158.441)	(162.358)	(140.078)	(113.87)	(58.939)	13.586	105.616	169.873
SELECTED YEARS	1986	1989	1991	1993	1995	1998	2000	2003	2006	2009	2012	2015	2018	2021	2024	2027	2029

Figure 3.4-8. National SPS Space Segment Corporation Concept (Federally-Owned) - Cumulative Cash Flow and Investment Recovery Schedule at 40 Mills per Kilowatt Hour

A total SPS cumulative cash flow performance and investment recovery schedule for the combined SPS - Space Segment and Ground Segment Corporations shows a satisfactory investment recovery based on 40 mills per kWh. Maximum cumulative investment for the combined entities reaches $182.684 billion in the year 2009. The investment recovery period is approximately 32-1/4 starting 10 years before the first SPS operational date (Figure 3.4-9). The cumulative net cash flow position at the end of 2029 amounts to $566.790 billion.

3.4.6 CONCLUSIONS

The financial and operational success of the projected Satellite Power System is protrayed through two large operating entities: an SPS Ground Segment Utility Consortia Corporation concept; and a National Space Segment SPS Corporation concept (Federally-owned entity). The projected financial and operational success of these two SPS entities stems, in part, from other space program activity such as Space Shuttle and anticipated space industrialization projects. That is, present study activities and funding will aid in the proof of feasibility and concept leading to expansion into prototype flight demonstrations in the 1980's and then to full scale programs in broad areas of applications after 1990. Space Shuttle and space laboratory experiments are expected to demonstrate the potential of space environment for material processing, manufacturing, assembly and related precursors that will also benefit SPS.

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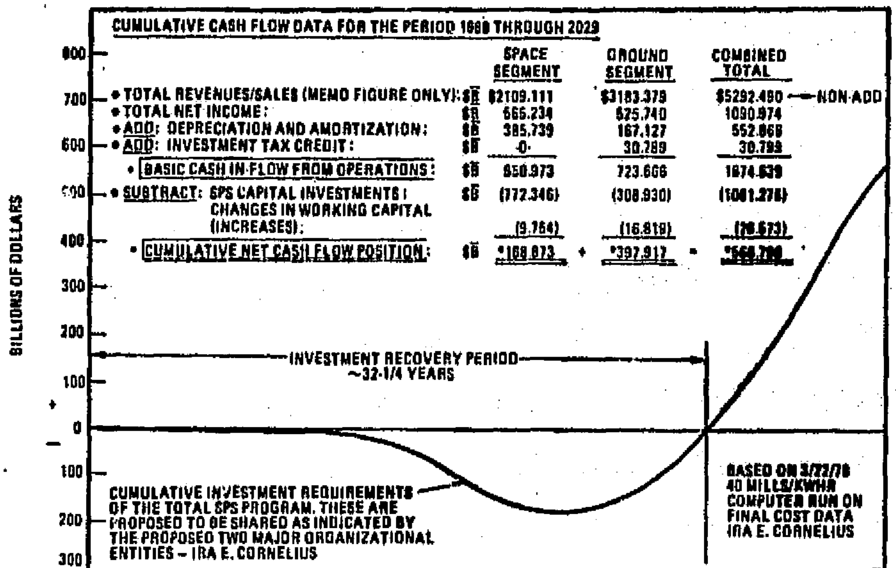

NO. OF OPERATIONAL UNITS	–	–	–	–	–	1	6	15	26	38	50	62	74	86	98	110	120
(1) NATIONAL SPS SPACE SEG CUM NET CAST FLOW $B	(0.166)	(0.476)	(1.759)	(4.283)	(8.700)	(19.179)	(42.458)	(88.005)	(129.840)	(156.440)	(162.350)	(148.078)	(113.871)	(59.939)	13.586	100.616	168.873
(2) SPS GROUND SEGMENT UTILITY CONSORTIA CUMULATIVE NET CASH FLOW $B	-0-	-0-	(0.083)	(0.579)	(1.447)	(3.973)	(15.749)	(29.398)	(33.586)	(20.243)	(3.829)	33.466	85.531	152.288	233.687	329.687	397.917
COMBINED CUMULATIVE NET CASH FLOWS	(0.166)	(0.476)	(1.842)	(5.740)	(10.156)	(23.152)	(58.207)	(117.053)	(163.435)	[illegible]	(166.109)	(114.612)	(28.340)	92.348	247.273	436.303	566.790
SELECTED YEARS	1988	1989	1991	1993	1995	1998	2000	2003	2006	2009	2012	2015	2018	2021	2024	2027	2029

