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CR-167869

GaAs SOLAR ARRAY SUBSYSTEMS STUDY FINAL REPORT

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Prepared for
NASA Lewis Research Center
Cleveland, Ohio 44135
Contract NAS3-22667

August 16, 1982

(NASA-CR-167869) GALLIUM ARSENIDE SOLAR ARRAY SUBSYSTEM STUDY Final Report, Jan. 1981 - Feb. 1982 (PRC Systems Sciences Co., Tucson, Ariz.) 221 p HC A10/MF A01 CSCL 10A
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7911 Charlotte Drive
Huntsville, AL 35802
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Planning Research Corporation

August 19, 1982

NASA-Lewis Research Center
21000 Brookpark Road
Cleveland, OH 44135

Attention: Don F. Hoffman, Contract Specialist, MS500-305

Subject: Submission of Final Report

Reference: Contract Number NAS3-22667, Gallius Arsenide Solar Array Subsystem Study

Gentlemen:

In compliance with the referenced contract, your copies of the Gallium Arsenide Solar Array Subsystem Study Final Report is hereby submitted.

Should you have any questions, please contact the undersigned at (205) 883-2900.

Very truly yours,

PRC SYSTEMS SERVICES

Fred Q. Miller

Fred Q. Miller
Project Manager

FQM/bjs

Enclosures: As stated

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NASA Lewis Research Center
Cleveland, Ohio 44135

16. Abstract

The effects on life-cycle costs of a number of technology areas are examined for a gallium arsenide space solar array. Four specific configurations were addressed: (1) a 250 KWe LEO mission - planer array; (2) a 250 KWe LEO mission - with concentration; (3) a 50 KWe GEO mission - planer array; (4) a 50 KWe GEO mission - with concentration. For each configuration, a baseline system conceptual design was developed and the life-cycle costs estimated in detail.

The baseline system requirements and design technologies were then varied and their relationships to life-cycle costs quantified. For example, the thermal characteristics of the baseline design are determined by the array materials and masses.

The thermal characteristics intern determine configuration, performance, and hence life-cycle costs.

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Final Report

GALLIUM ARSENIDE SOLAR ARRAY SUBSYSTEMS STUDY

by

Fred Q. Miller, Project Manager
Charles L. Graff, PE., Consultant

PRC SYSTEMS SERVICES

Prepared For

National Aeronautics and Space Administration
NASA-Lewis Research Center
Contract NAS3-22667

GaAs SOLAR ARRAY SUBSYSTEMS STUDY FINAL REPORT

Prepared for
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EXECUTIVE SUMMARY

Purpose of the Study

To develop computer models which are used to establish quantitative relationships between the total life cycle cost and technical parameters of Gallium Arsenide solar cell arrays for earth orbiting spacecraft.

Background

Future NASA and USAF space programs will require significant increases in electrical power requirements from the 1980 average for existing programs of 1 kW. These requirements are projected to increase to approximately 500 kW by the year 2000.

Solar arrays appropriately sized for future requirements and configured with today's technology will prove inordinately expensive in terms of projected life cycle costs. These costs must be considered truly significant in that they will command a disproportionate share of available resources thereby constraining the numbers and types of future space programs.

Accordingly, it is imperature that new technologies be developed for the design of electrical solar arrays. Implicit in the development of these technologies is the capability to analyze the impact on system life cycle costs resulting from varying design specifications. Every attempt must be made to maximize system performance and minimize life cycle costs. The models presented herein are a first step toward obtaining this critical capability.

Methodology

A series of four baseline Gallium Arsenide solar arrays using today's technologies were specified and hypothetically subjected to either a low earth orbit (LEO) or geosynchronous earth orbit (GEO). The following matrix applies.

SOLAR ARRAY	LEO 250 kW	GEO 50 kW
Planar	●	●
Concentrator	●	●

Algorithms representing life cycle costs were developed for each of the four baseline solar arrays in their designated orbit. Each solar array was then subjected to changes in design specifications and the resulting changes in life cycle costs were computed. These iterations resulted in the development of a series of mathematically expressed relationships between individual system components/parameters and life cycle costs.

The resultant solar array performance and life cycle cost model is logically correct, internally consistent, and realistic. Its full effectiveness as a design and budgeting tool will be even further enhanced when voids in empirical GaAs solar cell technical and cost data are filled.

For example, it is anticipated that advanced, high power arrays will be lightweight and will use standard solar cell modules with wraparound solar cells, light weight solar concentrators, and printed circuit power distribution networks. The module size will be optimized, considering transportation, packaging, space assembly, electrical characteristics, maintainability and production costs. The qualification and acceptance testing could, in large part, be accomplished on the module or small groupings of modules, since each module is a functioning entity, in itself a solar array.

The need for a large sheet of material, such as plastic film, to hold cells in proper relative position and to provide connection integrity depends on the basic module design. The modules could be designed for integrated mechanical/electrical interconnection to permit direct attachment to the structure to maintain planar geometry and required orientation. The integrated module concept lends itself to automated production and high production rate.

Since many factors, or elements, are involved in obtaining an optimum cell, module, and array configuration, the nature and extent of the many inherent interdependencies must be determined. The complexity of these interdependencies is a very significant consideration in determining the total life cycle cost for a space electrical power system.

Conclusions

A computerized performance/life cycle cost model provides an extensive and detailed series of mathematically expressed relationships between individual system components/parameters and life cycle costs. The objective is to define a set of cost-technology relationships inherent in the electrical power system for aerospace programs. These relationships are quantitative and include the interdependencies of various constituent technologies. Thus, the quantitative impact of changing a single technology will be evident initially on all the other technologies affected, and ultimately on the total life cycle cost of the electrical power system. Collectively, these relationships would provide NASA planners, engineers, and scientists with a tool for conducting the sensitivity analyses and trade studies necessary for systematically identifying the nature and extent of the cost driver technologies in an aerospace electrical power system - that is, which technologies are contributing the greatest portion of the system cost, and how they can be changed to bring about significant reductions in the system life cycle cost. Once identified as such, it will be these technologies on which NASA should focus its research and development resources.

Recommendations

Various areas for study having high potential returns on investment are readily apparent. Some of the more promising areas are:

- The conduct of comparative life cycle cost analyses on the development of alternative component technologies and on the configuration of alternative system designs.
- The use of computerized models, as guides, to plan and coordinate future component/system development and test programs, thereby maximizing the use of available resources.
- The use of computerized models to optimize specified solar array performance parameters for given levels of life cycle funding.
- The use of computerized models of discrete systems (e.g., Solar Array, Energy Storage, Electrical Power System) to compile a model of a larger system (e.g., space platform) for subsequent in-depth analysis.
- Development of a space solar array data center and a commensurate management information system for future use on other comparable programs.

1.0 INTRODUCTION/OVERVIEW

This "GaAs Solar Array Subsystems Study" was awarded to PRC under NASA LeRC Contract NAS3-22667. The study purpose was to determine the impact of technology variations upon the total life cycle cost of a Gallium Arsenide (GaAs) space Solar Array Subsystem (SAS). The output of the contracted study effort is a versatile cost estimating tool for NASA use. The combined performance/life cycle cost model described herein, also provides the capability to update the interrelationship of solar array performance and technology parameters versus total life cycle cost, by incorporating new test and/or cost data as it becomes available.

1.1 PRC Organization and Activities

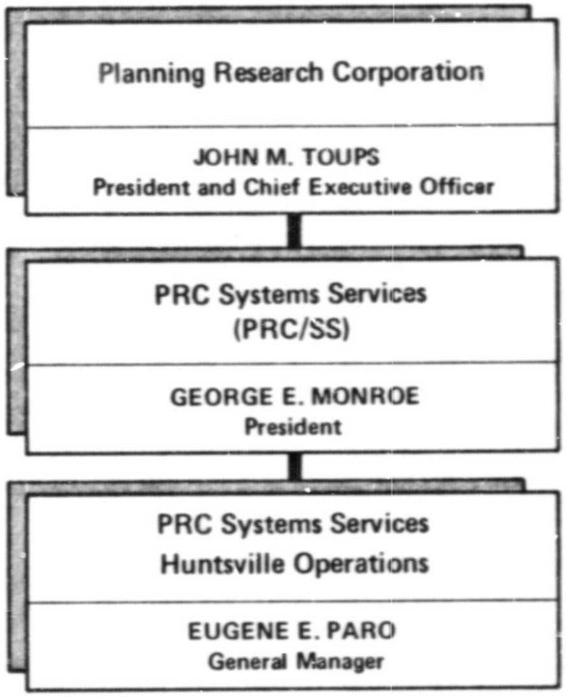
Since the establishment of Planning Research Corporation (PRC) in 1954, two of PRC's prime professional services to the Government have been the performance of: (1) Systems engineering and concept design; and (2) all aspects of engineering cost analysis. This latter service includes identification, location, and collection and analysis of aerospace technical and cost data, and the development of cost estimates and life cycle cost models.

1.1.1 PRC Systems Services

PRC Systems Services currently has 34 professional personnel in its Huntsville, Alabama office. Since 1971, the Huntsville office has continuously performed systems engineering, cost modelling, and estimating/analysis services to NASA. As shown in Exhibit 1-1, the Huntsville office is currently performing such work for five NASA Centers: Lewis Research Center (LeRC), Goddard Space Flight Center (GSFC), Marshall Space Flight Center (MSFC), Langley Research Center (LaRC), and Jet Propulsion Laboratory (JLP).

For LeRC, PRC has developed five computerized performance and life cycle cost models, including the model developed for the GaAs SAS Study. Two of the models are for large space solar cell arrays and three are for large space electrochemical energy storage subsystems (ESS). The solar array models include silicon and GaAs solar cells, planar and concentrator array configurations, and LEO/GEO space missions. The ESS models include nickel cadmium battery, nickel hydrogen battery, and hydrogen/oxygen fuel cell/electrolysis

Exhibit 1-1



NASA CONTRACTS WITH:	TASK AREAS:
LEWIS	SYSTEMS ENGINEERING (GaAs STUDY)
MSFC	ENGINEERING COST ANALYSIS AND DATA BASE DEVELOPMENT
MSFC	ENGINEERING TRADE STUDIES/SPACELAB AND DERIVATIVES
GSFC	ENGINEERING COST ANALYSIS AND DATA BASE DEVELOPMENT
GSFC	COST MODELLING SURVEY, NEEDS PROGRAM
LANGLEY	ENGINEERING COST ANALYSIS AND DATA BASE DEVELOPMENT
JPL	PLANETARY SPACECRAFT COST MODEL

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cell subsystems. All models include the capability to analyze the effect of variations in technology or technical parameters upon the total life cycle cost of the respective subsystem.

For MSFC, PRC has developed five models which are related to the GaAs SAS study. Two of these models - 25 kW Power Module and Solar Power Station (SPS) - address large space platform systems with power requirements on either side of the GaAs SAS. The third model - solar electric propulsion system (SEPS) - was also based on the space platform modelling approach. The other two models define relationships which are critical to evaluating two important aspects of space hardware ownership costs - namely transportation costs based on STS and Interim Upper Stage (IUS) costs, and in-space post-flight operations activities costs.

For GSFC, PRC has performed numerous tasks as a team of multi-disciplinary professionals which provide engineering cost analysis services for the government. The team efforts include data collection and analysis, and the development of parametric cost models. PRC has helped to prepare cost estimates for future aerospace programs, based upon the analysis of work breakdown structure, leading to the development of parametric life cycle cost models. Program hardware consisted of earth satellites with various scientific experiments and instrument packages. Computerized cost modelling activities included multiple variable regression analyses, a Space Transportation System (STS) Reimbursement Guide model, a Scientific Instrument Cost Model (SICM), a Support Equipment Cost Model (SECM), and a NASA End-to-End Data System (NEEDS) performance/cost model.

For LaRC, PRC has developed cost estimates and cost models for a variety of future space programs, including a model to generate cost estimates for various configurations and materials of large space structures.

For JPL, PRC is helping prepare a planetary spacecraft cost model, which is based upon data collection, analysis and cost estimating techniques similar to those used to develop the earth orbiting space hardware models described above, yet tailored to meet JPL's specific requirements.

1.1.2 REDSTAR

The Resource Data Storage and Retrieval (REDSTAR) is a data base system designed and developed by PRC since 1971 under contract to MSFC. The purpose of this system is to provide a systematic means for readily storing and retrieving historical cost, technical, and programmatic data for use by NASA systems engineers and cost analysts in developing and exercising parametric cost estimating relationships for future systems. Since developing the basic library system, PRC has been under continuous contract to NASA to operate and maintain REDSTAR. This includes collecting, analyzing, integrating new data into the system, and then using this data to develop comprehensive performance and cost models for use by various NASA centers in projecting the costs of new programs and space hardware systems. Currently, REDSTAR is comprised of over 5,000 documents which contain data at various levels - ranging from program to component - pertaining to a broad base of aerospace hardware systems, including electric power system space hardware, radars, lasers, aircraft, missiles, space satellites, telescopes, cameras, scientific instrument packages, and common/composite materials.

1.2 Study Objectives

The objectives of this study are to:

- Define a set of cost/technology relationships inherent in large planar and concentrated GaAs solar cell arrays, for two space power system missions - one of 250 Kilowatt (kW) output in Low Earth Orbit (LEO) and one of 50 kW in Geosynchronous Earth Orbit (GEO).
- Quantify the relationships and determine the interdependencies of the solar array technologies.
- Provide NASA with a tool for conducting sensitivity analyses and trade studies in order to identify the nature and extent of cost drivers in large space solar arrays using GaAs cells.

1.3 Background

Future NASA and USAF space programs will require significant increases in electrical power requirements from the 1980 average for existing programs of

1 kW. These requirements are projected to increase to approximately 500 kW by the year 2000.

Large electrical power systems appropriately sized for future space requirements, and configured with today's technology, will prove inordinately expensive in terms of projected life cycle costs. These costs must be considered truly significant, in that they will command a disproportionate share of available resources, thereby constraining the numbers and types of future space programs.

Historically, the solar array subsystem cost has contributed a significant percent of the total electrical power system (EPS) cost. This makes the solar array a logical candidate for potential reduction of the total life cycle cost. In the past, one of the most effective approaches to cost reduction has been through technology advances. However, implicit in the development of new technologies is the capability to analyze the impact on total life cycle costs resulting from varying design specifications.

Accordingly, it is imperative that new technologies be developed for the design of large space solar arrays; and one of the most promising solar array technologies combines the use of GaAs solar cells and solar concentration. Unfortunately, the analytical relationships between total life cycle cost and these GaAs solar array technologies have not yet been adequately defined.

Therefore, as depicted in Exhibit 1-2, it is important to examine and quantify the life cycle cost (LCC) benefits of GaAs physical, performance and operational technologies, as applied to large solar array electrical power systems, for use in high power LEO and GEO space missions. Every attempt must be made to maximize hardware performance and minimize life cycle costs. The GaAs solar array performance/life cycle cost model described herein is a step toward obtaining this critical capability.

1.4 Study Methodology

An overview of the study methodology is presented in Exhibit 1-3. As depicted, the methodology consisted of six tasks. The titles and outputs of the tasks are discussed in subsequent paragraphs.

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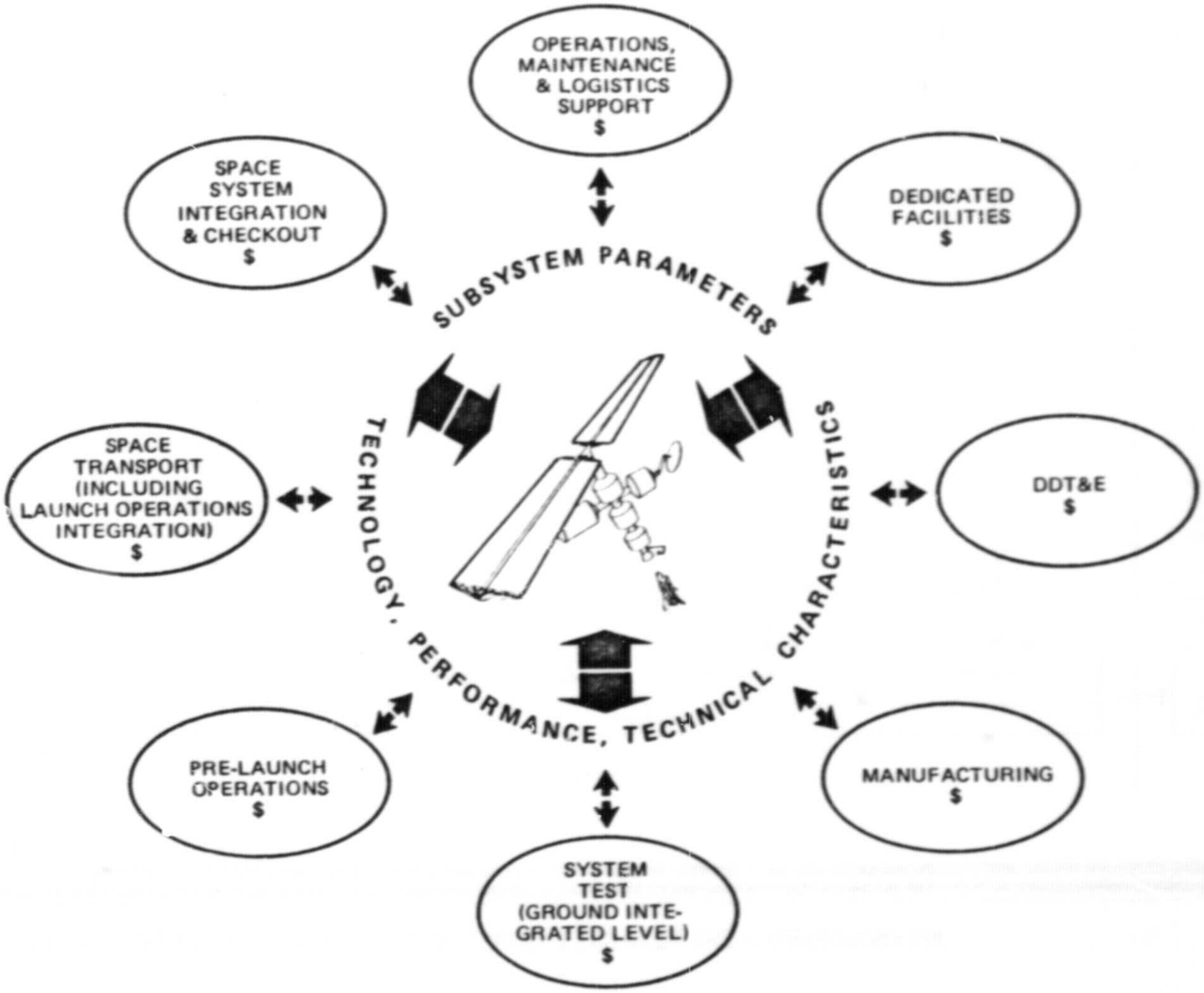
A REALISTIC METHODOLOGY FOR LIFE CYCLE COSTING AND TECHNOLOGY ASSESSMENT INVOLVES ALL SYSTEM ELEMENTS

Exhibit 1-2



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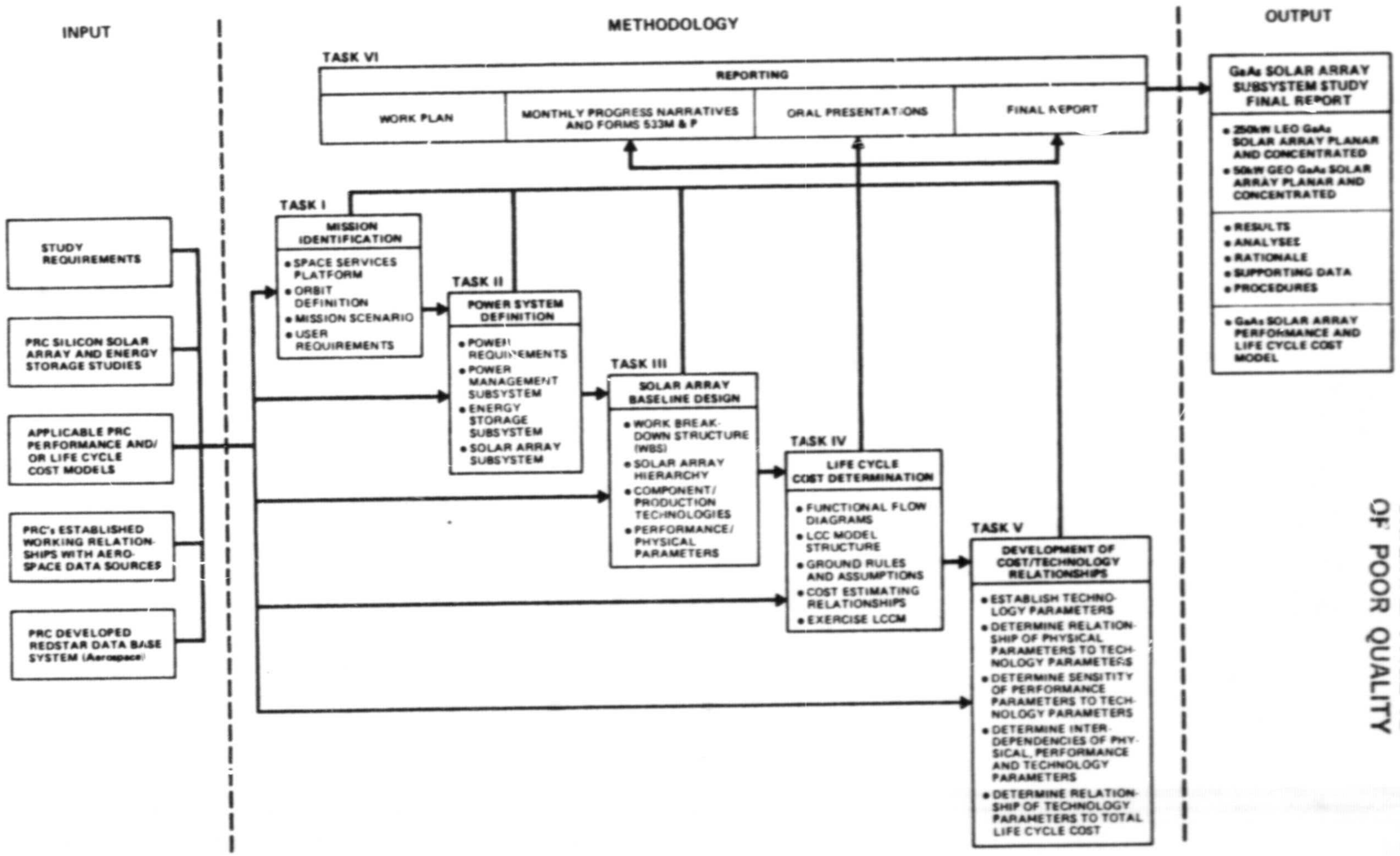
PRC's METHODOLOGY FOR GaAs LIFE CYCLE COSTING AND TECHNOLOGY ASSESSMENT

Exhibit 1-3



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1.4.1 Task I - Mission Identification

The purpose of this task was to develop a set of space mission requirements. These requirements would include definition of a space services platform, LEO and GEO orbit parameters, a mission life cycle scenario, and the user system(s) electrical power load requirements. These requirements are documented in Section 2.0.

1.4.2 Task II - Power System Definition

The purpose of this task was to develop and define the requirements for an electrical power system based upon the mission requirements developed in Task I. Included in the power system definition would be the power load requirements, as well as the performance requirements for the power management, energy storage, and solar array subsystems. The EPS definition is documented in Section 3.0.

1.4.3 Task III - GaAs SAS Baseline Design

The purpose of this task was to develop and define four baseline GaAs solar arrays: (1) One planar array to provide 250 kW average in LEO, (2) one array with solar concentration to provide 250 kW average in LEO, (3) one planar array to provide 50kW average in GEO, and (4) one array with solar concentration to provide 50 kW average in GEO. The baseline definitions would include a work breakdown structure (WBS), a solar array hierarchy, the selection of component/production technologies, and the quantification key of array performance and physical parameters. The baseline definitions would be preliminary activities for development of the GaAs SAS performance model, which in turn would result in numerous iterations. The final baseline definitions are documented in Section 4.0.

1.4.4 Task IV - Life Cycle Cost Determination

The purpose of this task was to develop and exercise a life cycle cost model (LCCM) for each of the solar array baselines defined in Task III. Development of the LCCM would include the development of functional flow diagrams for Design, Development, Test and Evaluation (DDT&E), Production, and Operations and Maintenance (O&M). Also included would be the LCCM structure, as well as various ground rules and assumptions, and cost estimating relationships for each major cost element. The LCCM is documented in Section 5.0.

1.4.5 Task V - Development of Cost/Technology Parameter Relationships

The purpose of this task was to establish the quantitative relationships between total life cycle cost and the GaAs component/production technologies defined in Task III. Implicit in this task was the development of a solar array performance model, which modelled the use of GaAs solar cells and various degrees of solar concentration. Development of the model would include the modelling of key technology parameters to be analyzed, as well as the relationships, sensitivities and interdependencies of numerous physical, performance and technology parameters. The solar array performance modelling is documented in Section 6.0. The results of the various technology parameter variations vs variations in life cycle cost are documented in Section 7.0.

1.4.6 Task VI - Reporting

The purpose of this task was to provide the necessary communication and coordination between PRC and LeRC concerning contract status, the baseline definitions, the LCCM activities, and in particular, the results of analyzing the numerous technology/life cycle cost relationships. The reporting would include a study work plan, monthly progress narratives, various oral presentations, and a written final report. The study results and conclusions are documented in Section 8.0.

2.0 MISSION IDENTIFICATION

Mission identification is accomplished by a set of space mission requirements. The requirements include definition of a space services platform, LEO and GEO orbit parameters, a mission life cycle scenario, and the user system(s) electrical power load requirements.

2.1 Space Services Platform System (SSPS)

The SSPS has been hypothesized to create a system structure within which a Solar Array Subsystem (SAS) can be defined to provide a baseline design for cost-technology studies. The purpose of the SSPS is to provide services to varied User System(s). The User System(s) may be engaged in materials processing, astronomy, solar systems and earth observation, life sciences, communications, or other operations. The User System(s) may be secured to the platform or docked for servicing or short-term operations. The general configuration of the SSPS is shown in Exhibit 2-1. The subsystems of the SSPS, their functions and major interfaces are summarized in Exhibit 2-2.

2.1.1. Solar Array Subsystem (SAS)

During the sunlight period of the orbit, the SAS converts solar energy into electrical power which in turn is provided to the Energy Storage and the Power Management Subsystems. Including losses, the SAS provides sufficient energy for the user system(s) and for internal SSPS power users as well as energy to be stored and subsequently provided to the same users during the eclipse period of the orbit. The SAS also provides outputs from on-array instrumentation and responds to attitude control and power switching commands from the Command and Data Subsystem.

2.1.2 Energy Storage Subsystem (ESS)

The ESS stores electrical energy from the SAS during the sunlight period of the orbit and provides electrical power to the user system(s) and other SSPS subsystems during the eclipse period of the orbit.

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SPACE SERVICES PLATFORM SYSTEM

Exhibit 2-1

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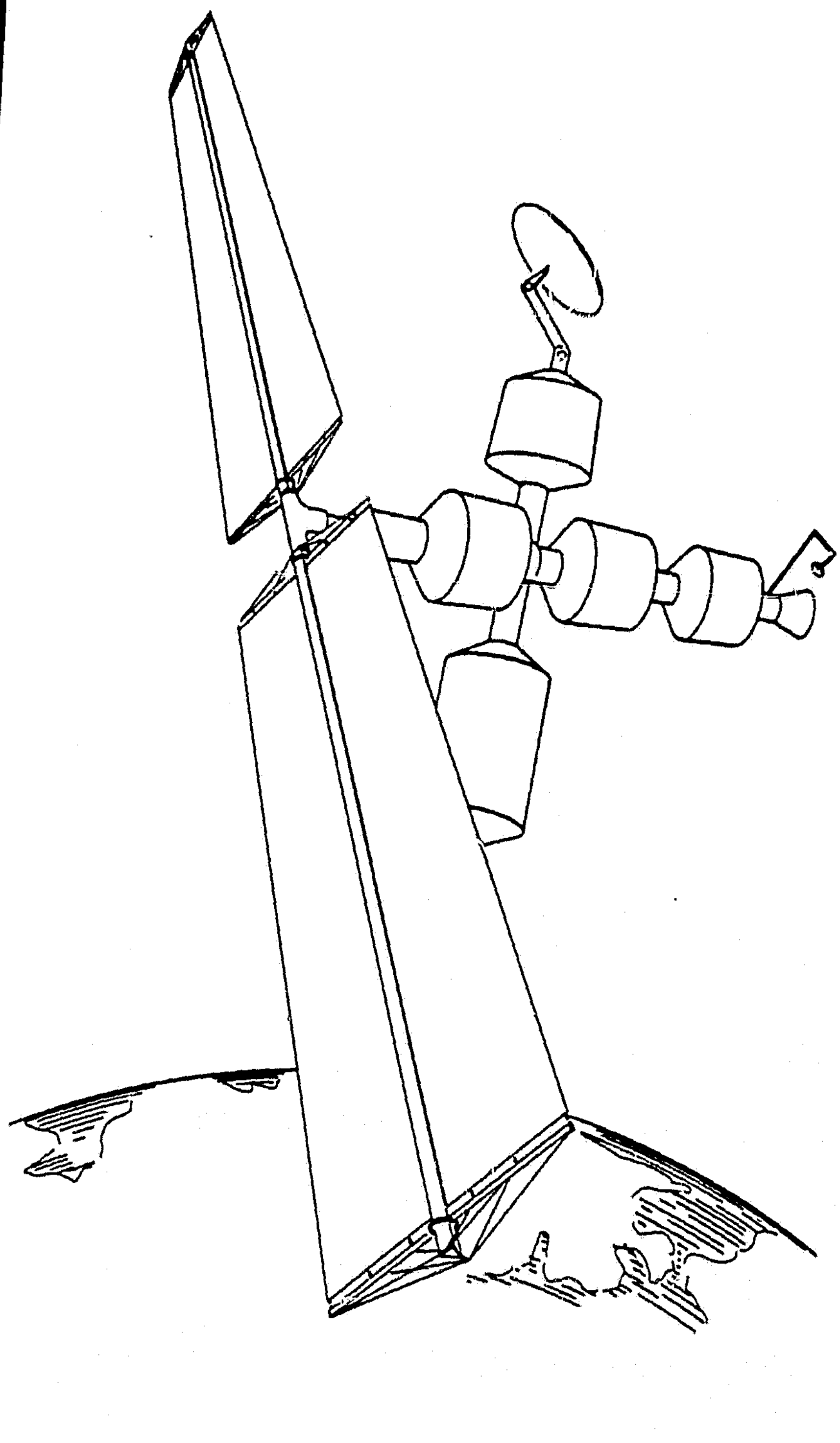

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LEO AND GEO SSPS SUBSYSTEM FUNCTIONS AND INTERFACES

Exhibit 2-2

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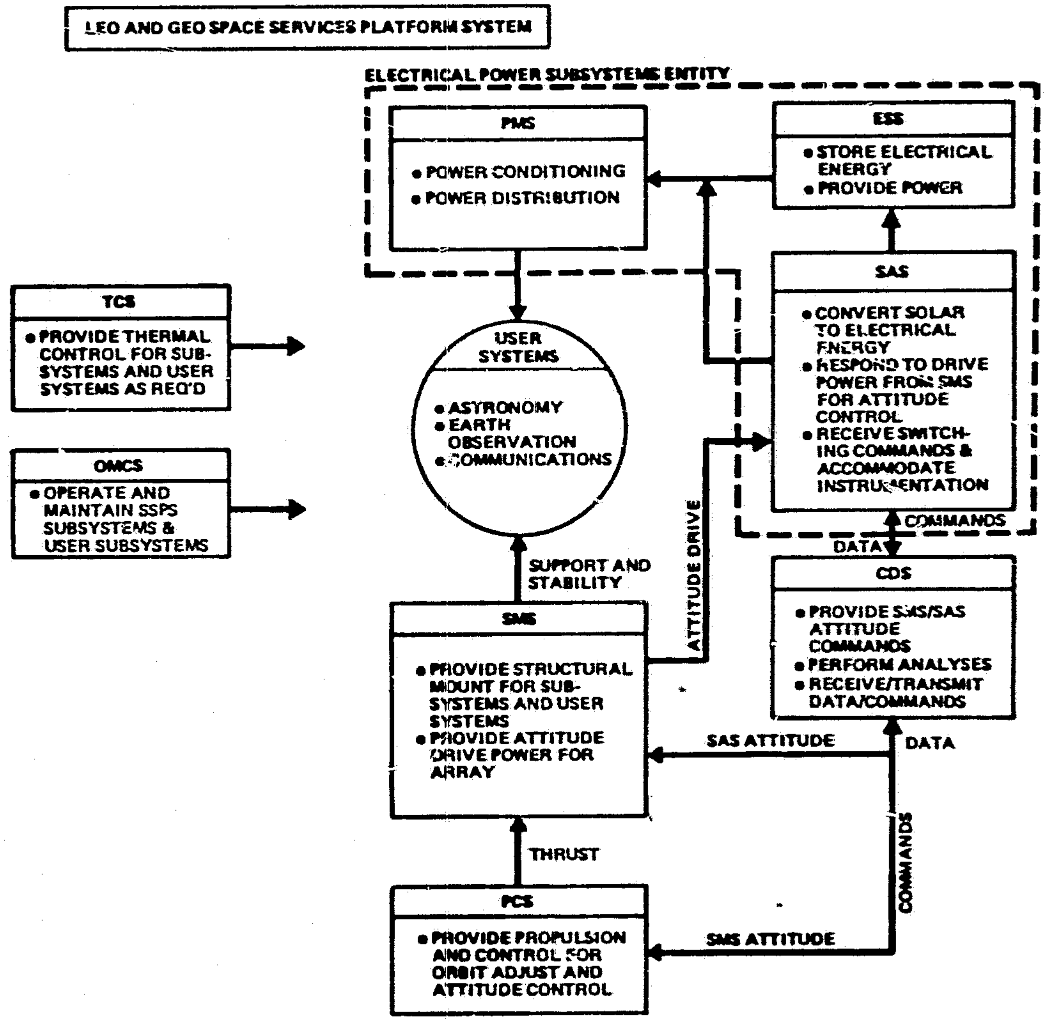
LEGEND:

- ESS ENERGY STORAGE SUBSYSTEM
- OMCS OPERATIONS AND MAINTENANCE CREW SUBSYSTEM (NOT APPLICABLE TO GEO SSPS)
- SAS SOLAR ARRAY SUBSYSTEMS
- CDS COMMAND AND DATA SUBSYSTEM
- SMS STRUCTURAL MECHANICAL SUBSYSTEM
- PCS PROPULSION AND CONTROL SUBSYSTEM
- PMS POWER MANAGEMENT SUBSYSTEM
- TCS THERMAL CONTROL SUBSYSTEM



2.1.3 Power Management Subsystem (PMS)

The PMS provides power conditioning and distribution of power to the user system(s) and to other SSPS subsystems.

2.1.4 Structural/Mechanical Subsystem (SMS)

The SMS provides (1) the structural mounting platform for User System(s) and for the SSPS subsystems, (2) drive power for the Solar Array Subsystem 2 axis/slip ring assembly, and (3) docking facilities for free flyers. The attitude of the platform is maintained by thrusters of the Propulsion & Control Subsystem (PCS), which are commanded by the Command and Data Subsystem (CDS). There are two interfaces of the SMS with SAS:

- structural mounting for the SAS 2 axis drive/slip ring
- mechanical drive of the SAS attitude at the input shafts of the SAS 2 axis drive/slip-ring assembly.

2.1.5 Propulsion and Control Subsystem (PCS)

The PCS provides attitude control and orbit adjust thrust for the SSPS. The thrusters are mounted on the SMS platform and at the end-booms of the SAS.

2.1.6 Command and Data Subsystem (CDS)

The CDS provides (1) the required attitude commands for the SMS and the SAS, (2) analyses, status reports, and corrective action based on telemetry data sensors located as required on the SSPS, SSPS subsystems and User Systems, and guidance and navigation sensors, and (3) command & data relay communications from external systems to SSPS and User System(s).

2.1.7 Operations and Maintenance Crew Subsystem (OMCS)

The OMCS provides operations services and maintenance for SSPS subsystems and the User System(s). The OMCS is stationed on-board the SSPS SMS platform.

2.1.8 Thermal Control Subsystem (TCS)

The TCS provides thermal control capability for SSPS subsystems and the User System(s) as required.

2.2 Orbit, Mission, and User Requirements

The mission requirements define reasonably typical mission scenarios and SSPS system/subsystem requirements which are representative of projected future LEO and GEO missions. The mission requirements are reflected by life cycle scenarios for each of the LEO and GEO missions.

The orbit, mission and user requirements for the GaAs SAS are defined in specification format, in Appendix A. Exhibit 2-3 is a summary of the specified requirements.

- Power output
  - LEO Missions: 250 kW Continuous, EOL
  - GEO Missions:50 kW Continuous, EOL
- Voltages (All Missions)
  - Input to power distribution & control subsystem 128.8 VDC
  - To Users: 75% of power at 120 VDC
  - To Users: 25% of power at 30 VDC
- LEO Orbit: 444 KM, 56^{o} Inclination
- GEO Orbit: 35,786 KM, Equatorial Stationary
- System Operational 1985-1995
- State-of-Art Design for Baseline
- Transportation to LEO: Shuttle
- Transportation to GEO: Shuttle/IUS
- Astronaut Deployment & C/O for LEO Missions
- Autonomous Deployment for GEO Missions
- 10 Year Life for LEO Subsystems
- 10 Year Life for GEO Subsystems
- LEO Reliability: Maximum of 10% of solar cell, solar cell module, or solar cell panel
- GEO Reliability: Same as LEO.

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3.0 POWER SYSTEM DEFINITION

Power system definition which is based upon the mission identification in Section 1.0, is accomplished by definition of the user system(s) power load requirements and the performance requirements for the power management, energy storage and solar array subsystems.

3.1 Power Load Requirements

The SSPS Electrical Power System (EPS) furnishes the power for the user system(s) and for internal SSPS power users, including other SSPS subsystems. The EPS is required to furnish a nominal orbital average power of 250 kW in LEO or 50 kW in GEO for external (user system) loads during the 10-year life of the system. Twenty-five percent (25%) of the rated output power must be available at a nominal low voltage of 30 VDC and the remaining 75% at a nominal high voltage of 120 VDC. In addition, 10% of the rated output power must be available to on-board SSPS subsystems also at a nominal low voltage of 30 VDC.

Exhibit 3-1 portrays typical End of Life (EOL) performance characteristics of the EPS. The composite efficiencies of the major elements and of the distribution cabling are indicated. To minimize losses, it is assumed that high efficiency components and large conductor sizes would be employed to the maximum extent possible. Also because of orbit conditions and degradation, the average available output power would be greater than the 250 kW LEO or 50 kW GEO requirements during maximum sunlight orbits, particularly early in the SSPS mission. From this, it is assumed that the distribution, power conditioning, and battery capacities will meet 150% of the average requirements. In addition, considering reasonable sizes and ratings for batteries and power conditioning equipment, the EPS is subdivided in 12 electrical groups, called power channels, whose outputs are combined to form the output distribution buses.

3.2 Power Management Subsystem

The PMS provides power conditioning and distribution of power to the user systems and to other SSPS subsystems. Power conditioning includes battery

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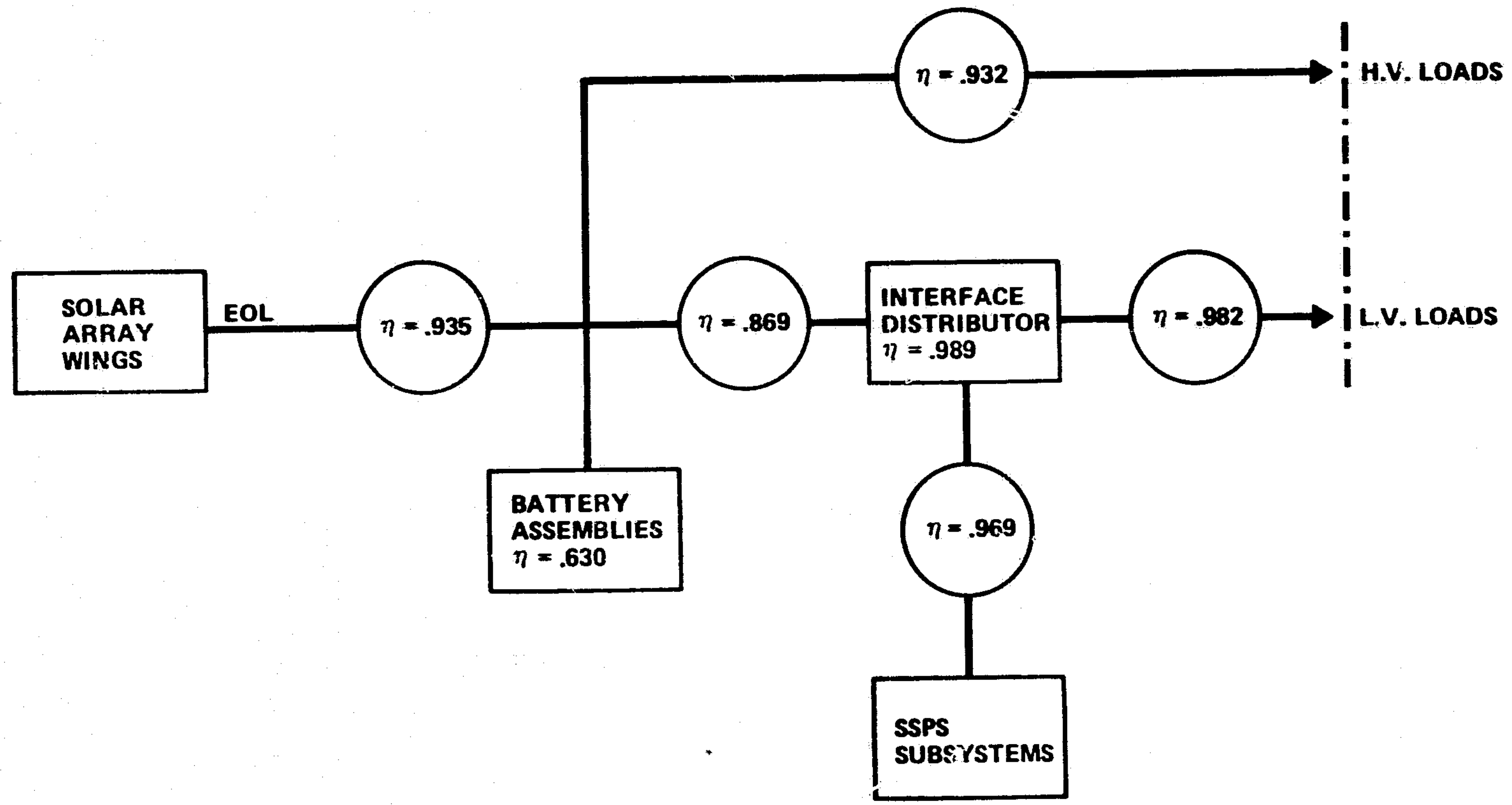
ELECTRICAL POWER SUBSYSTEM PERFORMANCE

Exhibit 3-1



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charging and voltage regulation. The functions of battery charging and voltage regulation can be accommodated by taking advantage of the technology developed by MSFC, which is nearing hardware readiness. The programmable power processor (P^3), a microprocessor-controlled multipurpose device, can, with appropriate programming, serve both as a regulator and a charger. The input voltage range of these devices is from 26 to 375 VDC, with an output capability from 24 to 188 VDC. The units weight approximately 25 Kg. Overall dimensions of the units are 63.5 cm X 26.9 cm X 16.5 cm.

3.2.1 Battery Charging

The P^3's used as chargers are programmed to track solar array peak power and then maintain a cumulative integration of the battery state of charge to provide optimum battery charging throughout battery life.

3.2.2 Voltage Regulation

The P^3's can be used for both 30 and 120 VDC regulation, with programmed slopes and selectable open circuit voltage settings to ensure proper load sharing among the regulators. Considering a maximum input voltage swing of 50V and a maximum load variation of 50 to 100 amps per unit regulator, the P^3's will be able to maintain the output voltage to within $\pm$ 1 percent of the preset voltage.

3.3 Energy Storage Subsystem

The ESS stores the electrical energy from the SAS during the sunlight period of the orbit and provides electrical power to the user systems and to other SSPS subsystems. The battery assembly efficiency indicated in Exhibit 3-1 is based upon nickel hydrogen technology and includes the efficiency of the P^3 charger. Integral to each battery are special reconditioning and cell protection circuits which will greatly extend the operational life of each battery. The cell protection circuits also provide by-pass circuits which allow each battery to continue to operate with as many as four cell failures out of 22 cells per battery.

3.4 Solar Array Subsystem

For an EPS with the internal efficiencies as indicated in Exhibit 3-1 to provide 250 kW of continuous power to the user system during a LEO orbit of 444 km and 56° inclination, the SAS must provide approximately 650 kW of electrical power during the sunlight period of the orbit. For the same EPS to provide 50 kW of continuous power during a GEO orbit of 35,786 km, the SAS must provide approximately 70 kW during the sunlight period. The array output will be held constant over the array life by controlling the sun vector angle. Physical descriptions of the SAS baselines (planar and concentrator) for each type of mission are contained in Section 4.0.

4.0 SOLAR ARRAY BASELINE DESIGN

Solar array baseline design was accomplished by the definition of four baseline GaAs solar arrays: (1) One planar array to provide 250 kW average power in LEO, (2) one array with solar concentration to provide 250 kW average power in LEO, (3) one planar array to provide 50 kW average power in GEO, and (4) one array with solar concentration to provide 50 kW average power in GEO. The baseline definitions include a WBS, a basic solar array configuration, the selection of component/production technologies, a solar array hierarchy, and the determination of key array performance and physical parameters. The values of the key parameters were determined by exercising the solar array performance model described in Section 6.0.

4.1 Work Breakdown Structures

The GaAs solar array subsystem WBS, which is shown in Exhibit 4-1, provides the skeleton for the baseline SAS's. The WBS was developed initially to accommodate a general SAS configuration and then made more specific after a review of current literature to determine reasonably typical GaAs hardware configurations for the LEO and GEO missions. A pictorial summary of the data base contained in REDSTAR, which was available for this review, is depicted by Exhibit 4-2.

The WBS identifies the elements which are assembled to make up an SAS. From a project standpoint, each element represents a design package. One major function of the WBS is to organize the various hardware element functions and their sequencing, which include materials processing, manufacturing, integration, transportation, assembly and checkout. In addition, the WBS also provides a basis for development of the functional flows and life cycle cost model described in Section 5.0.

4.2 GaAs Solar Array

The baseline GaAs solar array is a two wing array as shown in Exhibit 4-3. Each wing consists of two array blankets, with a single boom structure and tip pieces which hold the blankets in tension. For LEO, the SAS is a fold-up array, which will be shuttle transported and assembled in space. For GEO, the SAS will be integrated with the SSPS, and both transported to LEO by shuttle, and from there to GEO by the Boeing Interim Upper Stage (IUS).