Figure 3.4-9. Total Satellite Power System Cumulative Cash Flow Performance and Investment Recovery Schedule for the Combined SPS-Space Segment Corporation and the SPS Ground Segment Utility Consortia Corporation (at 40 Mills per Kilowatt Hour, with Investment Tax Credit)

The financial magnitude of the SPS capital investment requirements and operational costs show the obvious need to form a partnership between the Federal Government and the Utilities industry. From the studies conducted to identify acceptable financial participation arrangements and practical approaches for the funding and operation of a total satellite power system organization, evolved the recommended SPS financial and operational concept. The National SPS Space Segment Corporation would fund and operate all space-related functions and sell electricity to an SPS Ground Segment Utility Consortia Corporation which would fund and operate all SPS ground installations and perform all related functions. Both of these entities are required to become self-sustaining and provide suitable returns to the Government and the utilities.

Further studies of satellite power systems are anticipated as providing additional proof of feasibility concept and cost effectiveness. This is projected to result in positive recommendations and funding authorization of the SPS DDT&E phase by the government with concurring approvals from the utilities industry and general industry. Major investments by the utilities in satellite power systems are anticipated after successful demonstration projects have been performed under government funding of design, development, test and evaluation. It is projected that utilities will form regional consortia for providing funds in support of the satellite systems program (Ground Segment Rectennas) when it can be demonstrated that electrical power can be provided on a basis comparable to similar capability and overall costs in competitive power generating systems.

3.5 TAXES AND INSURANCE

The purpose of this section is to present the results of investigations concerning several specific areas of taxes and insurance related to the SPS program. This report addresses the items of regulatory tax exemptions, special SPS tax legislation, state and local property taxes, orbital property taxes, taxing jurisdiction, assessed values, and tax rates in the area of taxes; and includes new insurance concepts arising from the SPS development, self-insurance, government underwriting, and other insurance considerations that may surface as the SPS development unfoldes. In addition to these tasks, final calculations of cost for related federal and state income taxes, property taxes and insurance, and the responsibility of Marshall Space Flight Center (MSFC) were also considered in the study because of the uniqueness of these elements in their application and the way the SPS program will be funded and operated.

Accordingly, additional concept definition, in terms of the recommended financial and operational concepts, became an integral part of the discussion on SPS taxes and insurance. It is noted that both the WBS dictionary and the recommended financial/operational concept are somewhat flexible and subject to modification as the program develops. While many of the investigations on taxes and insurance are not appreciably affected with a change(s) to the baselines, some modifications to taxes/insurance may be in order depending on the nature of finalized program designs. Having established preliminary guidelines, the following analyses were concluded.

3.5.1 TAXES—REGULATORY TAX EXEMPTIONS

Property taxes are essentially levied and collected by local governmental or quasi-governmental agencies on property located within the legally established taxing jurisdiction in which such agencies operate. By "local .... agencies", it is meant cities, counties, states, and various configurations of taxing authorities within these structures such as special improvement districts, water and sewer districts, fire or police protection districts, combinations of cities or counties for the express purpose of generating tax revenues for special needs like highways/bridges, and any number of other organized taxing districts or authorities. The component makeup of these taxing authorities vary extensively among the states and is based on public need within each geographic and/or legal jurisdiction. Federal government influence definitely effects state and local property taxes (i.e., the extent of federal revenue sharing, etc.), but essentially, property taxes fall within the perview of local governmental agencies and not the federal government.

Basically, each taxing authority establishes its level of need, its source of revenues to meet those needs and, accordingly, levies a tax (or taxes) upon the property owners within the taxing jurisdiction. Since property taxes are only one type of a great many types of tax (i.e., sales tax, use tax, excise tax, employment tax, etc.), the amount and rate of taxing vary from agency to agency. There presently exists in all states certain regulatory property tax exemptions on specific categories of property based on organization of ownership, type and use of property, pertinent federal regulations, and other reasons for property tax exemption.

Relating this discussion to SPS concepts, property owned and/or operated by the taxing authority itself is generally exempt from tax and, likewise, property owned/operated by the federal government is either exempt from tax or enjoys a significantly reduced rate of tax. Therefore, based on the preferred financial and operational concepts proposed and the contract WBS/dictionary, property taxes should be non-existent or very minimal on DDT&E property and installations, since this area is conceived to be in the hands of the federal government via DOE/NASA.

As operational facilities are developed and the private sector begins to establish an ownership position (via a utility consortia), property taxes become more and more significant. It is reasonably certain that privately owned ground facilities/equipment would be subject to property taxes since such property generally enjoys no exemption from tax under existing regulations. Referring to the WBS and dictionary, the following elements appear to be subject to property taxes under existing regulations if owned by the private sector:

Ground Station System (WBS Row No. 04 00 00) - Within this element the major property items are the rectenna, satellite control facilities and site and facilities.

The property identified in the preceding paragraph would at least partially, if not wholly, be funded and owned by the federal government (DOE/NASA) initially since DDT&E on the first SPS unit necessarily includes all such facilities. Upon the ultimate acquisition of such facilities by the private sector [via transferring ownership of the first SPS unit and subsequent construction of follow-on SPS units throughout the investment (commercialization) phase], property taxes on these facilities come into play.

It should be noted that the extent of local government support necessary to maintain facilities located within the jurisdiction of the taxing authority, plays a key role in determining possible property tax exemptions. For example, rectenna areas located in remote areas may not require the same level of support (i.e., fire protection, streets and highways, water and sewer services, etc.) that a rectenna located in or near a major population center may require. Such physical considerations may well influence the degree of tax exemption a taxing agency is willing to permit.

As noted previously, property taxes essentially are levied at a local level as opposed to the national level and, as such, various types of regulatory tax exemptions will be available to SPS property—depending on the specific taxing agency involved. In general terms, it is the ownership configuration of the property that determines tax exemption under existing regulations.

3.5.2 TAXES—SPECIAL SPS TAX LEGISLATION, STATE AND LOCAL PROPERTY TAXES, ORBITAL PROPERTY TAXES, TAXING JURISDICTION

Since property taxes are generally influenced by literally thousands of taxing authorities spread across the nation, and local regulations/statutes vary widely among these agencies, special tax legislation at all levels (including the federal level) is a probable development. Complexities and conflicts within the miriad of agencies, as well as the pure cost-effectiveness of a project the size and scope of SPS, certainly warrant special legislation at a national level in order to minimize the cost of SPS to the ultimate consumer.

Initial estimates of development costs regarding SPS are quite substantial in terms of pure direct cost, and much of this cost is in the area of property that may well be subject to property tax. In order to manage the cost outlay during the development stage of SPS, it is suggested that the controlling federal agency(s) (NASA or DOE) sponsor special legislation in the Congress of the United States exempting SPS development installations from property tax until such time that SPS-related property is completely in the hands of the private sector. This recommendation is believed necessary for the following reasons:

- Even though owned primarily or fully by the federal agencies involved, many local taxing authorities levey special types of property taxes on such government-owned property. Because of its indirect nature, such a cost may be "lost" from contract cost visibility since much of the development will be subcontracted to the private sector, where it may be subject to local interpretation of property tax regulations. An overall exemption at the federal level would alleviate this potential maze of indirect cost from occurring during the development stage.

- Due to the literally thousands of taxing authorities spread across the nation, it is impractical to attempt to enact exemption legislation in each state or local jurisdiction. An overall property tax exemption at the federal level would assure both the federal government and the various tiers of prime contractors/subcontractors that the SPS program would not be burdened with a potentially large indirect cost.

Subsequent to the DDT&E stage of SPS development, when the private sector establishes an ownership position, property taxes on such privately owned/operated property would be borne by the utility industry and passed along to the ultimate consumer as an operating cost. As a control measure to limit significant state and local jurisdictional and regulatory license interpretation problems, it is recommended that federal legislation also include the following:

- Definitions of property tax exemption on operational property/equipment that is not conceived to be owned by the private sector even after initial operating capability (IOC) has been achieved. Preliminary identification of such items include the Satellite System (WBS Row Number 03 00 00), Space Assembly and Support Facility (WBS Row Number 05 00 00), Assembly and Support Equipment (WBS Row Number 06 00 00), Heavy-Lift Launch Vehicle (WBS Row Number 07 00 00), Space Transportation System (WBS Row Number 08 00 00), Cargo Orbital Transfer Vehicle (WBS Row Number 09 00 00), Personnel Orbital Transfer Vehicle (WBS Row Number 10 00 00), and Facilities (WBS Row Number 11 00 00).

- Limitations on local taxing authorities to assess property tax on only property that must be supported by public services, i.e., those WBS items previously identified in the Regulatory Tax Exemption section of this study. In other words, if a property item does not require local support services, it should not be burdened with a local property tax.