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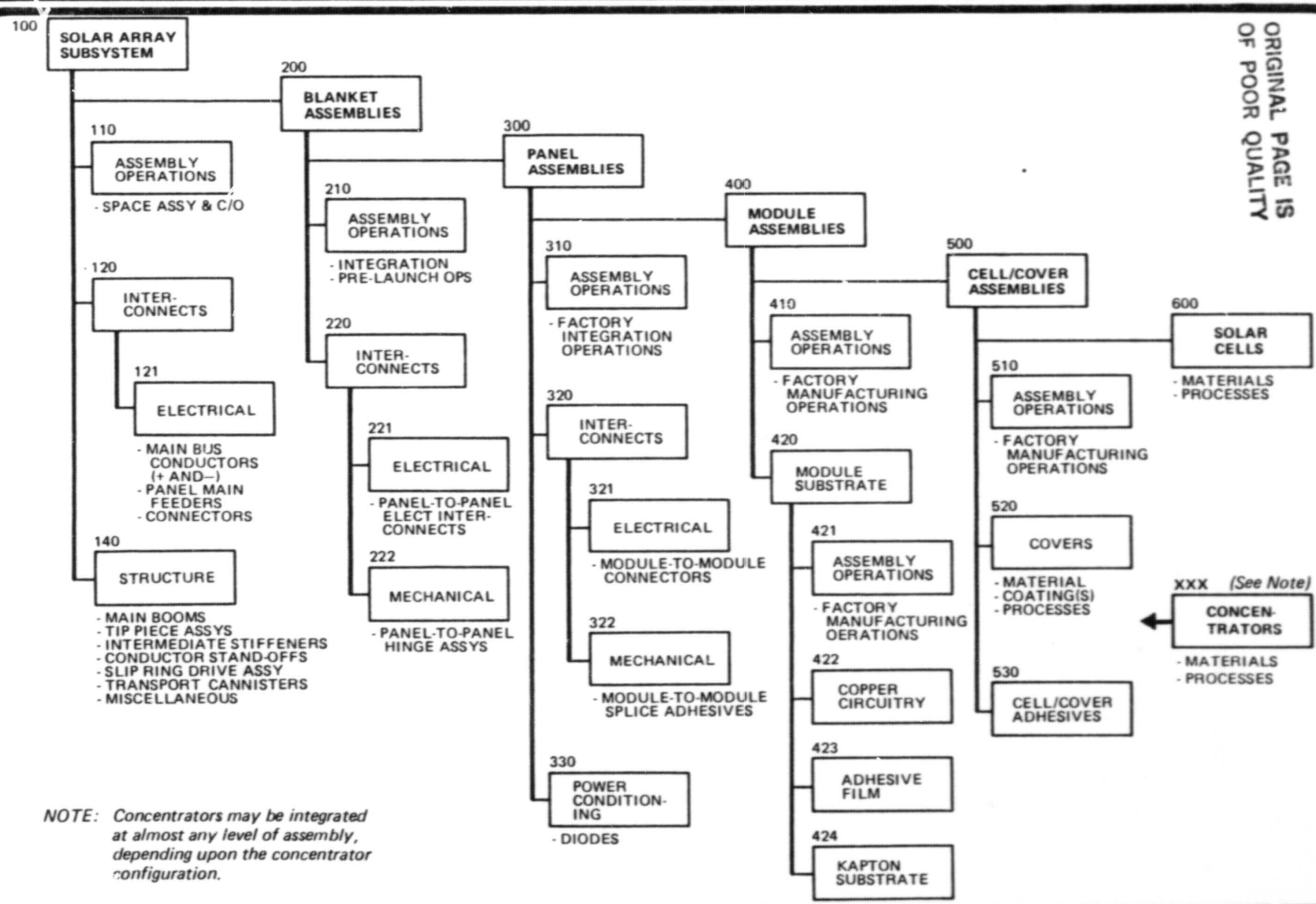
THE WBS PROVIDES ORGANIZATION, BASIS FOR LCCM STRUCTURE, AND FUNCTIONAL FLOW DEVELOPMENT

Exhibit 4-1



NOTE: *Concentrators may be integrated at almost any level of assembly, depending upon the concentrator configuration.*

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A SIGNIFICANT AMOUNT OF PHOTOVOLTAIC POWER SYSTEM/SOLAR ARRAY DATA IS CONTAINED IN REDSTAR

Exhibit 4-2

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Historical Photovoltaic Power Systems/Solar Arrays

AE
AIMP
APL
ATS
CTS
DSCS-II
ERTS
FRUSA
HASPA
HASPS
HEAO
HELIOS
IDSCP/A
INTELSAT
IUE
LUNAR ORBITER
M-35
MARINER
NIMBUS
OAO
OGO
OSO
SERT
SKYLAB ATM
SKYLAB OWS
SMM
SMS
TACSAT
TELESAT
TIROS
VELA
VIKING ORBITER
WESTAR

Planned Photovoltaic Power Systems/Solar Arrays

ULTRA LIGHTWEIGHT PANEL
ADVANCED LIGHTWEIGHT ARRAY
SPACE STATION SOLAR ARRAY
25 kW POWER MODULE
SOLAR ELECTRIC PROPULSION ARRAY
SATELLITE POWER SYSTEM
POWER EXTENSION PACKAGE
MULTI-kW SOLAR ARRAYS
MANNED ORBITAL CONCEPTS
LARGE SPACE POWER SYSTEMS
ECONOMICAL SPACE POWER SYSTEMS

Photovoltaic Power System/Solar Array Data in REDSTAR

SAMPLE OF PHOTOVOLTAIC DATA SOURCES	CONCENTRATORS	S, GaAs SOLAR CELLS	CONCENTRATION EFFECTS	LEO VS GEO CONSIDERATIONS	RADIATION TOLERANCE	PLASMA INTERACTIONS	COVERS/SUBSTRATES	MANUFACTURING/PROCESSES	SPACE TRANSPORTATION	SPACE ASSEMBLY/MAINTENANCE	ENERGY STORAGE	POWER MANAGEMENT	ECONOMIC/COST ANALYSES
AEROSPACE CORP													●
ARGONNE NATL LAB	●												
BOEING	●	●		●	●	●	●		●	●			●
GE							●				●	●	
GENERAL DYNAMICS		●			●		●		●			●	
GA INST OF TECH	●	●									●		
HUGHES AIRCRAFT		●			●			●			●		●
IBM		●											
IECEC REPORTS	●	●	●				●	●			●	●	
IEEE REPORTS	●	●	●	●	●	●	●	●	●	●	●	●	●
INTL PHOTO CONF		●					●	●					
JPL							●	●					●
LAWRENCE RAD LAB		●			●								
LMSC	●	●		●	●		●	●	●	●	●	●	●
MARTIN MARIETTA										●	●		
McDONNELL DOUGLAS							●	●		●	●	●	●
MOTOROLA													●
NASA-GSFC							●	●			●		
NASA JSC											●		
NASA-LARC		●			●								
NASA-LERC		●				●						●	●
NASA-MSFC	●						●	●			●	●	
OCLI		●					●	●					●
RCA		●								●			●
ROCKWELL INTL	●	●	●	●	●		●		●	●	●		●
SOLAREX CORP	●												
SHILDAHL INC							●	●		●	●	●	●
SPECTROLAB		●					●	●					●
TRW	●	●	●				●	●	●	●			●
VARIAN			●										

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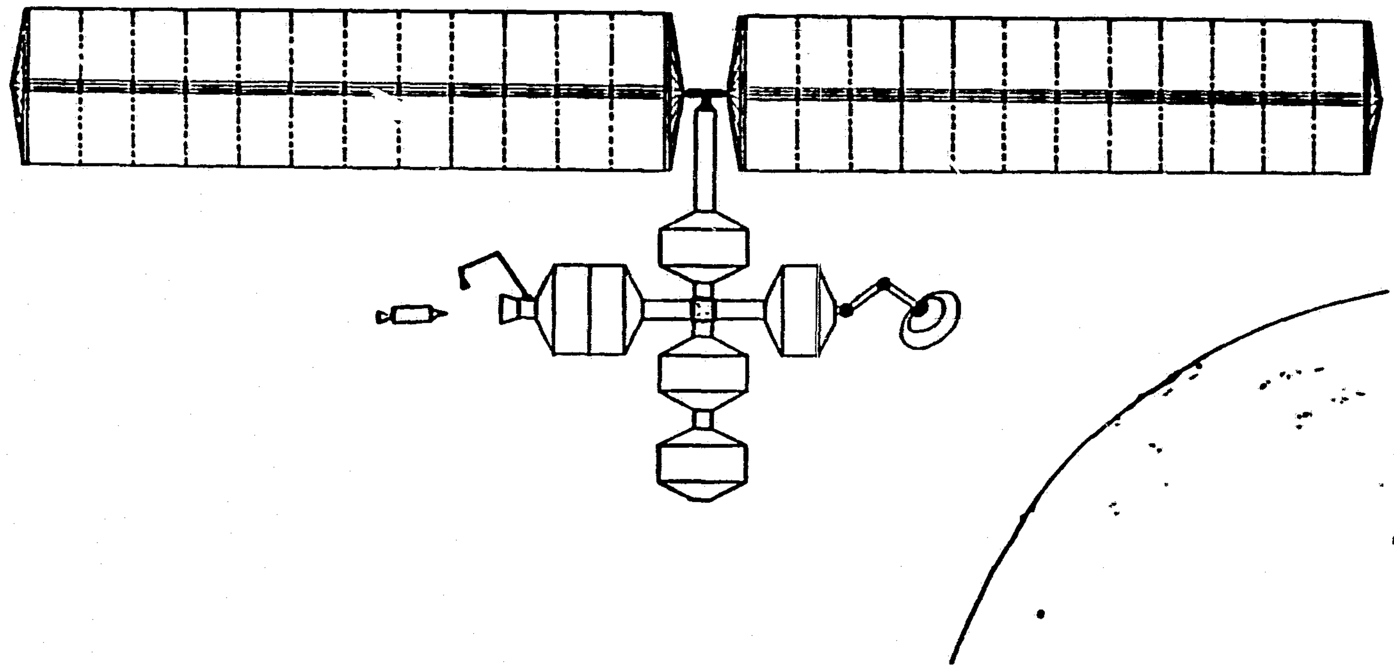
GaAs SOLAR ARRAY

Exhibit 4-3



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The SAS electrical power goes to a centrally located slip-ring assembly. The bus conductors are supported by a semi-conductor (300°) styrofoam segment attached to the bottom of the boom. The slip-ring assembly is double-gimballed to make the orientations and movements of the SAS independent of the user platform. The array output can be held constant over the array life by varying the sun-vector angle, if it is not desirable to take advantage of the additional power under array beginning-of-life (BOL) conditions.

4.3 Solar Array Module

The solar array module is the basic SAS building block. The module size is determined by the array geometry and the SAS power requirement. The module cross section, which is shown in Exhibit 4-4, consists of the following:

- Solar Cell

  2 cm x 4 cm x 8 mil, wraparound contact (assumed), liquid phase epitaxial (LPE) growth GaAs (developed by Hughes Aircraft Company), 18.1% efficiency (unglassed), 25°C ambient (AMO).

- Cell Cover

  2 cm x 4 cm x 6 mil, fused silica (Corning Glass 7940).

- Cover Adhesive

  2 mil DC-93500.

- Substrate

  Laminated printed circuit, 1 mil copper rolled annealed interconnect. Insulation is two sheets of 0.5 mil kapton/0.5 mil high-temperature polyester adhesive.

The cells are welded to the copper interconnect circuitry through the top layer of kapton, which together with the lower layer, form a kapton-copper-kapton sandwich. The basic pattern for the solar cell interconnects within the substrate consists of three parallel strings of series connected cells. The total number of series cells in the basic pattern is determined by the array geometry and the SAS voltage requirement.

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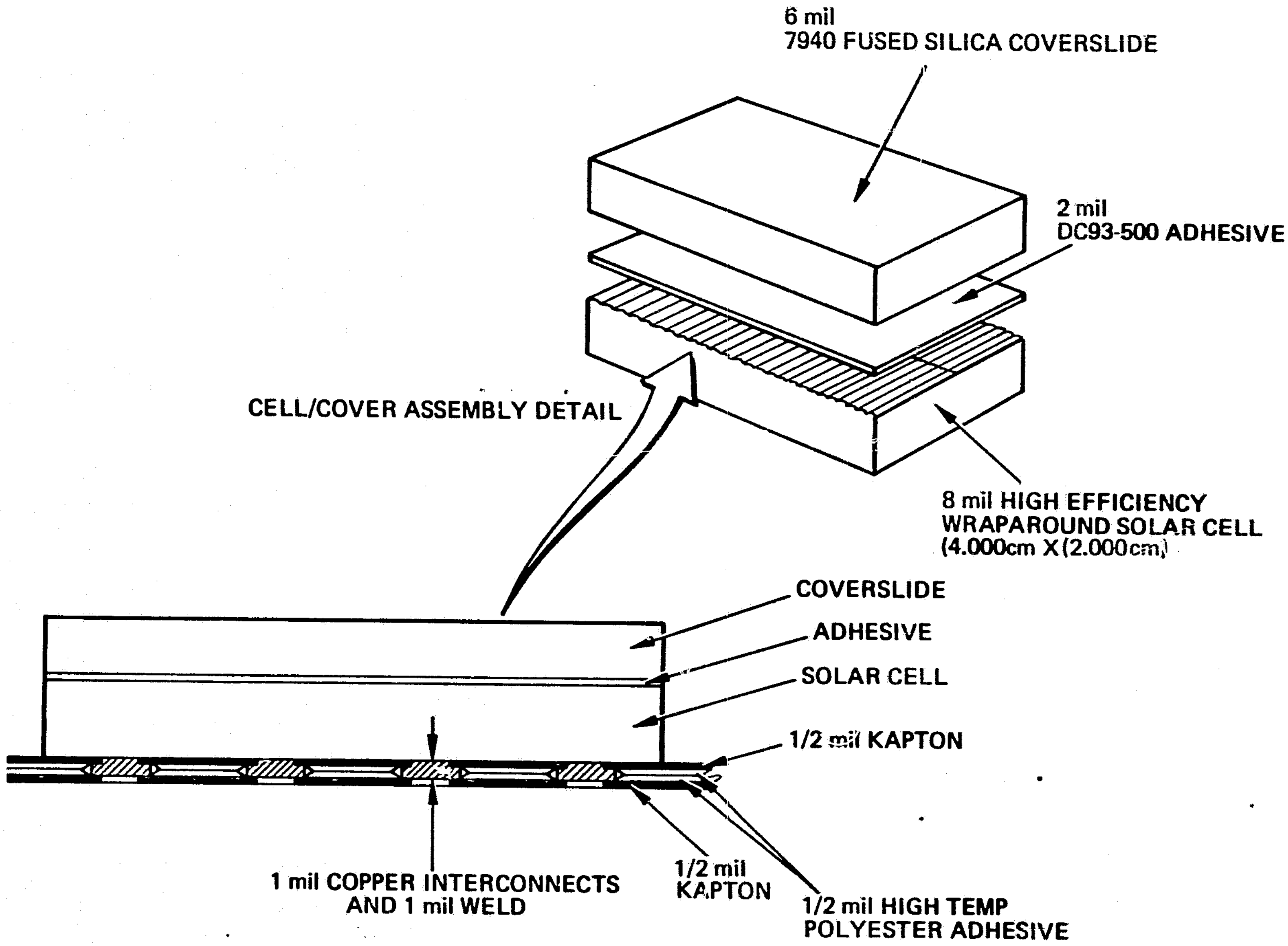
SOLAR ARRAY MODULE CROSS SECTION

Exhibit 4-4



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4.4 Concentrator

The baseline concentrator, which is called a Truncated Pentahedral Pyramid (TPP), is shown in Figure 4-5. The TPP provides a geometric concentrator ratio (GCR) of 5, and with it, several desirable properties. First, it provides a uniform reflected beam distribution onto the solar cells. Second, its geometry allows very dense a module packing factor (i.e., no wasted space between concentrators). Third, a tandem string of TPP's requires a fewer number of tension lines and the positioning of "back-to-back" reflectors can be controlled at the TPP corners. Fourth, the number of joints or pivots has been reduced to a minimum, permitting credible repeat ability of deployment angles. Fifth, an attractive folding scheme is possible which allows the TPP to be densely packaged and stowed for space transportation in the Shuttle, plus provides a deployed structure with good stability and stiffness. For a GCR of 5, the total area of concentrator material is approximately 9X the illuminated area, and the reflector depth ratio is 1.3. For the GaAs baseline, the concentrator is constructed utilizing a spectrally selective reflector material (cold mirror). (Lockheed Report LMSC - D715841).

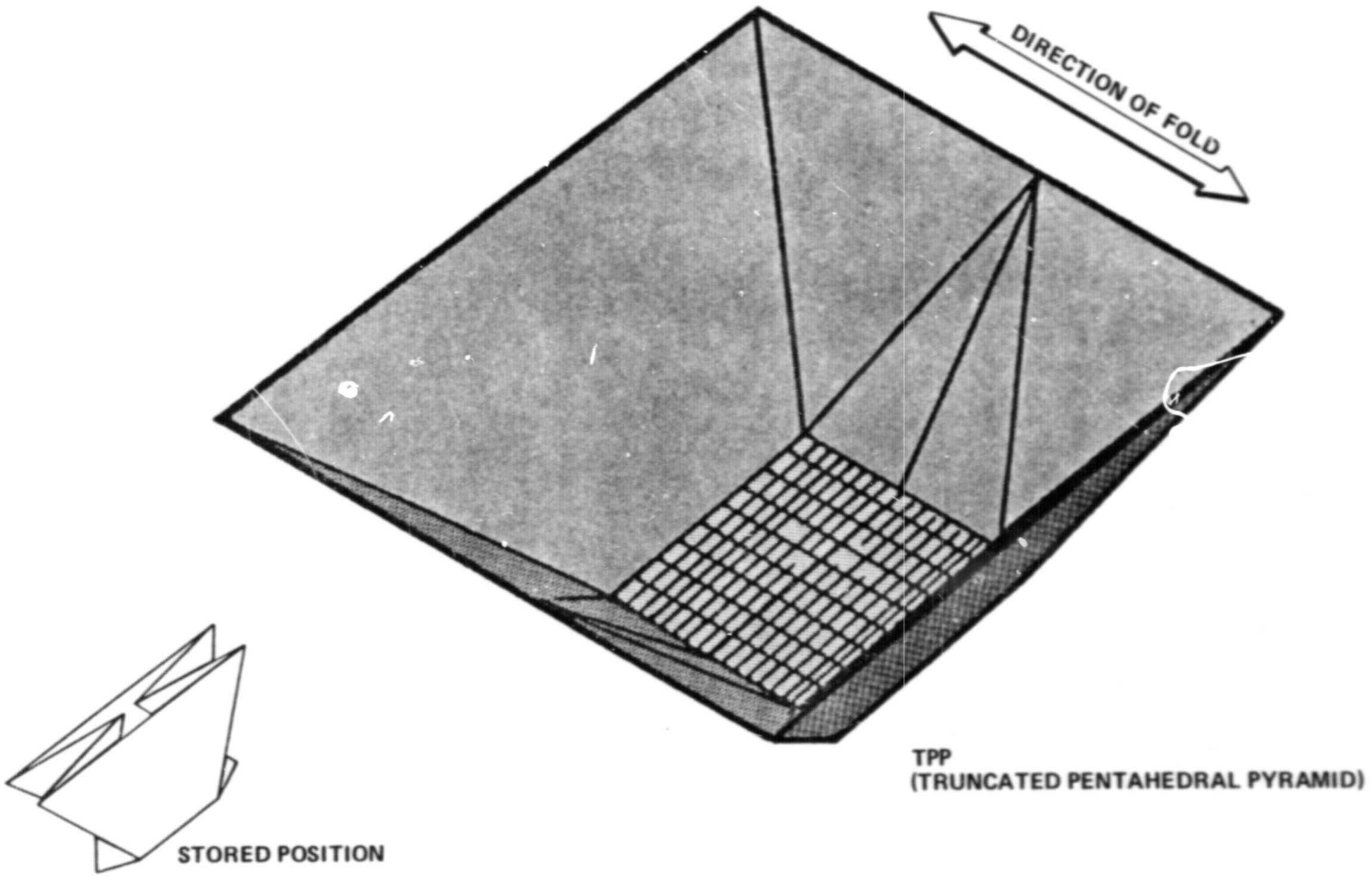
4.5 Array Structure

The solar array structural design assumes two wings, each including an astromast boom with tip-piece assemblies for tension, and a two-axis (pitch and roll) slip-ring/drive assembly as shown in Exhibit 4-3. The basic wing/boom concept is shown in Exhibit 4-6. The requirements and assumptions which apply to the structure are:

- aluminum booms
- 2-axis drive
- maximum angular acceleration (in pitch and roll), $\dot{\alpha} = 1.8 \times 10^{-5}$ radians/s^2
- maximum bend angle, $\Theta = 10°$ under 0.01G force applied at outboard tip
- first natural frequency, $\omega_1 = 0.04$ radians/s
- ratio of compressive preload to critical buckling load, P/Pcr = 0.3 (NAS TN D-8376)

SOLAR ARRAY CONCENTRATOR (TPP-REFLECTOR, FOLDABLE)

Exhibit 4-5



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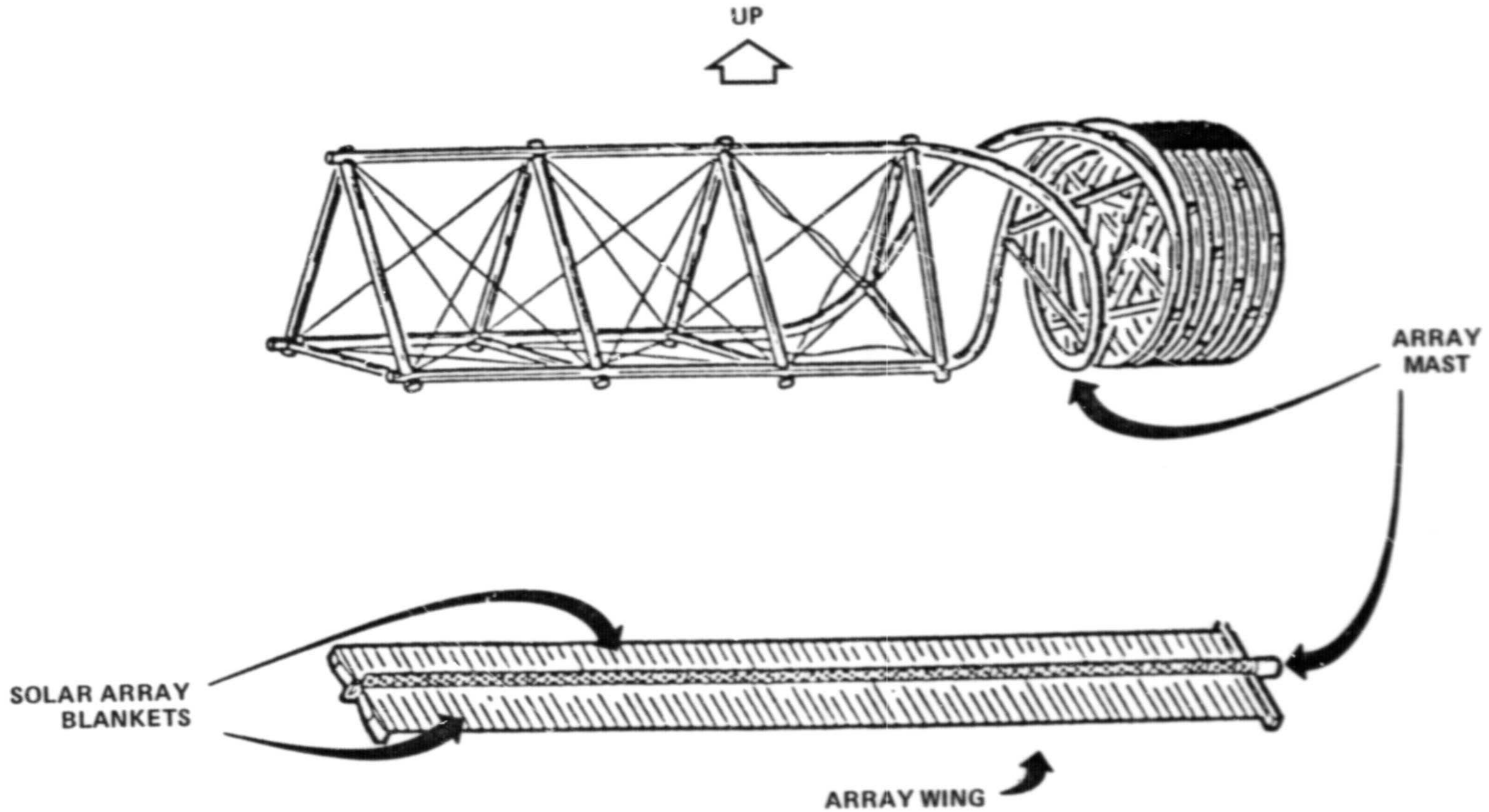
SOLAR ARRAY WING/STRUCTURE

Exhibit 4-6



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- ratio of blanket mass to boom mass, $\bar{M} = 6$
- mass of tip price << mass to boom $M_{tp} << M_b$
- length of each boom

  ℓ_b = blanket length + 7 meters

For the 250 kW LEO arrays, the structure would be packaged separate from the array blankets for space transportation aboard the Shuttle and then integrated into a deployed array during subsequent space EVA operations. For the 50 kW GEO arrays, a fold-up array configuration integrated with the SSPS would be required, which would allow Shuttle/IUS transportation to GEO and subsequent autonomous deployment in orbit.

4.6 Solar Array Hierarchy

The solar array hierarchy, which is based on the WBS, quantifies the number of elements which are assemblied to make up the solar array. Exhibit 4-7 depicts the hierarchies for the four baseline arrays, and also provides a size comparison between common types of elements. The basic hierarchy for each baseline array configuration breaks down as follows:

	250 kW LEO Planar	250 kW LEO Conc.	50 kW GEO Planar	50 kW GEO Conc.	
1 Array =	2	2	2	2	Wings
1 Wing =	2	2	2	2	Blankets
1 Blanket =	12	12	5	5	Channel
1 Channel =	2	4	3	4	Panels
1 Panel =	15	8	4	3	Modules
1 Module =	3,560	864	2,706	700	Cells

4.6.1 Array Blanket

The array blanket consists of panels which are mechanically interconnected to fold up for transportation into space and subsequent deployment. For LEO orbits, the blankets are transported separate from the structure and then integrated with the structure during EVA operations. For GEO orbits, the blankets

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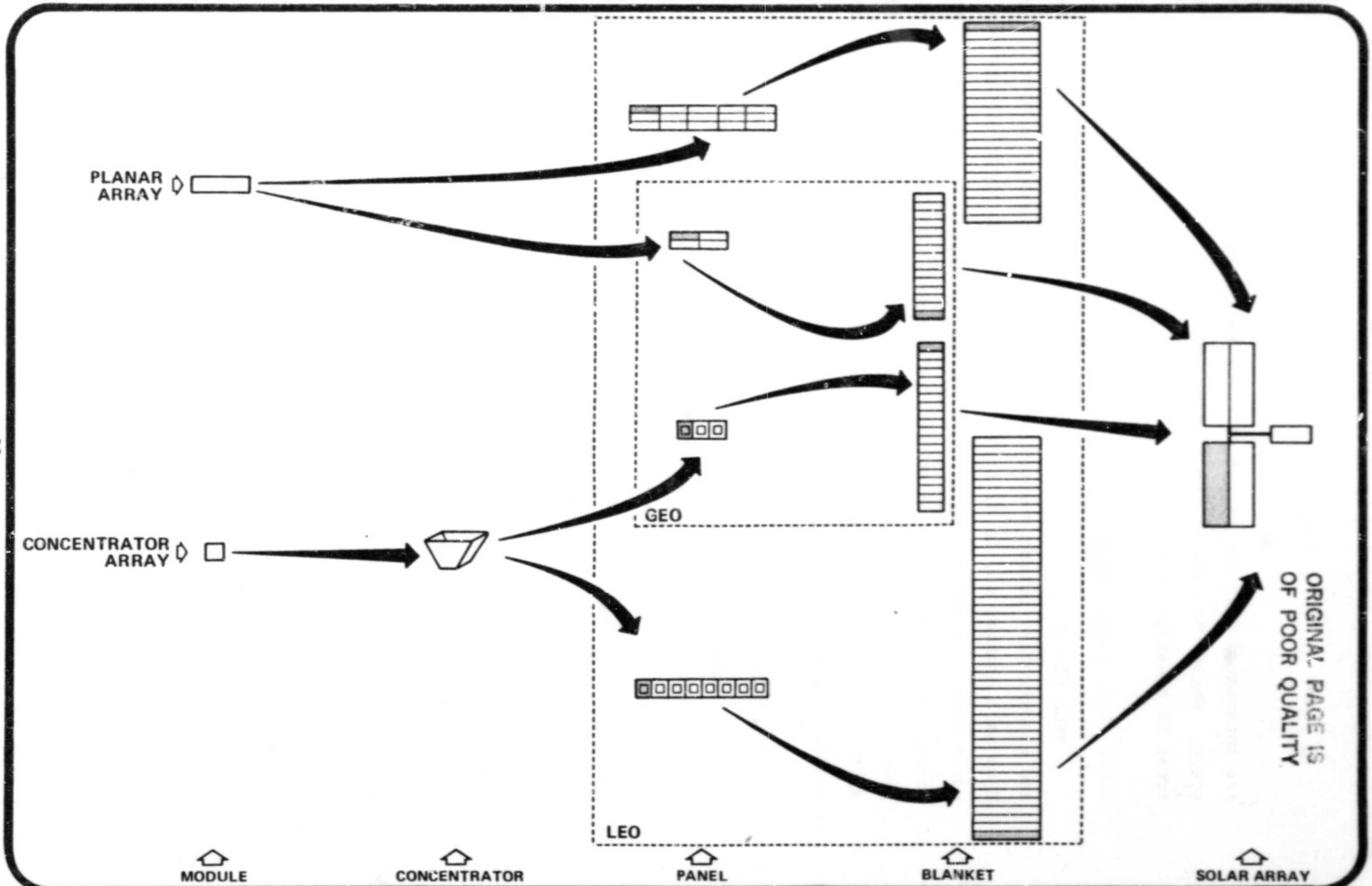
SOLAR ARRAY HIERARCHY

Exhibit 4-7



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are integrated with the structure prior to launch and subsequent deployment in space. While the size of the blankets may vary, the total number of blankets/ array is constant at 4.

4.6.2 Electrical Channel

Each electrical channel consists of array panels which are mechanically and electrically interconnected to provide an independent electrical entity. Thus each channel is, in effect, a separate solar array providing electrical power through a separate slip ring channel to separate hardware elements in the energy storage and power management subsystems. Electrically, each electrical power channel will provide approximately 13.55 kW in LEO and 3.5 kW in GEO at a minimum voltage of 180 VDC. These power levels are based on 650 kW total power and 48 channels in LEO, and 70 kW total power and 20 channels in GEO.

4.6.3 Array Panel

The number of array panels per channel is a function of the total number of solar cells, as well as a function of the cell size and the overall array geometry. While the panel size may also vary, the maximum dimensions are constrained by the space transportation requirements. For planar arrays, the size constraint is 18m x 3m in LEO and 6.75m x 2m in GEO. For concentrator arrays, the constraint in 18m length for LEO for GEO.

4.6.4 Concentrator

As stated previously, the TPP concentrator allows a very high module packing factor, plus the capability for dense packaging for space transportation. To take advantage of these features, the array panel for concentrator arrays will consist of a single row of concentrators with the fold axis parallel to the length dimension of the panel (i.e., the entire panel will fold up width-wise). The total number of concentrators per panel depends upon the concentrator size (i.e., GCR) and the maximum allowable panel length.

4.6.5 Array Module

For the 250 kW planar array in LEO, the number of array modules/panel is fixed at 5 x 3 = 15. For the 250 kW concentrator array in LEO, the number of modules is the same as the number of concentrators (i.e., one-to-one). For the concentrator array (GCR = 5), the layout is 8 x 1 = 8. In GEO, similar considerations apply, except on a smaller scale. For the planar array, the layout is 2 x 2 = 4. For the concentrator array (GCR = 5), the layout is 3 x 1 = 3.

The actual module sizes vary depending on the number of solar cells per module and the cell size. The maximum allowable module dimensions, reflect the space transportation requirements. The module for LEO planar has the maximum dimensions of 3.5m x 1m. The maximum dimensions for the GEO planar module is 3.375 m x 1m. For both concentrator array configurations (i.e., LEO and GEO), the maximum module size is 1m x 1m which assures that the size of the folded concentrator/panel will meet the respective transportation requirement.

4.7 Solar Array Baselines

The four array baselines are summarized in Exhibit 4-8. The exhibit is a computerized printout, which was generated by exercising the performance model described in Section 6.0. The computer program for the combined solar array performance and cost model is contained in Appendix C.

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BASELINE GaAs SAS PARAMETERS AND CHARACTERISTICS

Exhibit 4-8

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	LEO 250 KW PLANAR		LEO 250 KW CONC.		GEO 50 KW PLANAR		GEO 50 KW CONC.	
ARRAY PERFORMANCE								
No. of Hardware Life Cycles	1		1		1		1	
Total Cell Life Required (Yr)	10.0		10.0		10.0		10.0	
Total Power Required (KW)	650.1		650.1		70.6		70.6	
Total Voltage Required (V)	180.0		180.0		180.0		180.0	
Total EOL Min. Power (KW)	651.1		652.9		70.8		72.7	
Total EOL Min. Voltage (V)	215.0		197.0		192.0		182.0	
BOL Cell Efficiency (%)	18.1		18.1		18.1		18.1	
BOL Cell Max. Voltage (V)	.809		.843		.809		.843	
EOL Cell Power (MW)	127.0		492.0		109.0		433.0	
EOL Cell Voltage (V)	.715		.514		.726		.542	
Max. Avg. Illumination (W/M2)	1249.0		5995.0		1198.0		5753.0	
Min. Avg. Illumination (W/M2)	1169.0		5609.0		1122.0		5383.0	
Avg. Temp. (Deg-K @ Max Ill)	320.7		477.7		316.3		469.9	
Avg. Temp. (Deg-K @ Min Ill)	315.5		469.7		311.1		462.0	
POWER/VOLTAGE FACTORS	POWER	VOLTAGE	POWER	VOLTAGE	POWER	VOLTAGE	POWER	VOLTAGE
Assembly	.965	1.000	.965	1.000	.965	1.000	.965	1.000
Radiation	.891	.968	.891	.968	.779	.963	.779	.963
Temperature	.982	.969	.828	.708	.986	.977	.836	.721
Diode	.993	.993	.993	.993	.993	.993	.993	.993
Solar Cell IC	.999	.999	.999	.999	.999	.999	.999	.999
Module/Module IC	.999	.999	.999	.999	.999	.999	.999	.999
Panel/Panel IC	.999	.999	.999	.999	.999	.999	.999	.999
Main Bus	.975	.975	.927	.927	.988	.988	.967	.967
Slip Ring	.988	.988	.988	.988	.988	.988	.988	.988
Plasma Leakage	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Temperature Cycling	.800	1.000	.800	1.000	.800	1.000	.800	1.000
	-----	-----	-----	-----	-----	-----	-----	-----
CUM. EOL FACTOR	.644	.884	.518	.610	.572	.898	.475	.643
ILLUMINATION FACTORS								
Glassing (BOL)	1.017		1.017		1.017		1.017	
Cover Degradation (EOL)	.870		.870		.870		.870	
Concentration Ratio (BOL)	1.000		5.000		1.000		5.000	
Concentrator Degrad. (EOL)	1.000		.960		1.000		.960	
	-----		-----		-----		-----	
CUM. EOL FACTOR	.885		4.247		.885		4.247	
PHYSICAL CHARACTERISTICS								
Total Number of Cells	5126400		1327104		649440		168000	
No. of Modules/Panel	15		8		4		3	
No. of Panels/Blanket	24		48		15		20	
Blanket Weight (Kg)	1957.0		1498.0		300.0		224.0	
Structure Weight (Kg)	2196.0		1740.0		287.0		221.0	
Total Array Weight (Kg)	10024.0		7732.0		1487.0		1117.0	
Solar Cell Area (cm2)	8.000		8.000		8.000		8.000	
Module Area (M^2)	3.420		.880		2.610		.690	
Concentrator Area (M^2)	0.00		7.98		0.00		6.25	
Panel Area (M^2)	51.00		35.50		10.40		10.40	
Blanket Area (M^2)	1253.0		1743.0		166.0		216.0	
Total Array Area (M^2)	5012.0		6972.0		664.0		864.0	
Power Density (W/M2)	129.90		93.65		106.61		84.19	
Power/Weight Ratio (W/Kg)	64.95		84.44		47.61		65.12	

5.0 LIFE CYCLE COST DETERMINATION

Life cycle cost determination was accomplished by developing and exercising a GaAs SAS life cycle cost model. Development of the LCCM included (1) the development of functional flow diagrams for DDT&E, Production, and O&M; (2) the development of the LCCM structure; (3) the definition of basic ground rules and assumptions; and (4) the development of cost estimating relationships. Exercising the LCCM included (1) estimating the LCC of the GaAs SAS baselines which are defined in Section 4.0 and (2) quantifying the variations in LCC which resulted from variations in SAS physical, performance and technology parameters as described in Section 6.0. The LCCM input parameters are defined by the performance model. The input parameters consist generally of hardware quantities, weights, volumes, life, efficiencies and power outputs.

5.1 Functional Flow Diagrams

The basis for the LCCM structure is the DDT&E, Production and O&M functional flow diagrams, which are shown in Exhibits 5-1, 5-2 and 5-3 respectively. Although the DDT&E cost estimate was based on 35% of the production cost (derived from historical program costs), a breakdown of DDT&E functions is provided in Exhibit 5-1 for completeness and for possible future analysis (such as estimation of design and/or testing costs as a function of SAS reliability). The production flow (Exhibit 5-2) is consistent with the SAS work breakdown structure described in Section 4.0. It should be noted that the production phase for the LEO missions includes Shuttle transportation, as well as array assembly and checkout in space; while that for the GEO missions includes Shuttle/IUS transportation and automated array deployment. In the O&M flow (Exhibit 5-3), the "produce spaces" block is null since the required number of spares (panels) are assumed to be manufactured during production. However, this could be subject to a trade analysis, and therefore the function has been included for completeness.

5.2 Life Cycle Cost Model

As defined by the functional flows, the GaAs SAS LCCM consists of three phases: (1) DDT&E, (2) Production and (3) O&M. The LCCM structure, which reflects both the functional flow activities (horizontal axis) discussed in the previous

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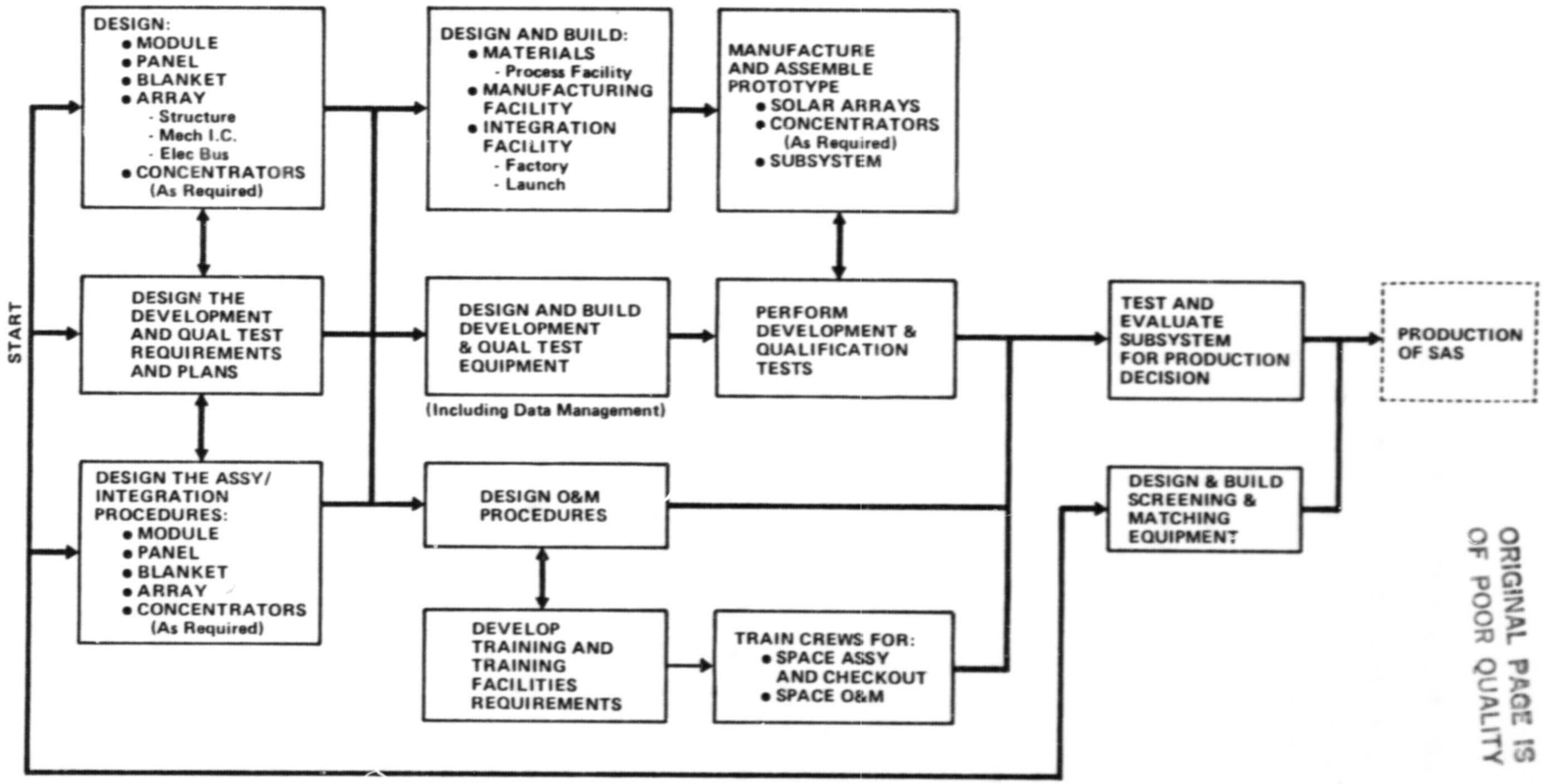
DDT&E FUNCTIONAL FLOW

Exhibit 5-1



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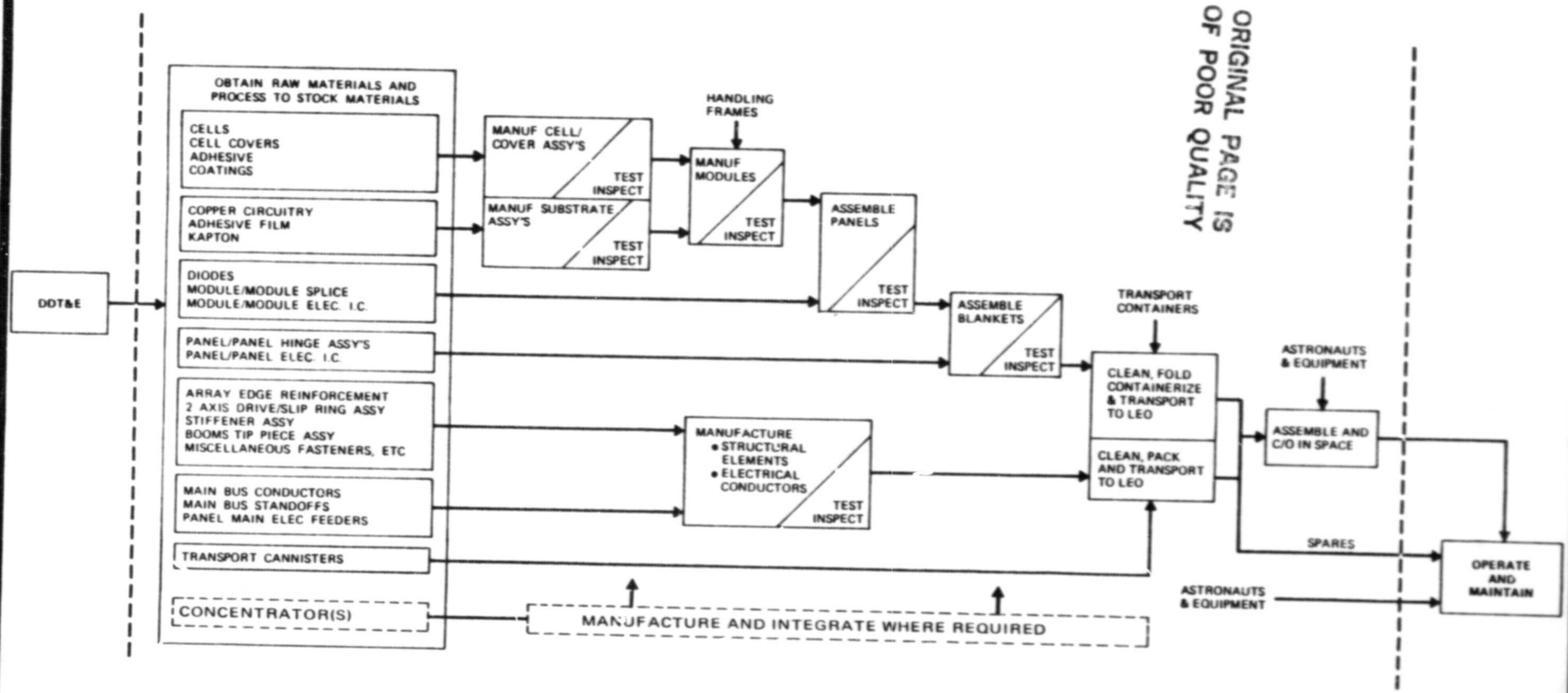
PRODUCTION FUNCTIONAL FLOW SPACE SERVICES PLATFORM SYSTEM

Exhibit 5-2



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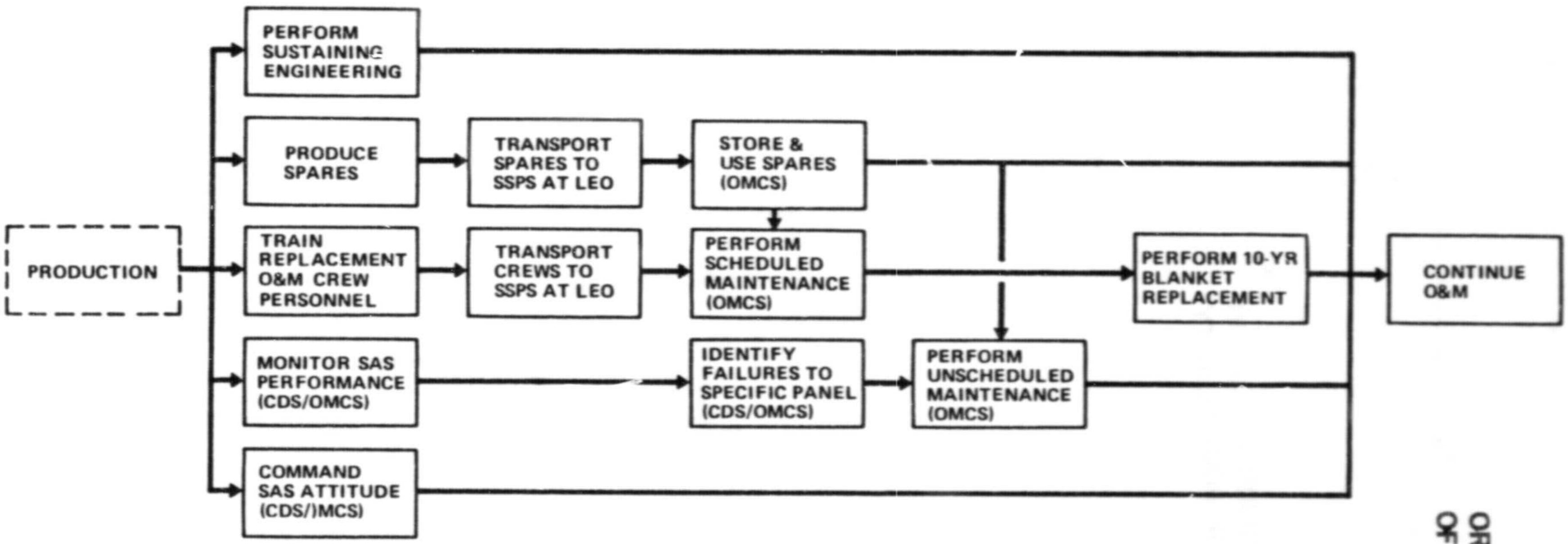
O&M FUNCTIONAL FLOW

Exhibit 5-3



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paragraph and the SAS WBS/hierarchy (vertical axis) discussed in Section 4.0, is shown in Exhibit 5-4. In conjunction with the LCCM structure, various top-level ground rules and assumptions, which were also used in the development of the total LCCM, are listed in Exhibit 5-5. In addition, the data sources used in the development of the GaAs SAS LCCM consisted of historical data from REDSTAR plus cost/technical data which was collected from various space hardware manufacturers as shown in Exhibit 5-6.

5.3 Design, Development, Test and Evaluation Cost

The cost of the DDT&E phase of life cycle cost is estimated to be 35% of the production phase cost. The DDT&E phase includes the following functions: (1) designing the array and the manufacturing facility, and manufacturing the prototype solar array subsystem; (2) designing the development and qualification test requirements and plans, and performing development and qualification tests; (3) designing the assembly/integration procedures, designing operations and maintenance procedures, developing training requirements and (4) testing and evaluating the solar array subsystem for production decision.

5.4 Production Cost

The cost of the production phase is divided into two categories: (1) the prelaunch manufacturing cost and (2) the cost incurred by NASA to deploy and checkout the SAS in orbit. For LEO, the NASA incurred cost include the transport of astronauts and array spares to LEO and the cost of space assembly and checkout. Referring to the LCCM structure shown in Exhibit 5-4, the intersections of the matrix represent cost elements, for which cost estimating relationships (CER's) were developed as shown in Exhibit 5-7. Generally, the prelaunch production manufacturing CER's included the costs of direct labor, materials and components, process equipment, and wraparound costs such as burdens, fringes, overheads, G&A, maintenance, and factory resources as summarized in Exhibit 5-8. Inputs consist of the total numbers of solar cells, weights and volumes, and other cost sensitive parameters such as attrition and number of spares required. An example of a typical CER is shown in Exhibit 5-9.