Particularly, since property taxes are indirect in nature and not subject to close contract control like direct costs, it is believed that these definitions at a federal legislative level will aid in keeping SPS operational costs to a minimum. Such definitions should aid in preventing the American taxpayer from being burdened with additional cost that might be assessed at the whim of various local agencies, and may not even be related to this important energy development program. Without such national-level definitions, state and/or local agencies may see a potential tax based that could be used to provide "get well" funds on non-related projects.

3.5.3 TAXES--ASSESSED VALUES AND TAX RATES

The methods by which state and local agencies assess values and determine tax rates vary among all of the applicable authorities. Due to the wide latitude of taxing methods among local authorities, no detail discussion of specific criteria used by property assessors is appropriate for this study. In terms of estimating property tax cost pertaining to SPS, it is believed that applying an estimated tax rate to the estimated cost of taxable property is representative of an acceptable tax impact analysis. This procedure is highly simplified and is designed only to provide a rough order of magnitude (ROM) consideration of property tax amounts.

Based on acceptance of previously discussed recommendations for tax exemptions, the base for applying the estimated tax rate should be the WBS elements identified for private sector ownership subsequent to IOC.

Coordination with a major utility corporation in the State of California has resulted in tax planning rates of 2.6% to 3.0% of initial cost investment. To survey the entire nation in order to determine a more accurate composite rate is beyond the funding scope of this study and, furthermore, would not likely result in reliable data since the timing is far in the future and many variables are yet to be determined. Accordingly, for overall planning purposes to provide ROM consideration of property tax impact, the 2.6% to 3.0% range on initial cost investment is considered adequate.

Table 3.5-1 summarizes tax exemptions and recommended special SPS legislation based on the recommended financial/operational concept. DDT&E is assumed to be tax exempt (100% government owned) and subsequent to IOC, the space segment remains tax exempt while the ground segment represents property subject to tax. Special federal legislation is proposed in order to avoid substantial regulatory interpretation at the local level. Such legislation will define tax exemption for all DDT&E, property exempt after IOC, property subject to tax after IOC, and limit taxes to property supported by local public services.

Table 3.5-1. SPS Property Tax Exemptions and Special Legislation

Recommended Financial/Operational Concept

Space segment—government owned and operated
Ground segment—utility consortia owned and operated

Property Tax Exemptions

Proposed federal legislation for special SPS tax exemptions
DDT&E 100% exempt
Subsequent to IOC: space segment exempt; ground segment taxable

Special SPS Tax Legislation

Federal legislation needed due to large number of local taxing authorities

Legislation to cover:

- Exemption for all DDT&E
- Defined property exempt after IOC
- Defined property subject to tax after IOC
- Limited local taxes to property supported by local public services
    - No "get well" SPS property tax for non-related projects

Table 3.5-2 presents a definition of taxable income based on the preferred financial/operational concept that the ground segment (utility consortia) will purchase energy from the space segment (government owned/operated). The income tax cost impact would then be calculated by applying the combined rate of federal and state/local income taxes to the taxable income. This resultant tax, reduced by the investment tax credit on capital investment by the utility consortia would result in the net income tax impact attributable to SPS.

Table 3.5-2. SPS Income Tax Calculations

Taxable Income—Time Phased

Gross revenue earned by utility
Less: energy cost paid to space segment (Reference: Preferred Financial Concept) and ground segment expenses

Operations and maintenance
Interest on debt financing
Property tax
Insurance
Depreciation on capital investment
Contingency costs

Tax Calculations

Taxable income (corporation federal and state income tax rate, 48% + 6%) minus investment tax credit on capital investment by utility (10%)

3.5.4 INSURANCE—NEW INSURANCE CONCEPTS, SELF-INSURANCE, GOVERNMENT UNDERWRITING

A great many types of insurance exist within the modern business environment. Insurance coverages are available for property damage, product and general liability, various types of personal insurance such as life, accident, workmen's compensation and disability, business interruption insurance, and a miriad of other insurance risks. Many of these insurance costs may apply to SPS-related activity of one sort or another. Those insurance costs related to personal risks should be considered as an element of labor costs associated with SPS development; that is to say, a part of fringe benefits applied to labor costs. Accordingly, this discussion will center around the two basic types of insurance—casualty and liability.

The evolution of SPS will undoubtedly result in new types of property not previously existing. Space vehicles of varying uses, sizes, and shapes will be developed along with operational procedures of construction, energy collection, conversion and dissemination, maintenance equipment, and many other SPS hardware items. State-of-the-art safety measures, maintenance procedures, and accident-prevention techniques will necessarily be developed and the degree of effectiveness will assuredly influence the cost of potential property damage.