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GaAs SOLAR ARRAY SUBSYSTEM LIFE CYCLE COST MODEL (LCCM) STRUCTURE

Exhibit 5-4

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GaAs SAS LCCM / FUNCTIONAL FLOW / WBS	DDT&E					PRODUCTION										O&M			
	DESIGN	TEST HARDWARE	TEST OPERATIONS	SYSTEMS ENGINEERING	MANAGEMENT	CELL/COVER ASSY	SUBSTRATE	MODULE ASSY	PANEL ASSY (INCL. CONCENTRATOR)	BLANKET ASSY	SUBSYSTEM ASSY	ACCEPTANCE	PRELAUNCH	SPACE TRANSPORT	SPACE DEPLOYMENT	SPARES	TRAINING	MAINT FUNCTIONS	SPACE TRANSPORT
SOLAR CELLS	■					■													
CELL/COVER ASSY		■	■	■	■	■		■											
COVER	■					■													
ADHESIVE	■					■													
SUBSTRATE		■	■	■	■		■	■											
COPPER CIRCUITRY	■						■												
ADHESIVE FILM	■						■												
KAPTON SUBSTRATE	■						■												
MODULE ASSY		■	■	■	■				■										
PANEL ASSY (INCL CONCENTRATOR)		■	■	■	■				■							■	■	■	■
INTERCONNECTS	■								■									■	
DIODES	■								■									■	
BLANKET ASSY		■	■	■	■					■								■	
INTERCONNECTS	■									■						■	■	■	■
SUBSYSTEM		■	■	■	■					■	■	■	■	■	■			■	
MAIN BUS CONDUCTOR	■										■	■	S	S	■			■	
STRUCTURE	■										■	■	■	■	■			■	
INTERFACES					■											■	■	■	■
THERMAL CONTROL	■	S	S	S							■				■		■		
OMCS	■	S	S	S											■			■	■

S=Simulated

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GROUND RULES AND ASSUMPTIONS

Exhibit 5-5

- ALL COSTS IN 1980$ MILLIONS
- STOCK MATERIALS AND COMPONENTS USED FOR MANUFACTURE OF ARRAY
- DEDICATED FACTORY FACILITY REQUIRED FOR MANUFACTURE OF ARRAY
- COST OF SPACE TRANSPORTATION AND SPACE DEPLOYMENT/CHECKOUT IS INCLUDED IN PRODUCTION PHASE OF LIFE CYCLE COST
- ALL SHUTTLE FLIGHTS ASSUMED TO BE DEDICATED TO SPACE SERVICES PLATFORM SYSTEM
- OPERATIONS AND MAINTENANCE PHASE OF BASELINE LIFE CYCLE COST COVERS TOTAL LIFE OF ARRAY

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TOP LEVEL COST RELATIONSHIP SOURCES

Exhibit 5-6

- AEROSPACE CORPORATION ADVANCED SPACE POWER REQUIREMENTS & TECHNIQUES
  - HISTORICAL AND PROJECTED DATA
- MSFC COMMON SOLAR ARRAY COST ESTIMATE SUMMARY:
  - CELL, CELL/COVER ASSEMBLY, MODULE ASSEMBLY
- PRC COST ESTIMATING TECHNIQUES FOR MISSION SYSTEM INTEGRATION AND TEST ELEMENTS OF FUTURE SPACE MISSIONS
  - PROJECT MANAGEMENT AND SE
- NASA REPORT TO THE SPECIAL PANEL FOR SPACE EVALUATION:
  - $300/WATT
  - DDT&E = 0.35 PRODUCTION COST
- JSC STS REIMBURSEMENT GUIDE:
  - $31 M/DEDICATED FLIGHT TO 444 KM 56^{o} INCLINATION
- MSFC/JSC TELECONS
  - ASTRONAUT LABOR OF $250 PER MAN-HOUR INCLUDES:

    OVERHEAD, TRAINING, LIFE SUPPORT, DIRECT LABOR
  - SPACE MANEUVERING PLATFORM COST
- LABOR, MATERIALS, PROCESS AND EQUIPMENT SOURCES:
  - BOEING
  - LOCKHEED
  - HUGHES
  - TRW
  - BALL BROTHERS
  - SPECTROLAB
  - OCLI
  - ASTRO RESEARCH
  - HEWLETT-PACKARD
  - 3M
  - REYNOLDS
  - UAL
  - OTHER

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EQUATION	LABOR	MATERIALS & COMPONENT	EQUIPMENT	TRANSPORT	SPECIAL EQUIPMENT
F Ø (1)	–	9.319 • AØ(1) Λ .5509	–	–	–
F Ø (2)	–	627.7 • AØ(1) Λ .7078 • PØ(2,1) Λ -.1616	–	–	–
F Ø (3)	–	900	–	–	–
F Ø (4)	.0000008165 • N8	(FØ(1) + FØ(2) + .11) • N8 • 1.25 E-6	.0000007666 • N8	–	–
F Ø (5)	.0001157 • A8	.0002034 • N9(2)	.0000011795 • N8	–	–
F Ø (6)	.003433 • N9(1)	.00283 • N9(1)	.000007374 • N8	–	–
F Ø (7)	F Ø(3) • A3(1) • .1725 E-6	FØ(3) • A3(1) • .2875 E-6	FØ(3) • A3(1) • .69 E-6	–	–
F Ø (8)	.05987 • N9(3)	.01129 • N9(3)	.000004128 • N8	–	–
F Ø (9)	.9786 • N9(5)	.08553 • N9(5)	.000002949 • N8	–	–
F Ø(10)	–	.001385 • W8(2)	–	–	–
F Ø(11)	–	.0003174 • W8(3)	–	–	–
F Ø(12)	.00001333 • W8(1) + .000008433(W8(2)+W8(3)+ W8(4))	–	.0000002949 • N8	.000002828 • W8	.600
F Ø(13)	–	.00275 • W8	4.228	–	–
F Ø(14)	.00002744 • W8	–	.193	–	–

PRODUCTION COST ACCOUNTING PROCEDURE

Exhibit 5-8

PRODUCTION COST ACCOUNTING

- **LABOR**
  - DIRECT LABOR (D/L) $20/MH
  - FRINGES @20% D/L
  - OVERHEAD @125% D/L
  - ODC @10% D/L

  LABOR SUBTOTAL

- **TOTAL MANUFACTURING**
  - S/T LABOR
  - S/T NON-LABOR
    MANUFACTURING S/T
  - PROJECT MGT (PM) @5.8%
    OF MANU. S/T
  - SYS. ENG. (SE) @4.8%
    OF MANU. S/T
  - G&A @15% OF
    MANU. + PM + SE

    SUBTOTAL
  - FEE @10%

- **TOTAL PRODUCTION**
  - TOTAL MANUFACTURING
  - TOTAL SPACE TRANSPORT

  TOTAL COST

- **NON-LABOR**
  - MTLS. & COMPS (M&C)
  - M&C BURDEN % M&C
  - EQUIPMENT (EQ)
  - EQ MAINT. @7% EQ
  - SPCL EQ
  - SURFACE TRANSPORT

    NON-LABOR SUBTOTAL

- **SPACE TRANSPORT (& DEPLOYMENT)**
  - SHUTTLE TO LEO/IUS TO GEO
  - SPACE DEPLOYMENT & C/O
    ($250/MH)

LEGEND

MH	=	MANHOUR
D/L	=	DIRECT LABOR
OH	=	OVERHEAD
ODC	=	OTHER DIRECT CHARGES
EQ	=	EQUIPMENT
SPCL	=	SPECIAL
S/T	=	SUBTOTAL
C/O	=	CHECKOUT
PM	=	PROJECT MANAGEMENT
SE	=	SYSTEMS ENGINEERING

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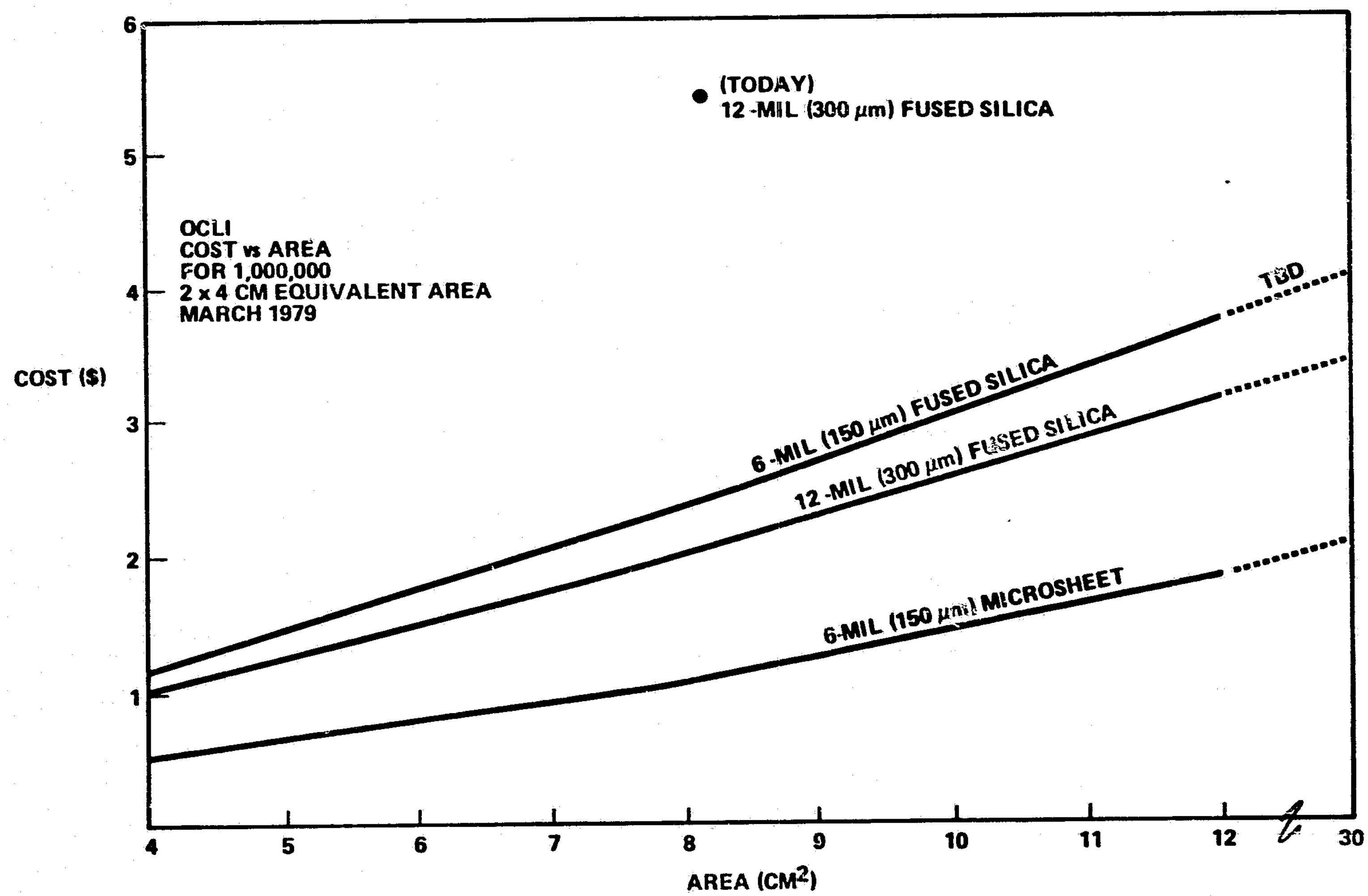
COVER UNIT COSTS VERSUS AREA (1982 PROJECTION)

Exhibit 5-9



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5.4.1 Prelaunch Manufacturing Cost

It is assumed that a prime contractor will manufacturer the solar array subsystem using raw stock and off-the-shelf hardware that is presently obtainable. The total manufacturers cost consists of labor cost, non-labor cost, Project Management and Systems Engineering. The labor and non-labor costs for each WBS item were estimated. These estimates are dependent on the configuration of the SAS.

5.4.1.1 Manufacturing Labor Cost

The total manufacturing labor cost consists of the labor cost associated with each manufacturing process.

This cost was estimated based on the number of components required. The number of components determined the number of labor hours. Refer to Exhibit 5-8 for the factors used to determine the labor hours required and the resulting direct labor cost for each manufacturing process.

The labor rate used was $20/hr. The indirect rates, fringes, overhead and other direct charges, were applied to the direct labor case to obtain the total manufacturing labor cost.

5.4.1.2 Non-Labor Manufacturing Cost

The non-labor manufacturing cost consists of materials, equipment, special equipment and surface transportation. These costs are also dependent on the array configuration.

5.4.1.2.1 Materials Cost

The cost of materials required for each manufacturing process was estimated based on the unit cost and amount required for the process. The unit cost is based on vendor quotes and the amounts required are dependent on the configuration of the SAS. A manufacturing burden to cover the expense of procuring and warehousing materials is applied to the total materials cost.

5.4.1.2.2 Process Equipment Cost

The equipment costs for each manufacturing process for the baseline were estimated based on the production rates required to manufacture the number of components needed for the baseline SAS.

5.4.1.2.3 Special Equipment Cost

The special equipment consists of containers for packaging the SAS blankets and structures for shipment to the launch site and into the appropriate orbit (LEO or GEO).

5.4.1.2.4 Surface Transportation Cost

Surface transportation costs consist of the cost of transporting the SAS blankets and structures to the launch site from the manufacturing facility. It was assumed the manufacturing facility would be located on the West Coast and the launch site would be Kennedy Space Center. The cost is dependent on the combined weight of the structure, blankets and the containers in which they are packaged.

5.4.2 NASA Cost

For the LEO missions, the NASA incurred cost portion of the total production phase cost includes: (1) the cost of transporting the SAS blankets, structure, and astronauts (space assembly and checkout crew) to LEO aboard the Space Shuttle and (2) the cost of the assembly and checkout in space. For the GEO missions, the NASA cost includes the cost of transporting the SAS integrated with the SSPS into GEO using Shuttle/IUS space transportation.

5.4.3 Project Management

The cost of Project Management is estimated to be 5.8% of the sum of the manufacturing labor and non-labor costs. Project Management includes planning, organizing, directing, coordinating and controlling the project to ensure that overall project objectives are accomplished.

5.4.4 Systems Engineering

The cost of the System Engineering is estimated to be 4.8% of the sum of the manufacturing labor and non-labor costs. This function includes the application of scientific engineering efforts to: (1) transform an operational need into a description of system performance parameters and a system configuration; (2) integrate related technical parameters and assure compatibility of all physical, functional and project interfaces in a manner which optimizes total system definition and design; and (3) integrate the efforts of all engineering disciplines and specialties into the total engineering effort.

5.5 Total Operations and Maintenance Phase Cost

The Operations and Maintenance Phase of the life cycle covers the ten year life span of the SAS. There are two categories of cost in this phase: (1) contractor cost for performing the sustaining engineering function and (2) for LEO missions, the cost incurred by NASA to train the operations and maintenance crew, transport the crew to LEO and perform maintenance on the SAS over a ten-year hardware life period.

5.5.1 Total Contractor's Cost

It is assumed that contractor housed at the launch site will provide sustaining engineering for the SAS over a ten-year period. It is assumed that one engineer working 2,040 hours a year at $20 an hour for ten years would constitute the labor cost. The total contractor cost for sustaining engineering is obtained by applying the fringes, overhead and other direct cost rates to the direct labor base. A general and administrative rate is also included in the total contractor's cost.

5.5.2 NASA Incurred Cost (LEO Missions)

For the LEO missions, the cost incurred by NASA in the O&M phase is the sum of the cost of training the crew, transporting them to the SSPS in LEO and performing the maintenance over a ten-year period.

5.5.2.1 Training Cost

For the LEO missions, it is estimated that it will be necessary to train one astronaut crewman per year for ten years. The cost for this training is estimated to be $250,000 per year per crewman.

5.5.2.2 Maintenance Labor Cost

For the LEO missions, the crew that performs the maintenance on the array is divided into two groups. One crew remains on the SSPS to perform scheduled maintenance. The crew works for three month periods on the space platform and

and is sent back to earth to be replaced by another crew. The unscheduled maintenance is performed by an earth based crew that makes a number of unscheduled trips to the SSPS per year.

5.5.2.3 Space Transport Cost

For the LEO missions, four trips a year for ten years are required for the crew that is housed on the SSPS. The cost is $250K per trip. The unscheduled maintenance crew requires 1.75 trips per year @ $100K per unscheduled maintenance.

5.6 Summary

The GaAs SAS LCCM provides a means of estimating the LCC of a SAS as shown in Exhibit 5-10. The baseline SAS designs are summarized in Exhibit 4-8. The corresponding LCC for the baseline designs are summarized in Exhibit 5-11. In Section 7.0, variations in LCC are discussed which result from variations in selected SAS physical, performance and technology parameters.

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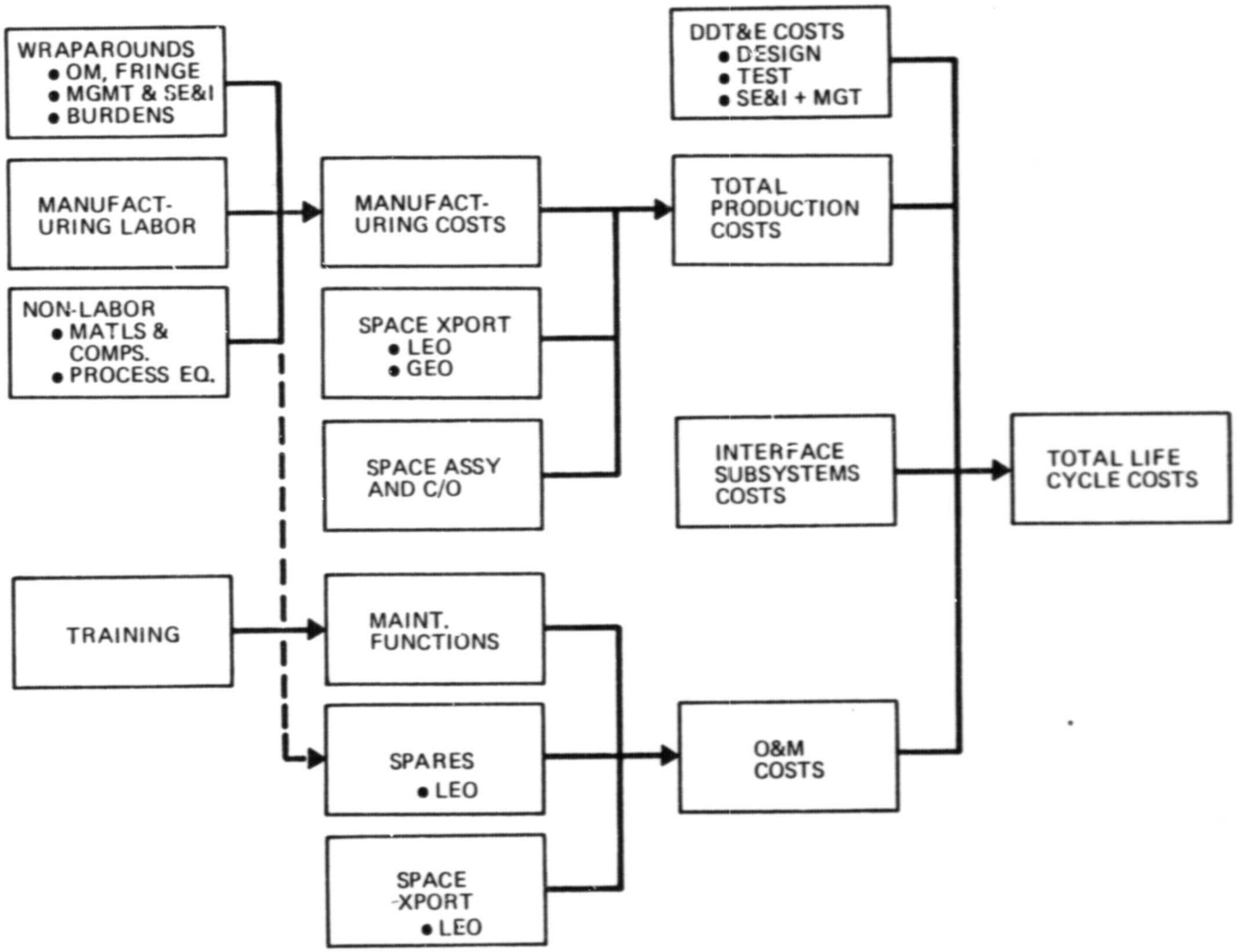
TOP LEVEL ELEMENTS OF LCC

Exhibit 5-10



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LIFE CYCLE COST (1980$M)	LEO 250 KW PLANAR	LEO 250 KW CONC.	GEO 50 KW PLANAR	GEO 50 KW CONC.
DDT&E	207.234	169.310	46.636	43.808
PRODUCTION	592.057	483.744	133.245	125.165
(Solar Cell - $/Cell)	(29.30)	(29.30)	(29.30)	(29.30)
(Cell Cover - $/Cover)	(5.39)	(5.39)	(5.39)	(5.39)
(Concentrator - $/M^2)	(900.00)	(900.00)	(900.00)	(900.00)
Cell/Cover Assembly	231.114	59.830	29.279	7.574
Module Substrate	7.869	2.065	.985	.256
Module Assembly	43.956	16.350	5.725	2.175
Concentrator Assembly	0.000	14.209	0.000	1.584
Panel Assembly	139.003	131.175	20.613	18.626
Blanket Assembly	134.552	232.259	67.165	86.673
Main Bus Assembly	.486	.384	.028	.021
Structure (w/Slip Ring)	.586	.464	.085	.065
Accept. & Surface Xport	2.269	1.112	.814	.667
Space Transport	31.794	25.491	8.317	7.300
Space Deploy. & Checkout	.468	.405	.234	.224
OPERATIONS & MAINTENANCE	165.624	183.327	.900	.900
Contractor Costs	.900	.900	.900	.900
Training	2.500	2.500	0.000	0.000
Labor	52.112	104.224	0.000	0.000
Space Transport	110.112	75.703	0.000	0.000
TOTAL LIFE CYCLE COST	964.955	836.381	180.781	169.873

6.0 DEVELOPMENT OF COST/TECHNOLOGY RELATIONSHIPS

The development of cost/technology relationships was accomplished by the development of a combined GaAs Solar Array Performance and Cost Model (SAPCM). This effort included (1) establish technology parameters; (2) determine relationships of physical parameters to technology parameters; (3) determine sensitivity of performance parameters to technology parameters; (4) determine interdependencies of physical, performance and technology parameters; and (5) determine relationship of technology parameters to total life cycle cost. This section discusses the performance model and its inputs to the LCCM. The LCCM itself is discussed in Section 5.0.

6.1 Modelling Approach

The modelling approach, generally, was to

- define the solar cell, cover, substrate and cell interconnect circuitry (module cross section)
- determine the value of the solar array factors which affect performance and apply to the BOL cell/cover assembly to determine the EOL per cell array performance.
- determine number of cell/cover assemblies required for baseline orbit and load power/energy requirements.
- determine total array area, dimensions and structural requirements (Array Configuration)
- determine array weight breakdown and totals
- determine life cycle cost.

6.2 Description of the Model

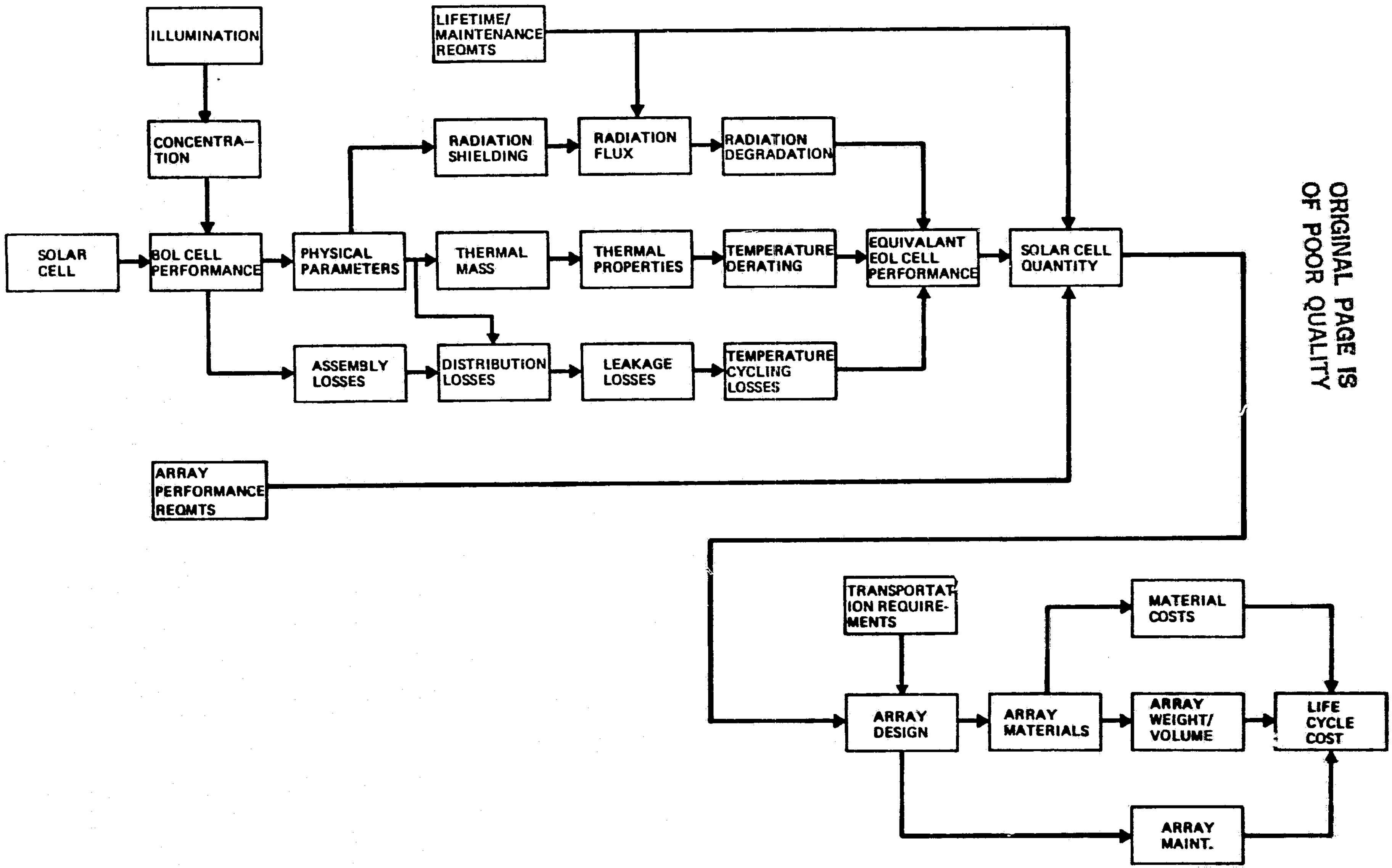
A block diagram of the SAPCM is shown in Exhibit 6-1. A discussion of the various blocks or functions is contained in the following paragraphs.

6.2.1 Per-Cell EOL Module Performance

The heart of the SAPCM consists of various solar array performance parameters which are used to determine the equivalent EOL per-cell module

SOLAR ARRAY PERFORMANCE AND COST MODEL

Exhibit 6-1



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performance. The individual parameters and their basic interrelationship are shown in Exhibits 6-2 and 6-3.

Generally, the basic methodology for defining the per-cell EOL module performance was to

- quantify the individual illumination factors
- determine the equivalent illumination as the result of these illumination factors
- determine the BOL per-cell performance given the equivalent illumination
- quantify the individual performance loss factors
- determine the EOL per-cell performance

As shown in Exhibit 6-3, feedback loops which affect the array average temperature and the main bus configuration lead to iterations in order to arrive at the final result. The above relationship is used to determine the average minimum power of the array at EOL for a unit area of 1 m^2, which is further scaled down on a per-cell module cross-section basis. The equivalent EOL per-cell power is then used to size the array and thus determine the array configuration. The per cell voltage is similarly calculated and used for sizing.

The individual factors are discussed in subsequent paragraphs; however, for comparison with Exhibit 6-1, the array factors are further categorized as follows:

- Radiation Degradation
- Temperature Derating
- Array Loss Factors
  - Assembly
  - Distribution (Diode, V_{IC})
  - Leakage
  - Temperature Cycling

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METHODOLOGY FOR DETERMINING THE PER-CELL MODULE PERFORMANCE

Exhibit 6-2

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$$EOL\,P_{mp}\ (W/m^2) = \left[\left(\eta_{BOL} \times \prod_{i=1}^{11} F_{P_i} \right) \times \left(S' \times \prod_{j=1}^{4} F_{P_j} \right) \times PF \right] \times A_s$$

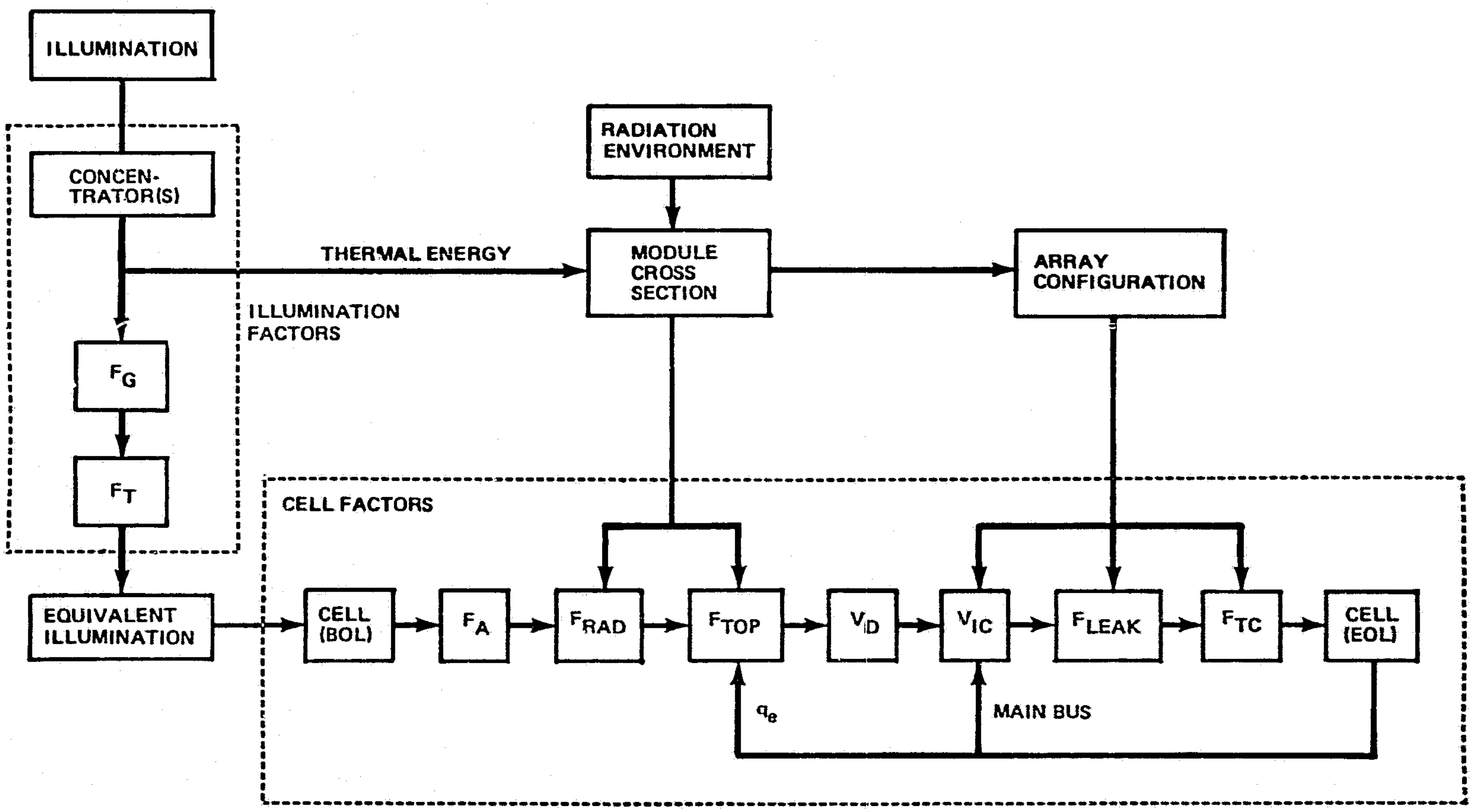
WHERE

- P_{mp} = MAX POWER PER CELL
- F_{p_i} = CELL PERFORMANCE FACTORS
- F_{p_j} = COVER PERFORMANCE FACTORS
- S' = EFFECTIVE ILLUMINATION
- η_{BOL} = CELL BOL EFFICIENCY
- PF = PACKING FACTOR PER CELL
- A_s = ARRAY AREA PER CELL

- CELL FACTORS
  - ASSEMBLY, F_A
  - CELL DEGRADATION, F_{RAD}
  - TEMPERATURE DERATING, F_{Top}
  - BLOCKING DIODE, V_D
  - SOLAR CELL IC, V_{sc}
  - MODULE/MODULE IC, V_{mm}
  - PANEL/PANEL IC, V_{pp}
  - MAIN BUS CONDUCTORS, V_{mb}
  - SLIP RING CONDUCTORS, V_{sr}
  - HIGH VOLTAGE LEAKAGE, F_{leak}
  - TEMPERATURE CYCLING, F_{tc}
- ILLUMINATION FACTORS
  - GLASSING, F_G
  - COVER DEGRADATION, F_T
  - CONCENTRATOR RATIO, F_C
  - CONCENTRATOR DEGRADATION, F_D

DEFINITION OF PER-CELL MODULE PERFORMANCE

Exhibit 6-3



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6.2.1.1 Module Assembly Cross Section

The module assembly is the solar array building block. For each of the four GaAs baselines, the module assembly cross section is the same. The physical characteristics of the module assembly cross section are summarized in Exhibit 6-4, for each material and assembly. The characteristics include thickness (T), density (D), mass (M), area (A), and weight (W).

6.2.1.2 Array Illumination

An average illumination summary for the GaAs SAS baselines is shown below. The orbit maximums and minimums reflect minimum and maximum distances from the sun respectively. The maximum albedo contribution in LEO and GEO is 27% and 0.5%, respectively, of the solar illumination. The values for total orbit averages were obtained by averaging the calculated values of the total effective solar illumination for fixed periods of illumination in the respective orbit. The total averages include the effects of cover glassing, cover degradation, concentration ratio and concentrator degradation as applicable.

	LEO 250 kW Planar	LEO 250 kW Conc.	GEO 50 kW Planar	GEO 50 kW Conc.
Max. Avg. Illumination (W/M^2)	1,249	5,995	1,198	5,753
Min. Avg. Illumination (W/M^2)	1,169	5,609	1,122	5,383

6.2.1.2.1 Cover Glassing

The cover glassing factor is a measure of the optical impedance matching between the cell cover and the solar cell. Nor only does the cover glass material and cover adhesive determine this factor, but also the antireflective coating applied to the solar cell itself. For each of the GaAs SAS baselines, the cover glassing factor is 1.017.

6.2.1.2.2. Cover Degradation

The cover degradation factor is a measure of how the transmissibility of the cover (and cover adhesive) degrades over the lifetime of the array. This

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GaAs PHYSICAL PARAMETERS

Exhibit 6-4

CELL AREA = L x W = Ac = 4.000cm x 2.000cm = 8.000cm^2

SUBSTRATE AREA (Per Cell) = $(L + d_L) \times (W + d_W)$ = As = 4.000cm + 0.225cm x 2.000cm + 0.225cm = 9.401cm^2

PACKING FACTOR = Ac ÷ As = PF = 8.000cm^2 ÷ 9.401cm^2 = 0.851

ASSEMBLY	COMPONENT	T (MIL)	D (kg/m^3)	M (kg/m^2)	A (cm^2)	W (g)
CELL/COVER ASSEMBLY	COVER	6	2200	0.3353	8.000	0.2682
	ADHESIVE	2	1080	0.0549	8.000	0.0439
	CELL	8	5315	1.0800	8.000	0.8640
	TOTALS	16	3618	1.4702	8.000	1.1761
SUBSTRATE ASSEMBLY	KAPTON	0.5	1400	0.0178	9.401	0.0167
	ADHESIVE	0.5	1420	0.0180	9.401	0.0170
	COPPER	1	8890÷3	0.0753	9.401	0.0708
	ADHESIVE	0.5	1420	0.0180	9.401	0.0170
	KAPTON	0.5	1400	0.0178	9.401	0.0167
	TOTALS	3	1928	0.1469	9.401	0.1382
MODULE ASSEMBLY	CELL/COVER ASSEMBLY	16	3078	1.2510(1)	9.401(1)	1.1761
	SUBSTRATE ASSEMBLY	3	1928	0.1469	9.401	0.1382
	TOTALS	19	2897(1)	1.3979(1)	9.401	1.3143

(1) Includes Packing Factor (PF)

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effect is caused by a cumulation of the following effects:

- ultraviolet radiation dose
- particulate radiation dose
- micrometeorites

For each of the GaAs SAS baselines, the cover degradation factor is .870.

6.2.1.2.3 Concentration Ratio

The concentration ratio is a multiplication factor for the solar illumination based upon the concentrator geometry and material optical effects such as reflectivity, absorptivity and transmissability. For the planar array baselines, the concentration ratio is 1. For the concentrator array baselines, the concentrator ratio is 5.

6.2.1.2.4 Concentrator Degradation

The concentrator degradation factor is a measure of how the reflectivity of the concentrator degrades over the lifetime of the array. The effect is caused by a cumulation of the same effects which cause cover degradation. For each of the concentrator baselines, this factor is .960.

6.2.1.3 BOL Cell Performance

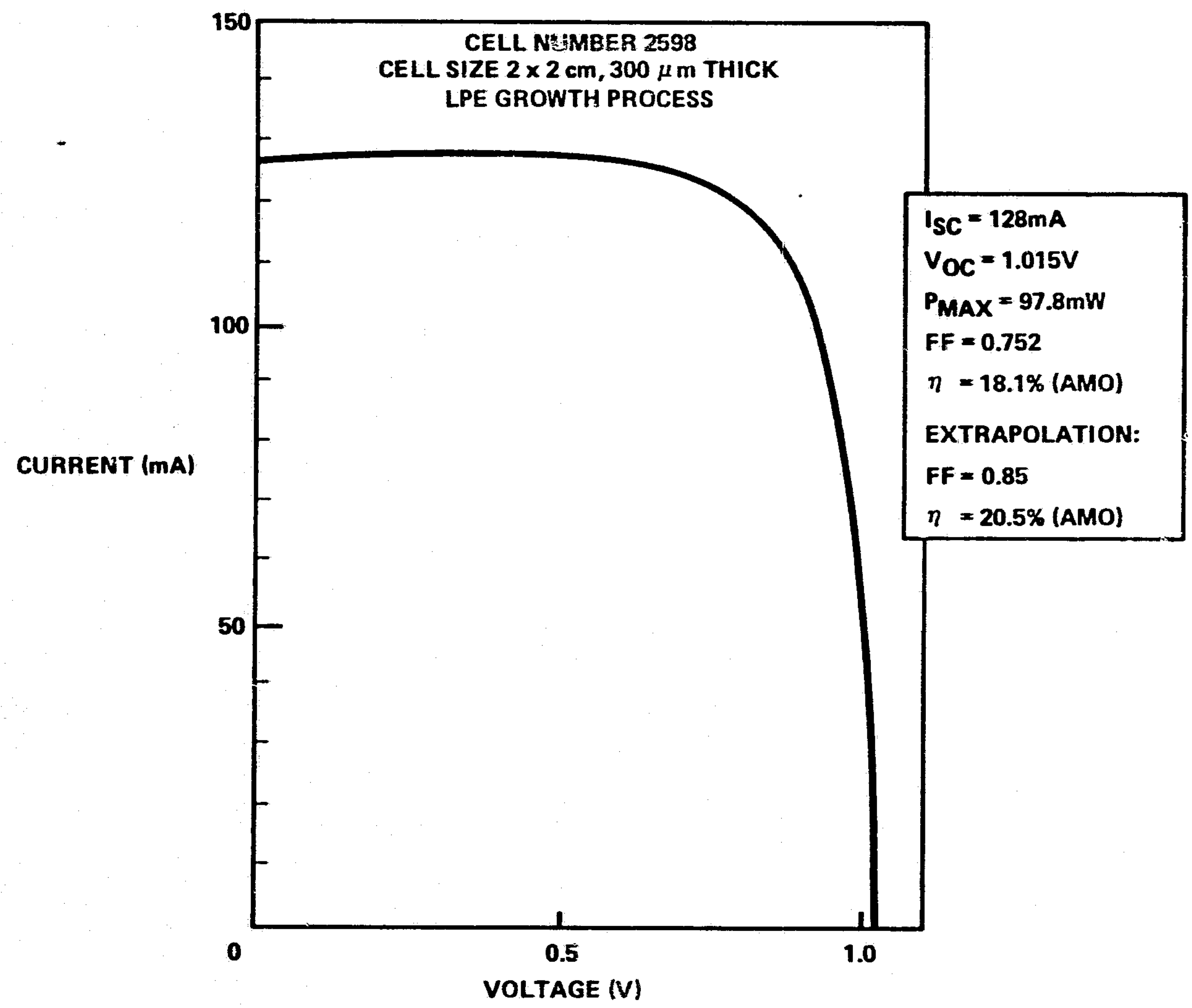
The BOL cell performance for each of the GaAs SAS baselines is as shown in Exhibit 6-5. The unglassed efficiency is 18.1% (AMO 25°C). The cell voltage at the maximum power increases linearly from .810V for an effective concentration (CR) ratio of 1 to .851V for an effective CR of 5 (as seen by the solar cell). This results in a voltage of .809V for the baseline planar arrays (CR = .885) and .843 for the baseline concentrator arrays (CR = 4.247).

6.2.1.4 Physical Parameters

This function consists of calculating the parameters indicated in Exhibit 6-4. These parameters are also used as inputs to radiation shielding, thermal mass, main bus calculations as described in subsequent paragraphs. The SAS baseline parameters are summarized in Exhibit 6-4.

GaAs SOLAR CELL MEASURED I-V CHARACTERISTICS (HUGHES RESEARCH LABORATORY)

Exhibit 6-5



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6.2.1.5 Radiation Environment

The radiation degradation factor is a measure of the degradation in solar cell output due to high-energy charged particles, e.g., electrons and protons in the orbital environment. The degradation involved is a cumulative effect measured over the lifetime of the array in orbit. The amount of degradation is determine by the number of particles which have sufficient energy to penetrate the solar cell and cause permanent damage. Hence, the primary function of the solar cell cover is to reduce the quantity of particles which penetrate the solar cell. The substrate materials also assist in reducing radiation degradation. The methodology for determining this factor is discussed in the next three paragraphs.

6.2.1.5.1 Radiation Shielding

First, the effective radiation shielding provided by the various solar array module materials is determined. This analysis is accomplished by converting all materials to equivalent fused silica density shielding.

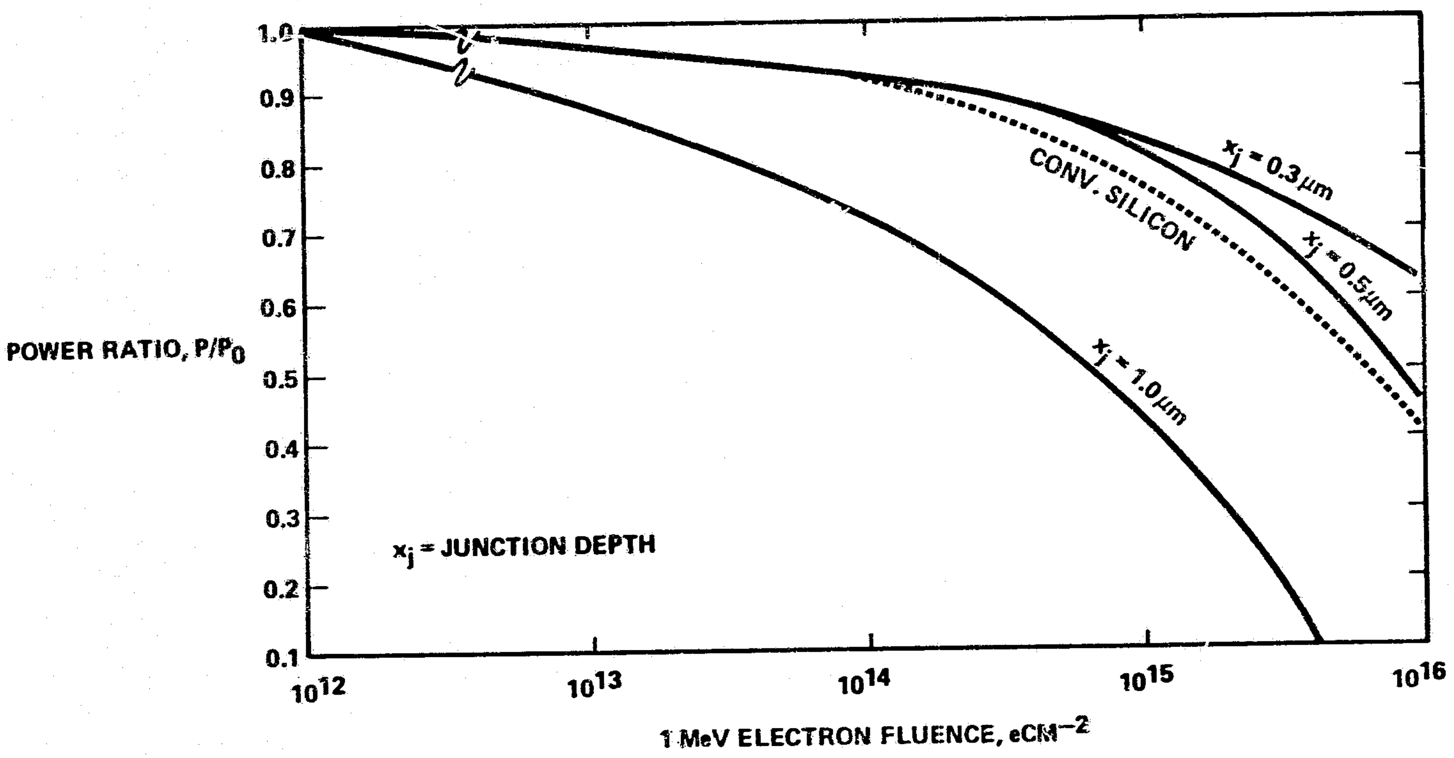
6.2.1.5.2 Radiation Flux

Next, the protection provided by the radiation shielding is determined. This is accomplished by the use of historical data for different thicknesses of fused silica in a radiation environment similar to that anticipated for the baseline solar arrays. The output of this analysis is the cumulative fluence of charged particles which will have sufficient energy to cause degradation of the solar cell over the array lifetime.

6.2.1.5.3 Radiation Degradation

Finally, the predicted solar cell degradation, which caused by particles with sufficient energy to penetrate the radiation shielding and cause solar cell damage, is determined. To accomplish this, the data in Exhibit 6-6 is used. Based upon the equivalent fluence, a predicted degradation is determined. For the LEO baselines, the power degradation factor is .891 for an array life of 10 years, while the voltage factor is .968. For the GEO baselines and the same array lifetime, the power degradation factor is .779 and the voltage degradation factor is .963. This does not include annealing effects.

GaAs SOLAR CELL JUNCTION DEPTH AND RADIATION DAMAGE



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6.2.1.6 Array Temperature

The temperature derating factor is a measure of the effect of the average operating temperature upon cell performance. The methodology for determining this factor is discussed in subsequent paragraphs. (See Appendix B for a more thorough discussion of the methodology for determining the array average operating temperature.)

6.2.1.6.1 Thermal Mass

The array thermal mass is calculated as a function of temperature by summing the thermal masses for each of the array materials in the array module cross section. The thermal mass for a given material is the product of the material mass and specific beat as a function of temperature. Thermal mass is in turn used as a parameter in calculating the array average operating temperature.

6.2.1.6.2 Array Thermal Properties

The array thermal properties to be calculated include the following:

- Effective thermal absorptivity for both the front and back of the array module
- Effective thermal emissitivity for both the front and back of the array module
- Total energy absorbed by the array module due to solar illumination, albedo, earth radiation and the SSPS
- Total energy emitted from the array module
- Total electrical energy produced by the array module.

The above thermal properties are calculated for subsequent use in an energy balance equation to determine the average array operating temperature for a given mission and array configuration (See Appendix B).

6.2.1.6.3 Temperature Derating

The most complex function of the SAPCM is determining the cell temperature derating factor. Using the array thermal mass profile and the thermal properties discussed in the preceding paragraphs, this factor is calculated using the following procedure:

- Determine array temperature vs time profile during period of minimum solar illumination (including effects of albedo, earth radiation, and heat from the space platform).
- Determine average array temperature during same period.
- Determine array illumination vs time profile during period of minimum solar illumination (including albedo).
- Determine average illumination during same period.
- Determine effect of cell cover glassing and degradation factors upon effective illumination "seen" by solar cell.
- Determine power derating factor using the data summarized in Exhibit 6-7, based on the average operating temperature and effective illumination determined above.
- Repeat same procedure for voltage derating factor for period of maximum solar illumination, using average operating temperature only.

An average temperature summary for the GaAs SAS baselines in shown below.

	LEO 250 kW Planar	LEO 250 kW Conc.	GEO 50 kW Planar	GEO 50 kW Conc.
Max. Avg. Temperature (°K)	320.7	477.7	316.3	469.9
Min. Avg. Temperature (°K)	315.5	469.7	311.1	462.0

6.2.1.7 Assembly Factor

The assembly factor is a measure of the reduction in solar cell output due to design and assembly processes. This factor is assumed to be .965 for power and 1.000 for voltage for all GaAs baselines.