All in all, however, property damage insurance is simply a matter of determining the amount and extent of property, the relative risk of it being lost or damaged, and the cost of insuring or absorbing such losses. In terms of property damage insurance, SPS should not result in any revolutionary new insurance concepts.

On the other hand, SPS will result in new insurance concepts pertaining to liability. Catastrophic losses associated with development, construction, collection, conversion, transmission to earth, and dissemination of solar energy are all new areas of liability insurance. Relatively small hazards of loss of life or disability in an individual space vehicle, to catastrophic losses of an enire space station or a large ground-based area located in or near a rectenna site, are potential realities. A list of considerable length could be generated based on broad concepts already developed for SPS—not to mention countless new liability areas that will surface as the program evolves. The magnitude of some SPS-related liability risks is far too great to even consider insurance coverage, and the program must necessarily assume that state-of-the-art measures will be developed to prevent such catastrophic occurrences.

Due to the unique nature of SPS, the insurance community at large has little or no firm experience criteria from which to evaluate potential risks associated with the program. It is anticipated that significant self-insurance will be in effect as the program develops—particularly, since risk factors and potentials are relatively unknown in the initial stages. As the program unfolds and more experience is established, certain risks will undoubtedly surface that might be better handled by the private insurance community. One such area might be the umbrella type of property damage insurance coverage. The umbrella concept is based on combining a relatively large quantity of physical assets under one insurance policy on the theory that the risk of damage to the entire combination of assets is far less than damage to a single asset component. The insurance cost of an umbrella type of combination is less than insuring each component separately. It is anticipated that the relative sizes of physical installations in the ground segment of SPS will be condusive to cost efficiencies offered by umbrella concept combinations.

In terms of the operational concept of a space segment (government owned/operated) and a ground segment (utility consortia owned/operated), the space segment insurance costs are conceived to be self-insured by the government owner/operator. Operation costs of the space segments are considered to be sufficient to cover the insurance-related costs of replacement, repair, and maintenance associated with each space segment.

In summary, it is believed that the magnitude of potential liability on certain SPS activities is of such a tremendous size as to preclude insurance coverage. A basic presumption is that risk of major catastrophy is unlikely due to state-of-the-art technological advancement—but even if such a catastrophy were to occur, it would be uninsurable. Casualty insurance losses will be self-insured relating to the space segment and a combination of self-insurance/purchased insurance relating to the ground segment.

Table 3.5-3 presents basic concepts concerning casualty and liability insurance. Casualty losses of the space segment will be self-insured by the government owner, while the ground segment will be covered by a combination of self-insurance and purchased insurance by the utility owner. New concepts of liability insurance are summarized concerning potential major catastrophic loss. The private sector will continue to provide insurance for negligence and general liability. State-of-the-art technology will effect both casualty and liability insurance categories.

Table 3.5-3. SPS Insurance Concepts

Casualty Insurance

Space segment, government-owned and self-insured

Ground segment, utility owned—combination of self-insurance/purchased insurance

- Dependent on scope of specific SPS property
- Dependent on state-of-the-art safety, maintenance and prevention

Liability Insurance

Potential loss (life and property) from major catastrophy too large to insure:

- Loss of space station
- Major energy transmission accident
- Major microwave radiation accident
- Major component failure

Continuing liability policies in private sector for negligence, etc.

State-of-the-art technology must minimize risk/loss

3.6 RISK ANALYSIS

The SPS cost risk analyses were quantified for the satellite and ground station system elements of the program. Substantial cost definition has occurred in these areas and, therefore, provided a complete data base at the subsystem/assembly levels of the WBS.

The Rockwell Risk Analysis Profile Computer Program (RAP-1) was used to determine probability distributions of cost. The RAP-1 program is a generalized program for the determination of risk analysis profiles. It is generalized in that the equations and data describing a given situation are entered as input to a subroutine called FVAL. This program was applied in the early period of contract study, by implementing the ECON equations describing the cost of an SPS unit. This activity verified the program flexibility and adaptability to obtain risk profiles.

The costs determined from Rockwell cost estimating relationships (CER's) of the SPS solar photovoltaic concept were entered along with the frequency distributions for these costs. Cost uncertainties were established for each subsystem/assembly of the WBS after a review and analysis of all elements within the cognizant system/subsystem engineer. The RAP-1 program then performed repeated samplings (2000) from these distributions, and then tallied the SPS costs associated with each set of values to obtain the applicable cost risk profile.

The RAP-1 program synthesized cost uncertainties of the SPS satellite system and the ground station system from cost uncertainties established for each element of the SPS WBS. The resultant histograms of cost, Figures 3.6-1 and 3.6-2, show an expected cost of $5.23 billion for the satellite system, and $2.59 billion for the ground station system, with standard deviations of $0.48 billion and $0.34 billion, respectively. Figure 3.6-3 shows an average total satellite system cost of $7.82 billion, with a standard deviation of $0.58 billion. This variability is primarily due to the wide range in cost inputs for solar blankets (WBS 03-04-00), microwave (WBS 03-05-00), and rectenna (WBS 04-03-00). To reduce cost variability of the satellite system and ground station system, the variability in the WBS items given above must clearly be reduced.

Input data distributions of cost for the WBS items comprising the satellite system and ground station system are shown in Tables 3.6-1 and 3.6-2. Table 3.6-1 shows the normalized range in costs for each component WBS item from which RAP-1 determines the data distribution applicable. Table 3.6-2 shows the most likely cost for each component WBS item to which the cost distribution for that component is to be applied. The cost of the satellite, GSS, and total GSS was calculated for each set of component costs, and the 2000 results were tallied in the histograms.

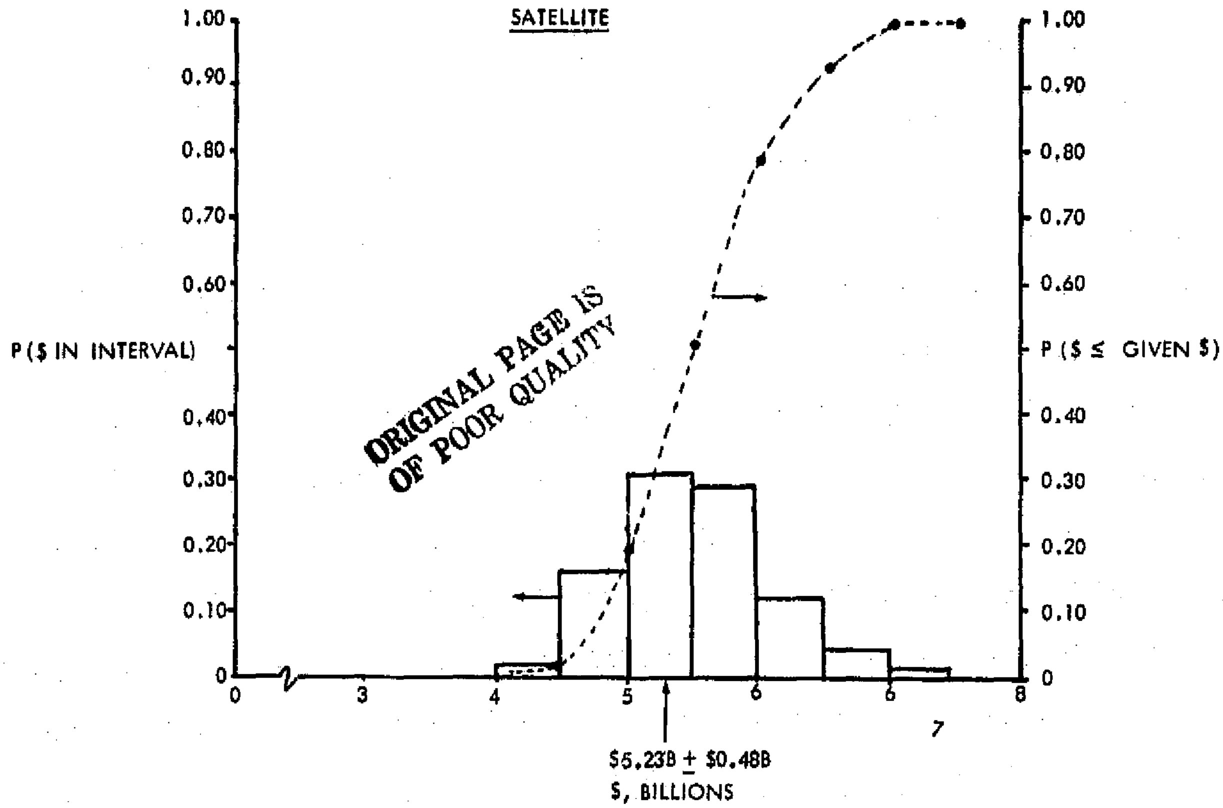

Figure 3.6-1. Cost Histogram—Satellite System

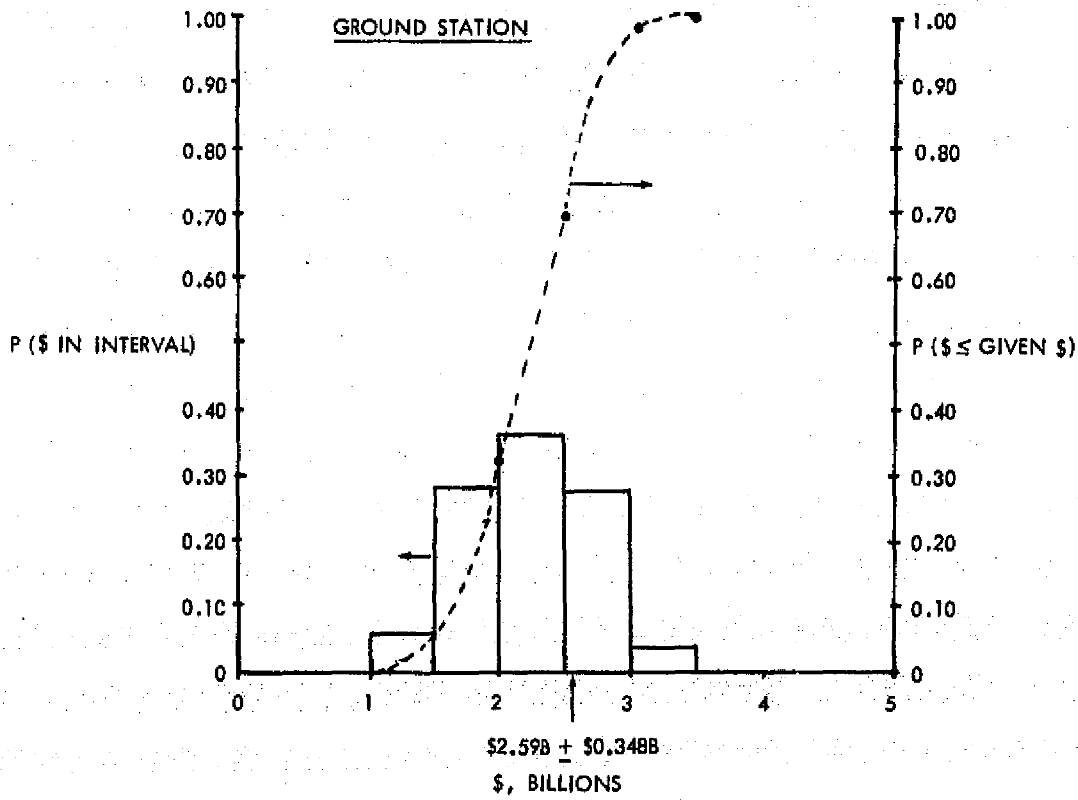

Figure 3.6-2. Cost Histogram—Ground Station System

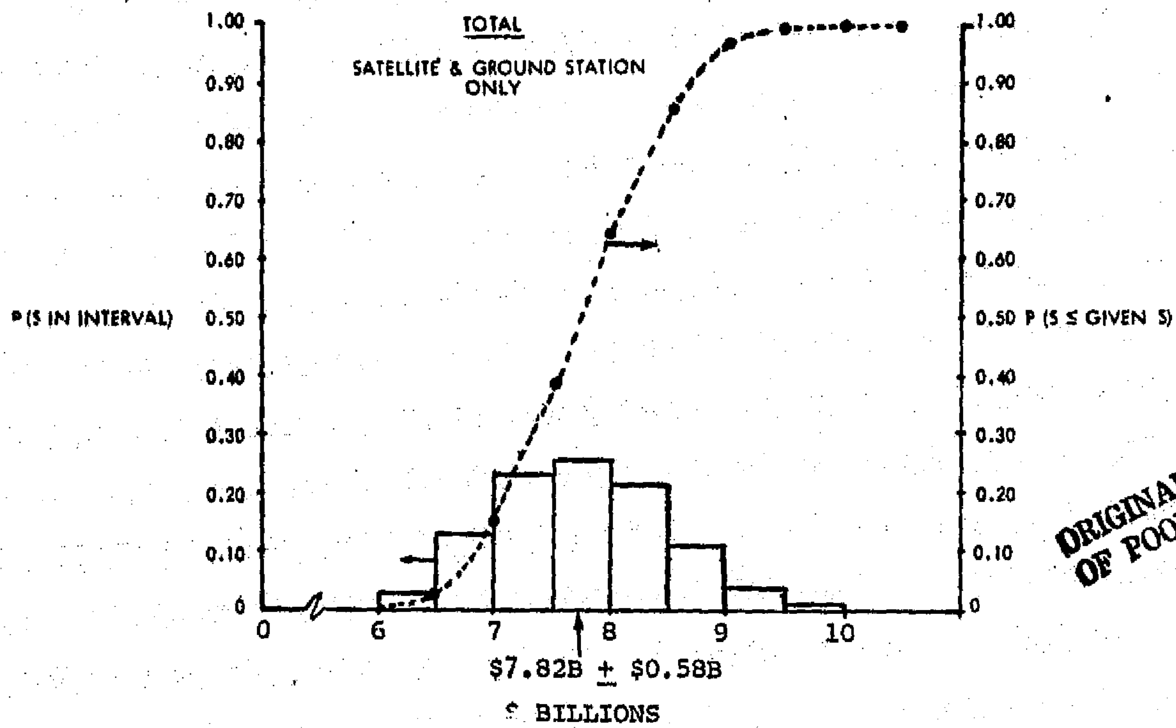

Figure 3.6-3. Cost Histogram—Satellite and Ground Station Only

Table 3.6-1. Normalized Range in Component Costs

IUV/SATELLITE RISK ANALYSIS

A(I),	VARIABLE	PARAMETER	SPECIFICATION
1	1.0000	1.0000	1.0000
2	0.5000	0.6500	1.0000
3	0.8500	1.0000	1.1000
4	0.8500	1.0000	1.1000
5	0.9000	1.0000	2.0000
6	0.9000	1.0000	1.1000
7	0.8000	1.0000	1.6000
8	1.0000	1.3000	2.1000
9	1.0000	1.0000	1.9000
10	0.9500	1.0000	1.9000
11	0.9000	1.0000	1.1000
12	0.9000	1.0000	1.1000
13	0.9000	1.0000	1.1000
14	0.8500	1.0000	1.6000
15	0.8500	1.0000	1.6000
16	0.9500	1.0000	2.0000
17	0.8500	1.0000	1.1000
18	0.8500	1.0000	1.1000
19	0.8500	1.0000	1.1000
20	0.8500	1.0000	1.1000
21	0.8500	1.0000	1.1000
22	0.8500	1.0000	1.1000
23	0.8500	1.0000	1.1000