6.2.1.8 Distribution Loss Factors

Distribution losses include voltage drops and power losses due to blocking diodes, various electrical interconnects on the array, the main bus

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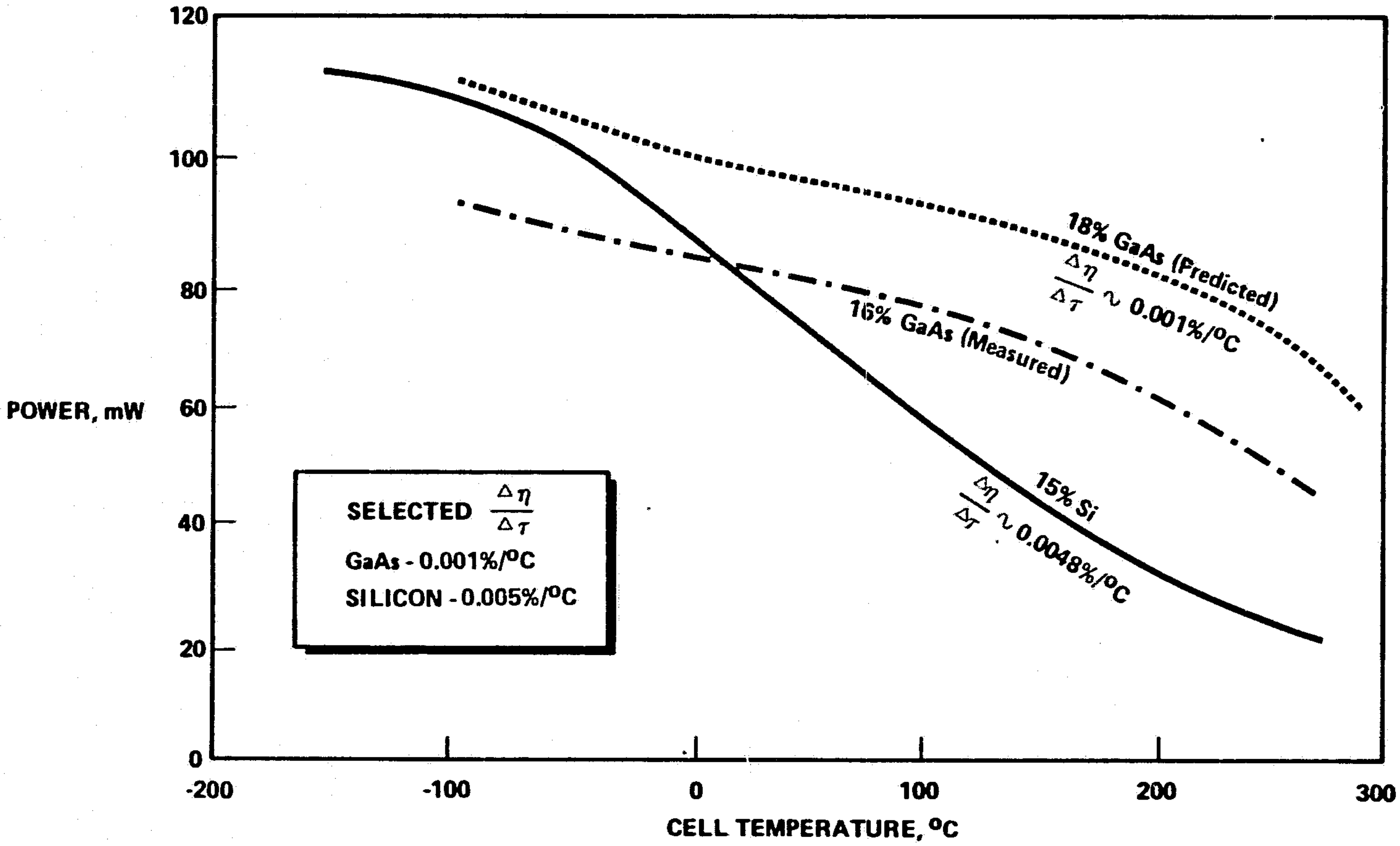
TEMPERATURE DEPENDENCE OF SOLAR CELL POWER (ONE-SUN, 2 x 2 -cm CELL)

Exhibit 6-7



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conductor, and the slip ring assembly. These factors are discussed in the following paragraphs.

6.2.1.8.1 Blocking Diodes

This factor is a measure of the voltage drop and power loss due to blocking diodes (3 in parallel for each array panel). For all GaAs SAS baselines, this factor is assumed to be .993 for both power and voltage.

6.2.1.8.2 Solar Cell Interconnects

This factor is a measure of the voltage drop and power loss due to solar cell interconnects. For all GaAs SAS baselines, this factor is assumed to be .999 for both power and voltage.

6.2.1.8.3 Module-To-Module Interconnects

This factor is a measure of the voltage drop and power loss due to module-to-module electrical interconnects. For all GaAs SAS baselines, this factor is assumed to be .999 for both power and voltage.

6.2.1.8.4 Panel-To-Panel Interconnects

This factor is a measure of the voltage drop and power loss due to panel-to-panel electrical interconnects. For all GaAs SAS baselines, this factor is assumed to be .999 for both power and voltage.

6.2.1.8.5 Main Bus Conductor

This factor is a measure of the voltage drop and power loss due to the main bus conductor. The methodology for determining this factor is as follows:

- Determine sizes of conductors (optimized weight and volume).
- Determine conductor resistance @ 55°C (L/A = constant).
- Determine voltage drop and power loss.
- Determine percentage of total output.

For an electrical configuration of 12 channels/blanket, there will be a total of 12 pairs of conductors/blanket. For 5 channels/blanket, there will be 10 pairs of conductors. The conductor material is 37/36 aluminum/copper alloy.

The Length/Area ratios for the bus conductors are the same throughout each array and have been optimized for each blanket using the following parametric relationship (LSMC-D384250):

$$\frac{L}{A} = \sqrt{\frac{P_D \times C_D \times \Sigma L^2}{N \times I^2 \times \rho}}$$

where P_D = power density of module cross section

C_D = conductor density

ΣL^2 = sum of conductor lengths

N = number of conductors

I = current

ρ = conductor resitivity

From the resultant L/A ratio, each conductor was sized assumed a constant cable thickness of .060 in = .15 cm. For insulation, 1 mil kapton + 1 mil high temperature polyester adhesive is assumed. The total weight of the insulation and adhesive is assumed to be 2.5% of the total conductor weight. For the GaAs SAS baselines, the main bus factors are summarized below.

	LEO 250 kW Planar	LEO 250 kW Conc.	GEO 50 kW Planar	GEO 50 kW Conc.
Main bus power factor	.975	.927	.988	.967
Main bus voltage factor	.925	.927	.988	.967

6.2.1.8.6 Slip Ring Assembly

This factor is a measure of the voltage drop and power loss due to the slip ring assembly. For all GaAs SAS baselines, this factor is assumed to be .988 for both power and voltage.

6.2.1.9 High Voltage Leakage

This factor is a measure of the voltage drop and power loss due to High Voltage leakage currents in a plasma radiation environment. For all GaAs baselines, this factor is assumed to be 1.000 for both power and voltage.

6.2.1.10 Temperature Cycling

This factor is a measure of the voltage drop and power loss due to temperature cycling failures. For all GaAs SAS baselines, this factor is assumed to be .800 for power and 1.000 for voltage.

6.2.1.11 Equivalent EOL Per-Cell Performance

The equivalent EOL per-cell performance is determined by applying the solar array performance factors to the BOL cell/cover assembly. For the GaAs SAS baselines, the cell performance factors are summarized in Exhibit 4-8. This results in an equivalent EOL per-cell performance as shown below.

	LEO 250 kW Planar	LEO 250 kW Conc.	GEO 50 kW Planar	GEO 50 kW Conc.
EOL Cell Power (MW)	127	492	109	433
EOL Cell Voltage (V)	.715	.514	.726	.542

6.2.2 Maintenance Requirements

The maintenance requirements include the array life and also the paralleling of various electrical components to assure design reliability. For the SAS baseline, this results in the following:

- 10-year array life (greater cell and cover degradation factors and temperature cycling losses)
- minimum of 3 cells in parallel
- two sets of interconnects/solar cell
- minimum of 3 blocking diodes in parallel/panel.

6.2.3 Array Performance Requirements

The array performance requirements determine the number of solar cells required, which in turn determine the size and panel/channel configuration of the array. For the GaAs SAS baselines, these requirements are:

	LEO 250 kW Planar	LEO 250 kW Conc.	GEO 50 kW Planar	GEO 50 kW Conc.
Total Power Required (kW)	650.1	650.1	70.6	70.6
Total Voltage Required (V)	180.0	180.0	180.0	180.0

6.2.4 Solar Cell Quantity

The quantity of solar cells is determined by the interaction of the solar array performance requirements and the EOL equivalent per-cell performance. For the GaAs SAS baselines, the cells required to meet the array total power requirements are shown below.

	LEO 250 kW Planar	LEO 250 kW Conc.	GEO 50 kW Planar	GEO 50 kW Conc.
Total Number of Cells	5,126,400	1,327,104	649,440	168,000

6.2.5 Transportation Requirements

The transportation requirements influence the array design in two ways:

- Fold-Up Array to fit in Shuttle (fold between panels)
- Size of Panel for LEO Arrays limited by size of shuttle bay (3m x 18m Max).

6.2.6 Array Design

The basic array design is a fold-up blanket/array which fits in the shuttle bay. The resultant building block concept is depicted in Exhibit 4-7.

6.2.7 Array Materials

Variations in the quantities of the various array materials very significantly affect the life cycle cost for a solar array, particularly one as large as 650 kW EOL. The array inputs to the life cycle cost model are summarized below.

- Total Number of Solar Cells
- Total Number of Modules/Concentrators
- Total Number of Panels
- Total Number of Blankets
- Blanket Weight
- Main bus Conductor Weight
- Array Structures Weight

6.2.8 Material Costs

Variations in the per unit material costs also significantly effect the array LCC. The assumed costs of materials for the GaAsSAS baselines are summarized below.

• Solar Cell ($/Cell)	29.30
• Cell Cover ($/Cover)	5.39
• Concentrator ($/$M^2$)	900.00

6.2.9 Array Weight

The array weight determines the space transportation and LEO space assembly/checkout costs. The array weights for the GaAs SAS baselines are summarized below.

	LEO 250 kW Planar	LEO 250 kW Conc.	GEO 50 kW Planar	GEO 50 kW Conc.
Blanket Weight (Kg) (one of four)	1,957	1,498	300	224
Structure Weight (Kg) (Incl. Main Bus)	2,196	1,740	287	221
Total Array Weight	10,024	7,732	1,487	1,117

6.2.10 Array Maintenance

The LEO array maintenance scenario affects the cost of the operations and maintenance phase of LCC, as well as the production phase costs. The primary cost contributions are number of spares required and number of maintenance trips and activities required. For the LEO GaAs baselines, approximately 10% of the total area is required, plus an average of 1.75 maintenance trips/year during the array life of 10 years.

6.2.11 Life Cycle Cost

The life cycle cost consists of three phases:

- DDT&E
- Production
- O&M

The total manufacturing cost during the production phase is basically a quantity related cost, while the NASA cost during the production phase is a weight driven cost. The Life Cycle Costs for the GaAs SAS baselines are summarized in Exhibit 5-11.

6.3 Summary

The SAPCM is a very versatile tool which can be used to derive various technology vs LCC relationships. Using assumed relationships, a basic model has been developed. In Section 7.0, the results of varying various parameters are discussed. It should also be noted, that the data base indicated for radiation flux and radiation degradation, and for temperature derating can be changed, to analyze the effect of newly acquired data in these areas. In addition, the model can be further expanded to address other pertinent factors such as reliability, and other manufacturing and/or maintenance scenarios.

7.0 TECHNOLOGY VARIATIONS VS LIFE CYCLE COST

Assessment of technology variations vs life cycle cost was accomplished by using the SAPCM described in Section 6.0 to quantify the results of the analyses involved. Conclusions to be drawn from the results are valid in the vicinity of the various baselines defined under the assumptions, requirements, and scenarios of this study report. In particular, parameter interdependencies and trends should be emphasized rather than actual numerical results.

7.1 Methodology

The study results were achieved by addressing each technology area separately and varying key technology related parameters in the models to determine the resultant variations in life cycle cost. The variations in numerous performance parameters were also observed. This was accomplished for both planar and concentrator arrays providing 250 kW average power in LEO and 50 kW average power in GEO. The basic methodology consisted of the following:

- Selection of technology input parameters to be varied.
- Variation of one technology input parameter at a time.
- Determine resultant effect on performance and life cycle cost.
- Determine relative magnitude of effect on LCC.
- Plot and print in final format, the technology input parameters which have the greatest effect on LCC.

7.2 Technology Parameters to be Varied

With coordination, which included comments from LeRC technical personnel, the following list of technical parameters to be varied was established for the four GaAs SAS baselines.

- Cell Area
- Concentration Ratio
- Temperature
- Cell Efficiency
- Concentrator Degradation

- Cell Degradation
- Hardware Life
- Reliability (Spares)
- Cell Cost

7.3 Discussion of Technology Parameters

Exhibits 4-8 and 5-11 in Sections 4.0 and 5.0 respectively, contain the baseline printouts for the various missions and power levels. For each baseline, a set of performance and life cycle cost parameters are listed which describe the respective type of SAS (i.e., LEO or GEO, planar or concentrator). To perform a technology variation, one of the performance parameters is varied and the resultant effect on life cycle cost is determined. In terms of actual output, this means that the parameter is varied through nine distinct values and a set of "baseline printouts" are generated, one "printout" for each value of the varied parameter. The resultant output is a nine-column matrix with SAS parameters corresponding to the list of parameter titles shown in Exhibits 4-8 and 5-11.

This is the basic process for determining the effect on a technology variation on LCC (i.e., compute the nine distinct SAS configurations and LCC's which result from varying a technology parameter over nine distinct input values). As a result of this process, major technology parameters were identified, which are discussed in subsequent paragraphs. The supporting data for these parameters is contained in the exhibits listed below, which are in Appendix C. Each exhibit consists of a standardized-format data printout and a graphical display corresponding to the data printout.

GaAs SAS Parameter	Appendix C Exhibit #'s
1. Cell Area (Ribbon)	1 [a - d]
2. Cell Area (Square)	2 [a - d]
3. Concentration Ratio	3 [a - b]
4. Temperature (Average)	4 [a - d]
5. Cell Efficiency	5 [a - d]
6. Concentrator Degradation	6 [a - b]

GaAs SAS Parameter (Continued)	Appendix C Exhibit #'s (Cont.)
7. Cell Degradation	7 [a - d]
8. Hardware Life	8 [a - d]
9. Reliability (Built-In Spares)	9 [a - d]
10. Spares/Maintenance	10 [a - b]
11. Cell Cost	11 [a - d]

7.3.1 Cell Area (Ribbon) - Exhibits 1[a - d]

This technology variation consisted of varying only one dimention (length) of the solar cell to determine its impact on life cycle cost. The input variation consisted of holding the cell width fixed at 2 cm and varying the cell length from 2 cm to 18 cm, in increments of 2 cm. The initial impact is on the average EOL power per cell, which varies in proportion to the variations in cell area. This in turn results in a fewer number of cells and a slightly higher array packing factor. The resultant cost impact is a slight decrease in LCC as the cell area increases, based on the assumed cost/cell as shown. The trade involved is two-fold. First, the unit cell cost increases with area, while the number of handling and manufacturing functions decrease at the array module level. Given a sharp increase in unit cell cost and a small decrease in manufacturing costs, the LCC could actually increase with cell area. The second trade is cell geometry versus array geometry. The biggest impact here is the number of panels/blanket. Also, for the same area, a longer/narrower panel results in a shorter array boom and main bus conductor, which in turn results in a cost reduction. The bottom line for this variation, is that for a given array power level, an optimum cell area (or configuration) exists based on these two LCC trades.

7.3.2 Cell Area (Square) - Exhibits 2[a - d]

This technology variation is a result of varying both cell dimensions from 2 cm to 18 cm in increments of 2 cm, producing at all times a square cell. As expected, the same basic comments as for the ribbon cell (7.3.1) apply to this variation. Again the comment, that for a given array power level, there is an optimum cell configuration based on LCC. Conversely, for a given cell configuration and unit cell cost, there is probably an optimum application for that cell in terms of mission and LCC considerations.

7.3.3 Concentration Ratio - Exhibits 3[a - b]

The input for this technology variation consisted of varying the geometric concentration ratio (i.e., size of concentrator) from 1 to 5 in increments of .5. The results are obviously applicable only to the concentrator configuration baselines. It should also be noted that for GCR = 1, the resultant array configuration is not the same as the baseline planar array, but rather the lower limit for the concentrator array geometry (See Exhibit 4-7, Solar Array Hierarchies). The initial impact is two-fold. First, the cell illumination increases with concentration as expected. However, the array temperature also increases, which results in lower cumulative EOL loss factors for both power and voltage. Hence, while the power per cell does increase, it does not do so directly proportional with the GCR. The next result is a decrease in the total number of cells required, which in turn cause two conflicting effects. First, the array area increases, since the basic trade in a concentrator array is between total active cell area vs total concentrator area. However, because the resultant concentrator area is both lighter (i.e., less total array weight) and cheaper (i.e., lower manufacturing costs), the total LCC decreases for an increase in GCR.

7.3.4 Temperature - Exhibits 3[a - d]

As previously noted in the concentration ratio variation, an increase in array temperature causes a decrease in per-cell power. By itself, this effect causes an increase in the total number of cells, which in turn result in an increase in total array area and total array weight. The end result is an increase in LCC. (Note that this variation does not include any temperature effects on solar cell self-annealing).

The converse statement (i.e., a decrease in LCC for a decrease in array average operating temperature requires two comments. First, the LCC shown does not include any thermal control costs or change in array configuration to achieve the decrease in temperature. Hence, it may not be cost effective to operate at a lower temperature if this requires large radiators and/or a complex thermal control system. The second comment pertains to array utilization - in that immediately after eclipse, the array is coldest and thus its power output is highest. Thus, it may be possible to take advantage of this effect during a given mission, and even design to take advantage of it by increasing the array thermal mass.

7.3.5 Cell Efficiency - Exhibits 5[a - d]

This technology variation analysis consisted of varying the solar cell efficiency from 11.1% to 19.1% in increments of 1%, while holding all other performance parameters constant except for a very small resultant variation in array operating temperature. Under these conditions, an increase in cell efficiency decreases the total number of cells required, which then causes a decrease in the total array area and weight. The end result is a decrease in LCC for an increase in cell efficiency. The step decreases noted in the LCC curves, particularly for the GEO configurations, is due to step decreases in the total number of panels required as opposed to a further decrease in panel area for the same number of panels. Note that the unit cell cost is artificially held constant, which would very probably not be the case if a choice was being made between two competitive cells. Given an increase in unit cell cost for a increase in cell efficiency, the total LCC probably still would decrease, although not as much - depending upon the relative cost trends involved. This technology area (i.e., increased cell efficiency) appears to be a promising potential cost reduction area, depending upon the development costs (and subsequent unit cell costs) involved.

7.3.6 Concentrator Degradation - Exhibits 6[a - b]

This technology variation has the same effect as a variation in concentration ratio. The difference is in the order of magnitude of the results. Concentrator degradation is a second order effect which amounts to fine tuning the BOL concentrator size; based upon the amount of degradation expected over the life of the array. The bottom line is the less degradation the smaller the increase in LCC.

7.3.7 Cell Degradation - Exhibits 7[a - d]

One potential advantage of the GaAs solar cell is the self-annealing effect, which results in a lower cell degradation for a given array lifetime. The approach used for this variation was not to quantify the self-annealing effect itself, but rather to quantify the effect on LCC for a given amount of degradation. As expected, the less the degradation, the greater the decrease in LCC.

7.3.8 Hardware Life - Exhibits 8[a - d]

This variation in hardware life vs LCC combines the effect of numerous degradations for a given array lifetime. Because of the many different types of degradations which are involved, this variation is more difficult to quantify. However, the trend is obvious. The longer the array life, the greater the LCC because of added components and consequently, additional array area and weight. To assist in the evaluation of a maintenance concept, particularly for LEO - all input variations are in multiples of 30 life years. While not strictly accurate, a good ballpark estimation for the relative costs of overhauling an array a given number of times, can be achieved by multiplying the cost for a given input array life by the number of overhaul cycles required to achieve the desired total life (i.e., multiply the 10-year LCC value by 3 and compare to the 15-year value multiplied by 2).

7.3.9 Reliability (Built-In Spares) - Exhibits 9[a - d]

This variation is a measure of how the LCC would increase due to manufacturing a larger array to compensate for various reliability failures and/or degradations during the array lifetime. The approach is similar to that for cell degradation. Rather than define an array reliability which results from a multitude of various component reliabilities, the input parameter for this technology variation consists of varying the percentage of built-in spares for 5% to 45% in steps of 5%. The resultant variation in LCC shows the expected effects of array configuration constraints on LCC (i.e., step increases due to step increases in the total number of panels vs lower-slope increases due to small increases in the module and/or panel sizes).

7.3.10 Spares/Maintainability - Exhibits 10[a - b]

For LEO missions, an alternative to built-in array spares is to replace faulty hardware in space. This can be accomplished by utilizing the Space Shuttle to transport both hardware spares and the maintenance personnel to the array in orbit, and then perform "on-site" maintenance. For this variation, the hardware spares consisted of array panels, and the maintenance function that of hardware replacement at the panel level. Again the input variation consisted of varying the percentage of spares from 5% to 45% in steps of 5%. Note the lack of a step increase in LCC for this variation in contrast to the built-in spares variation. It should also be noted that the LCC variations resulting from hardware "add-on" maintenance in LEO would be very comparable, although probably somewhat less, than spares replacement as defined in this variation.

7.3.11 Cell Cost - Exhibits 11[a - d]

Due to the fact that GaAs solar cell technology is not an established production technology, it is difficult to accurately predict what the unit cell cost will ultimately be. For the purposes of this study, a unit cell cost of $29.30 was assumed, in order to be compatible with the data in Rockwell International Report SSD80-0064. However, other estimates of unit cell cost can go as high as $500/cell. Therefore, the purpose of this technology variation is to quantify the effect of unit cell cost on total LCC. As expected, the effect is quite substantial for planar arrays as opposed to concentrator arrays. The input variation for this analysis consisted of varying the unit cell cost from $5/cell to $500/cell while holding all other performance and cost parameters constant.

8.0 SUMMARY AND CONCLUSIONS

The results of the various technology areas vs LCC are summarized in Exhibit 8-1. It should be emphasized that the results apply only within the immediate region of the baseline SAS's. It should also be noted that while the individual results were obtained by varying only one independent parameter at a time, it is possible to use the various results in various combinations. For example, given a solar cell which does not exactly fit one of the technology variations vs LCC curves, it is possible to adjust the effect of a different cell efficiency, cell degradation, and/or unit cell cost on the LCC by combining the relative effects in conjunction with one another. However, it should also be emphasized that this method will give only approximate results, and should be used in only relatively simply combinations. To obtain a more accurate composite result, the Solar Array Performance and Cost Model should be adjusted and/or exercised accordingly.

The eleven parameters analyzed are graded according to the relative LCC sensitivity. As can be seen, different applications (i.e., planar, concentrated, LEO, GEO) produce different results. The parameter ratings are based on the relative variation in LCC (max value minus min value) which resulted in the analyses discussed in Section 7.0.

TECHNOLOGY VARIATION	INFLUENCE ON LCC			
	LEO		GEO	
	250kW PLANAR	250kW CONCENTRATOR	50kW PLANAR	50kW CONCENTRATOR
CELL AREA (RIBBON)	STRONG	MODERATE	WEAK	VERY WEAK
CELL AREA (SQUARE)	STRONG	MODERATE	WEAK	VERY WEAK
CONCENTRATION RATIO	–	VERY STRONG	–	MODERATE
TEMPERATURE (AVERAGE)	MODERATE	MODERATE	VERY WEAK	VERY WEAK
CELL EFFICIENCY	STRONG	VERY STRONG	MODERATE	WEAK
CONCENTRATOR DEGRADATION	–	MODERATE	–	VERY WEAK
CELL DEGRADATION	STRONG	VERY STRONG	MODERATE	WEAK
HARDWARE LIFE	VERY STRONG	VERY STRONG	STRONG	STRONG
RELIABILITY (BUILT-IN SPARES)	STRONG	STRONG	MODERATE	MODERATE
SPARES MAINTENANCE	MODERATE	MODERATE	–	–
CELL COST	VERY EXCESSIVE	EXCESSIVE	STRONG	MODERATE

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9.0 RECOMMENDATIONS

During the course of this study, many potential uses of the Solar Array Performance and Cost Model became evident. Some of these uses would be applicable with the models as they are presently configured, while other uses would require modification and/or expansion of the existing programs. Exhibits 9-1 and 9-2 present the more significant uses/recommendations which are as follows:

- Determine Potential LCC Savings vs Development Costs

  This recommendation has two potential applications. First, direct effects on LCC for a given parameter would be determined. A second application would allow the insertion of hypothetical or actual characteristics into the solar array model to determine the potential LCC benefit and/or compare competitive technologies. The point to be made is that the models in this study were constructed based upon actual, state-of-the-art interactions between parameters. Yet the use of these models must not be limited accordingly. Not only is it important that models could be used to determine "design" type trades for one given technology; it is equally important that competitive technologies be compared with respect to LCC. In addition, it is important that whoever is making a financial decision has the appropriate insight into the total picture.

- Plan and Coordinate Development/Test Programs

  During the development of the Solar Array model discussed in this report, it rapidly became very evident that the available technical and cost data was not necessarily obtained with the total life cycle cost picture in mind. Too often, only the individual cell is addressed; and even then, the data available for the various cell performance parameters may not be a complete set. In addition, there are numerous other materials and manufacturing technologies associated with a solar array which, if uncoordinated, will inevitably promote a composite multitude of different tests, rather than a planned and coordinated test program, implemented specifically to provide a standardized data base. The point is, that given a very limited budget, the models in this report can be used to optimize the effective use of these monetary resources

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RECOMMENDED FURTHER APPLICATIONS OF SPACE ELECTRICAL POWER SYSTEM FOR LIFE CYCLE COSTING AND TECHNOLOGY ASSESSMENT

Exhibit 9-1

- CONDUCT LIFE CYCLE COST SENSITIVITY ANALYSES BY VARYING ONLY ONE DESIGNATED TECHNOLOGY PARAMETER.
- CONDUCT COMPARATIVE LIFE CYCLE COST ANALYSES OF COMPETITIVE COMPONENT TECHNOLOGIES AND/OR SYSTEM DESIGNS.
- USE COMPUTER MODEL(S) TO PLAN AND COORDINATE FUTURE COMPONENT OR SYSTEM DEVELOPMENT PROGRAMS AND/OR TEST PROGRAMS.
- USE COMPUTER MODEL(S) TO OPTIMIZE SYSTEM PERFORMANCE PARAMETERS FOR AVAILABLE LEVELS OF LIFE CYCLE FUNDING.
- USE COMPUTER MODEL(S) TO PREDICT TOTAL LIFE CYCLE COST OF SPECIFIED COMPONENT TECHNOLOGIES AND/OR SYSTEM DESIGNS.