24	0.8500	1.0000	1.1000
25	0.8500	1.0000	1.1000
26	0.8500	1.0000	1.1000
27	0.8500	1.0000	1.1000
28	1.0000	1.0000	1.0000
29	1.0000	1.0000	1.0000
30	0.8000	1.0000	1.2000
31	1.0000	1.0000	1.2000
32	0.6000	1.0000	1.5000
33	0.8500	1.0000	1.1000
34	0.8000	1.0000	1.2000
35	0.8000	1.0000	1.1000
36	1.0000	1.0000	1.0000
37	1.0000	1.0000	1.0000
38	1.0000	1.0000	1.0000
39	1.0000	1.0000	1.0000
40	1.0000	1.0000	1.0000
41	1.0000	1.0000	1.0000
42	1.0000	1.0000	1.0000
43	1.0000	1.0000	1.0000
44	1.0000	1.0000	1.0000
45	0.8000	1.0000	1.1000
46	1.0000	1.0000	1.0000
47	0.5000	0.6500	1.0000

Table 3.6-2. Most Likely Cost for Each Component WBS Item

X(I),NON-VARIABLE PARAMETER SPECIFICATION

1	49.0280	25	82.9600
2	320.7439	26	0.7370
3	38.8700	27	20.6270
4	18.5640	28	0.0
5	7.7670	29	67.1090
6	280.1089	30	16.6840
7	1845.8679	31	9.1170
8	84.1510	32	[illegible]6.1951
9	3.6400	33	44.7560
10	80.2680	34	297.1531
11	87.3340	35	105.3450
12	1.1260	36	8.9000
13	2.2240	37	331.3999
14	5.1600	38	4.8000
15	1735.5090	39	4.0000
16	14.6620	40	0.0
17	2.4670	41	0.0
18	0.4250	42	0.0
19	0.9500	43	0.0
20	2.1900	44	0.0
21	5.6380	45	89.8440
22	5.4930	46	25.4530
23	6.0530	47	166.7780
24	66.5570		