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RECOMMENDED EXPANSION OF GaAs LIFE CYCLE COSTING AND TECHNOLOGY ASSESSMENT

Exhibit 9-2

- EXPAND GaAs AS A TOOL TO MAXIMIZE PERFORMANCE FOR SPECIFIED FUNDING LEVELS

- STUDY SOLAR ARRAY AC PERFORMANCE AND SECOND-ORDER EFFECTS LEADING TO NON-LINEAR PERFORMANCE
  - OPTICAL
  - THERMAL
  - PLASMA
  - ANNEALING

- COMBINE SILICON/SOLAR ARRAY GaAs AND ENERGY STORAGE MODELS INTO AN OVERALL ELECTRICAL POWER SYSTEM MODEL

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and achieve a coordinate and complete result.

- Develop Optimized Solar Array

This recommendation has a very significant application. Given a program which would provide an optimized configuration, it would be possible to "work backwards" and arrive at a required configuration, from a predetermined life cycle cost figure. This would allow a Program Manager to control his program and it would assist the designer to get the most out of the resources available to him.

- Develop Integrated Electrical Power System and/or Total Space Platform Model

The Solar Array is only one part of the total electrical power system. It is possible to optimize the LCC of a given solar array configuration and not have an optimized LCC for the total power system. An integrated model would provide the same capability on the EPS that was just discussed for the Solar Array.

The same comments apply as for a total space platform model. While it would probably become exceedingly more difficult to have a complete and accurate model for such a large application, this problem could be minimized by a LCC impact analysis,using integrated smaller models to determine the most significant technologies vs LCC; and then structure the space platform model accordingly.

- Develop and Use a Space Solar Array Data Center

Most of the comments previously made concerning the planning and coordinating of development/test programs also apply to this recommendation. The point is that given limited monetary resources, it is very important that there not be duplication or significant gaps in the respective data base. The model described in this report could be used to determine the most significant parameters, and to prioritize what should be done if a choice must be made between two or more competing courses of action.

10.0 BIBLIOGRAPHY

An extensive bibliography was used during the performance of this study. The data sources and references listed below are only the major ones which were ultimately used. It should be noted that a vast amount of data collection, research, and reading was involved in this study; and only after culling down to the items which were meaningful, was this bibliography constructed.

1. PRC Solar Array Subsystems Study Final Report, NASA CR-159857, June 6, 1980.

2. Rockwell International, Study of Multi-kW Solar Arrays for Earth Orbit Applications Final Report, NASA CR-165420, September 1981.

3. LMSC Study of Multi-kW Solar Arrays for Earth Orbit Application Final Report, LMSC-D715841, April 30, 1980.

4. TRW Study of Multikilowatt Solar Arrays for Earth Orbit Applications Final Report, TRW 33295-6001-UT-00, September 19, 1980

5. PRC Electrochemical Energy Storage Subsystems Final Report, NASA CR-165420, September, 1981.

6. LMSC Solar Array Technology Development for SEP (Solar Electric Propulsion), LMSC-0715820, January 9, 1981.

7. JPL Solar Cell Array Design Handbook, Vol I & II, N77-14193, October 1976.

8. NASA 25 kW Power System Reference Concept (Preliminary), PM-001, September 1979.

9. NASA TN D-8376,"Free-Vibration Characteristics of a Large Split-Blanket Solar Array in a 1-g Field", December 1976.

10. NASA CP 2058, "Future Orbital Power Systems Technology Requirements", May 31 and June 1, 1978.

11. Aerospace Advanced Space Power Requirements and Techniques, Task I: Mission Projections and Requirements, Volume I: Technical Report, ATR-78(7667)-1, Vol. 1, March 1, 1978.

12. NASA TM 80280, "Synchronous Orbit Power Technology Needs", April 1979.

13. Hughes GaAs Solar Cells, January 14, 1981.

14. NASA TM 78215, "A Programmable Power Processor for a 25-kW Power Module", January 1979.

15. NASA Common Solar Array Cost Estimating Summary, July 11, 1978.

16. NASA 25 kW Power Module Cost Estimate, August 1, 1978.

17. NASA Space Transportation System User Handbook, June 1977.

18. Boeing IUS Users Guide (STS/IUS), 0290-10078-1, December 15, 1976.

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SUMMARY - PRC's REALISTIC METHODOLOGY FOR LIFE CYCLE COSTING AND TECHNOLOGY ASSESSMENT INVOLVES ALL SYSTEM ELEMENTS

Exhibit 10-1

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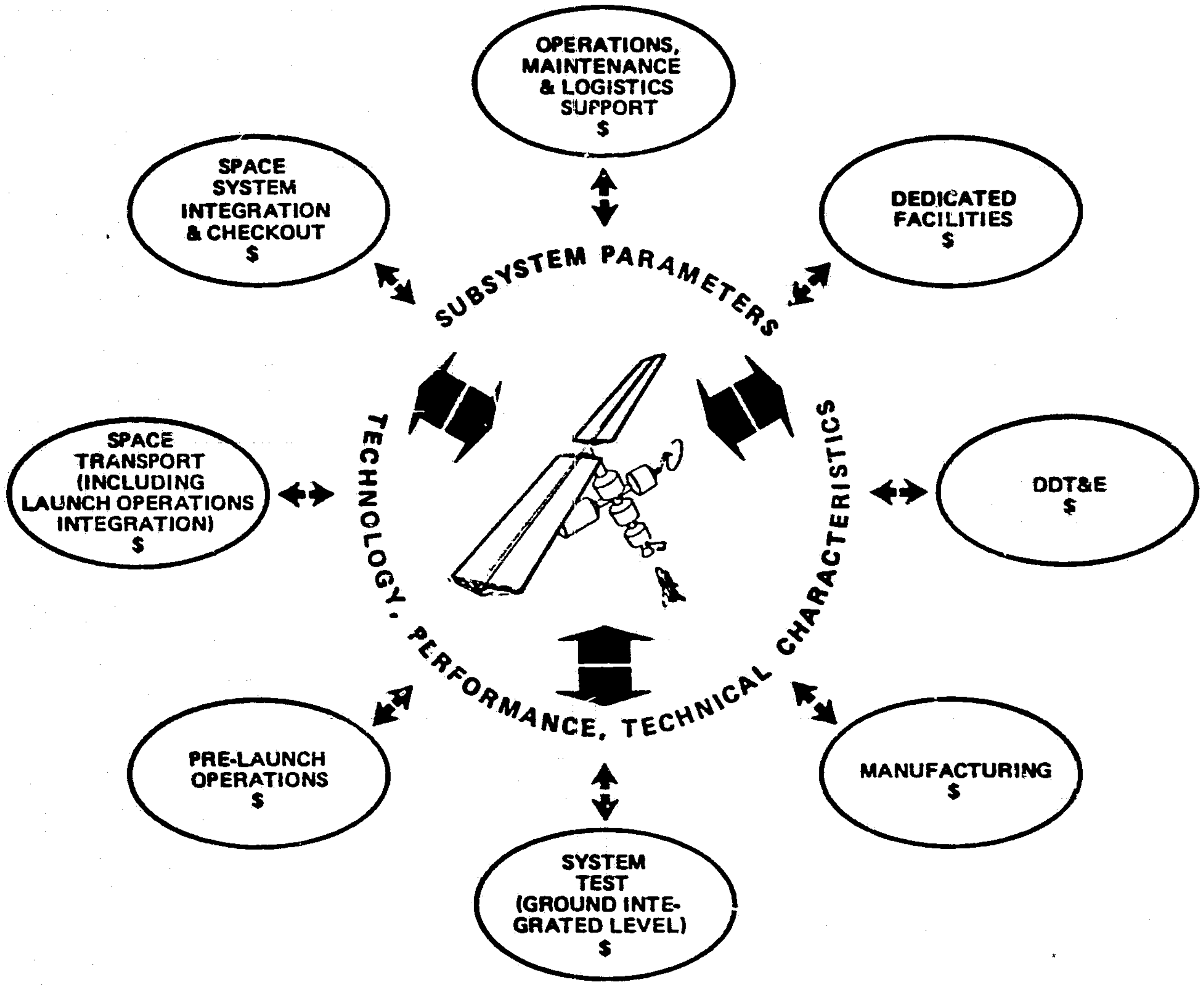

GaAs Solar Array Subsystems Study Final Report

Appendix A

SPECIFICATION:
BASELINE 500KW GAAS SOLAR ARRAY
SUBSYSTEMS REQUIREMENTS

SPECIFICATION

BASELINE 500kW GaAs SOLAR ARRAY SUBSYSTEMS REQUIREMENTS

Prepared For

NASA LEWIS RESEARCH CENTER

CLEVELAND, OHIO 44135

JANUARY 27, 1981

CONTRACT NAS3-2266

prc

PRC/SSc Systems Engineering Department

7911 CHARLOTTE DRIVE · HUNTSVILLE, ALABAMA 35802

SPECIFICATION

BASELINE 500 kW
GaAs SOLAR ARRAY SUBSYSTEMS
REQUIREMENTS

CONTRACT NAS3-22667
JANUARY, 1981

TABLE OF CONTENTS

1.0 INTRODUCTION AND SCOPE

Under contract to NASA LeRC, baseline GaAs Solar Array Subsystems (GaAsSAS) conceptual designs are being developed for the purpose of determining the influence of technology variations on the life cycle costs of the subsystem and its interfacing elements.

This specification defines the requirements for the GaAs SAS, as a subsystem of a Space Support Platform System (SSPS). This is a top level subsystem specification. The relationship of this specification to the SSPS hierarchy of specifications is contained in Section 2.0.

This specification defines the requirements for GaAsSAS subsystems for two missions:

(1) A Low Earth Orbit Space Support Platform System (LEO/SSPS) requiring 250 kW average power. This LEO/SSPS is to support User Systems which are to be engaged in, for example, Materials Processing, Astronomy, Earth Observation, Communications, Space Shuttle Operations, etc.

(2) A Geosynchronous Orbit Space Support Platform System (GEO/SSPS) requiring 50 kW average power. The GEO/SSPS is to support User Systems which are engaged in Astronomy, Communications, Earth Resources Measurement, etc.

Changes to this specification, when required, will be accomplished by change pages identified by date of issue and page or pages superseded, e.g.:

"1 July 1981 Change. (Supersedes basic)"

or

"1 September 1981 Change. (Supersedes the 1 July, 1981 Change)."

2.0 APPLICABLE DOCUMENTS

2.1 The SSPS System Specification Tree is shown in Exhibit 2-1.

2.2 JSC 07700 Volume XIV, Space Shuttle Payload Accommodations.

2.3 Space Transportation System User's Handbook, NASA, July, 1977 (maintained by JSC, Everline).

2.4 Interim Upper Stage Users Guide (IUS/STS) Technical Operating Report, D290-10078-1, Boeing Company, 1 February, 1978.

2.5 IUS Mass Properties Status Report, D290-10048-49, Boeing Company, 28 November, 1980.

2.6 Solar Cell Array Design Handbook, Volumes I & II, N77-14193/ CR-149364, JPL, October, 1976.

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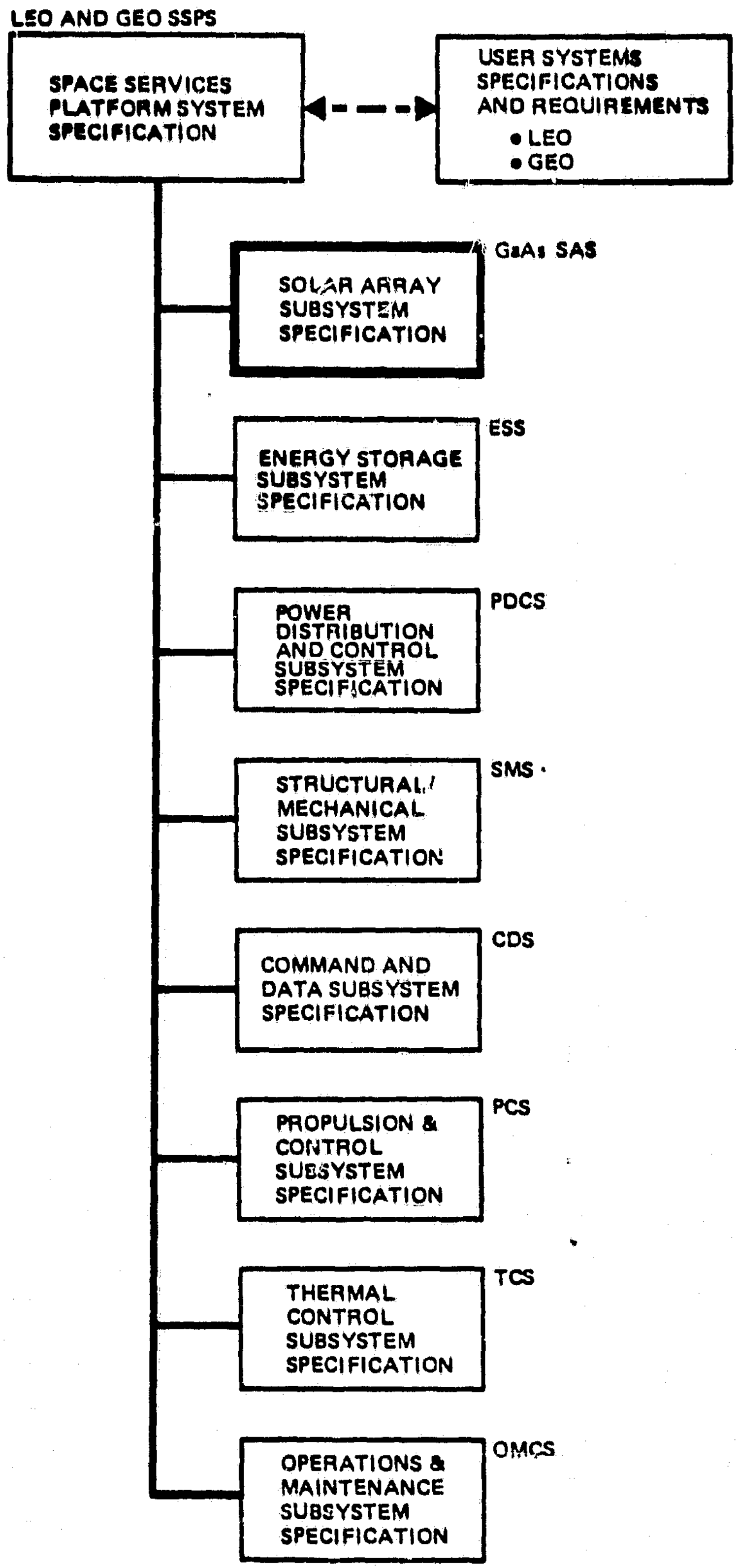

EXHIBIT 2-1. SSPS SPECIFICATION TREE

3.0 REQUIREMENTS

3.1 System Level Requirements

These requirements apply to the system level (the Space Service Platform System (SSPS) directly. The requirements on the Solar Array Subsystem derive from the system level requirements and are specified in Sections 3.2 through 3.5.

3.1.1 LEO and GEO SSPS System Level Description

The purpose of the Space Services Platform System (SSPS) is to provide services to varied User Systems. The LEO User Systems may be engaged in materials processing, astronomy, solar system and earth observation, life sciences, communications, or other operations. The GEO User Systems may be engaged in astronomy, communications, earth resources measurements, weather sensing, or other GEO operations. The User Systems may be secured to the platform or docked for servicing or short term operations.

The general configurations of the LEO and GEO SSPS is shown in Exhibit 3-1. The subsystems of the SSPS, their functions and major interfaces are identified in Exhibit 3-2. The User Systems will interface with the SSPS subsystems* as follows:

- Electrical power - GaAsSAS + ESS + PDCS
- Thermal control - TCS
- Structure - SMS
- Mechanical - SMS
- Instrumentation - CDS
- Operations/Maintenance - OMCS
- Gross Pointing Stability - CDS (Guidance)
  PCS (Attitude and Orbit Maintenance)

3.1.2 Mission Requirements

The following characteristics shall be used in the system and subsystem design.

* These acronyms are defined in Exhibit 3-2.

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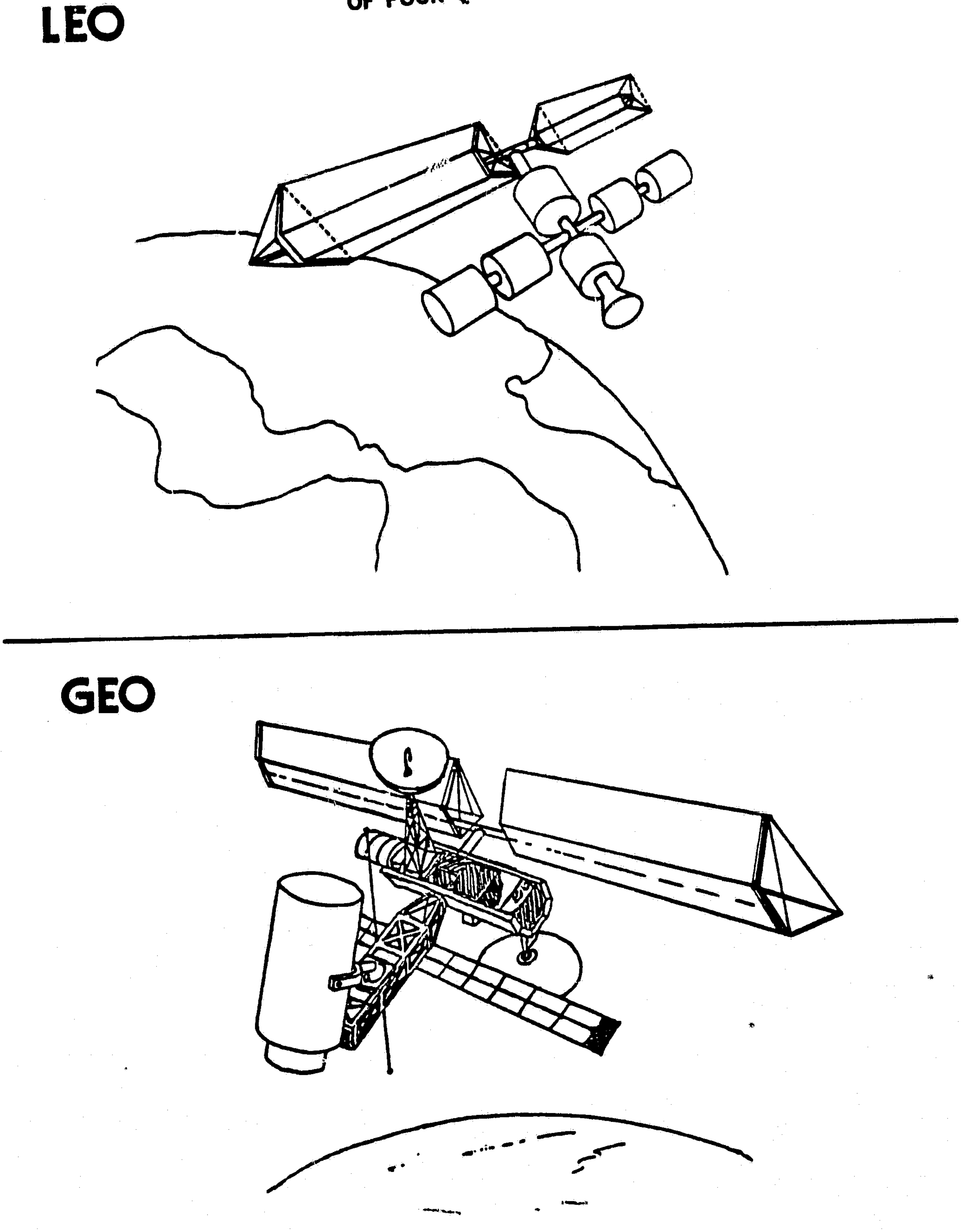
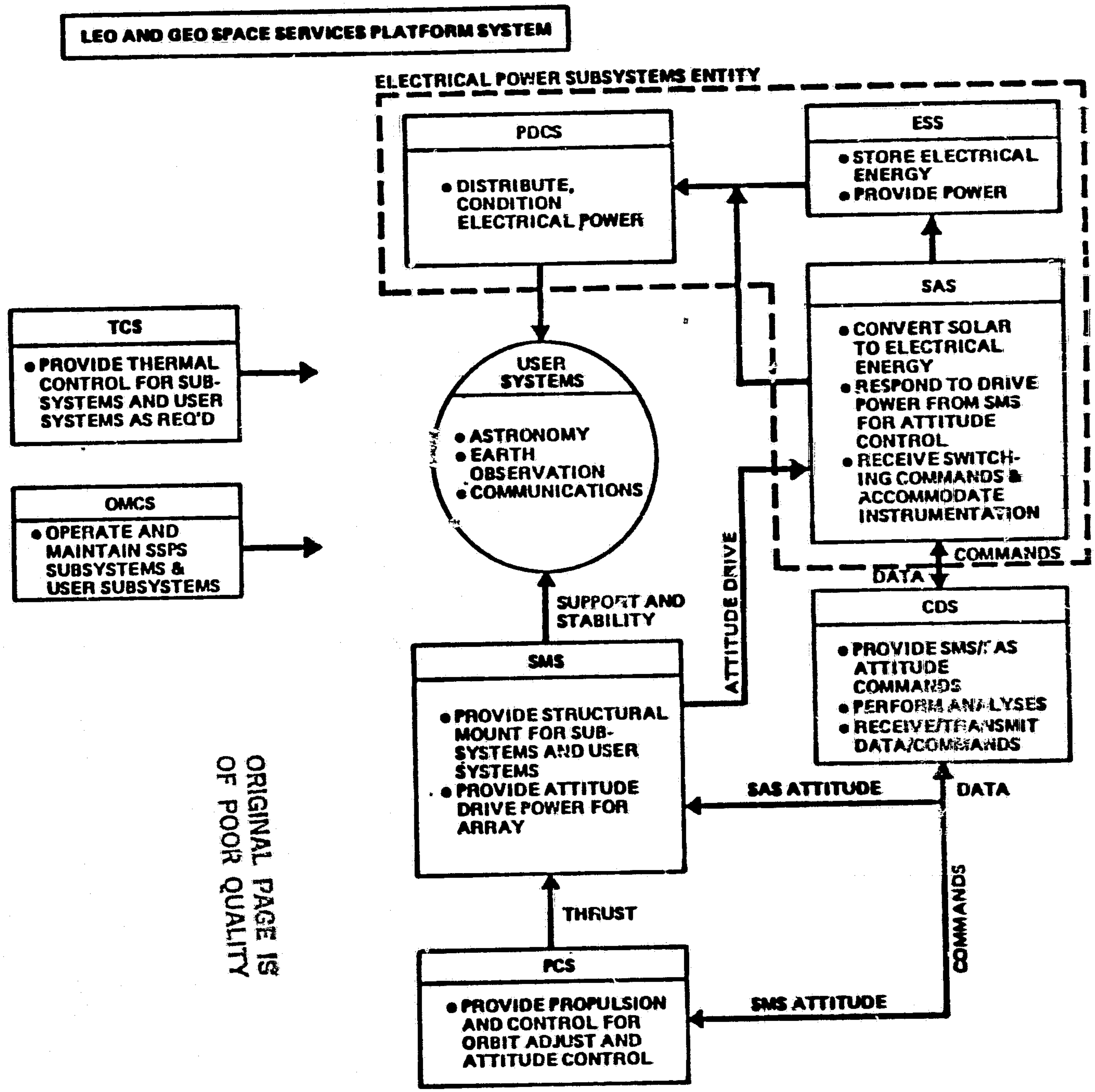


Exhibit 3-1. LEO and GEO SSPS General Configurations.
(To Be Updated as Configurations are Developed)



LEGEND:

ESS	ENERGY STORAGE SUBSYSTEM
OMCS	OPERATIONS AND MAINTENANCE CREW SUBSYSTEM (NOT APPLICABLE TO GEO SSPS)
SAS	SOLAR ARRAY SUBSYSTEMS
CDS	COMMAND AND DATA SUBSYSTEM
SMS	STRUCTURAL MECHANICAL SUBSYSTEM
PCS	PROPULSION AND CONTROL SUBSYSTEM
PDCS	POWER DISTRIBUTION & CONDITIONING SUBSYSTEM
TCS	THERMAL CONTROL SUBSYSTEM

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EXHIBIT 3-2. LEO AND GEO SSPS SUBSYSTEM FUNCTIONS AND INTERFACES

3.1.2.1 General

- System operational: 1985-1995
- State-of-the-art (1980) design
- Gallium Arsenide solar cells; 1 to 5 contentration ratio.
- Mission Life: 10 years in LEO; 5 years in GEO
- Transportation to LEO: Shuttle
- Transportation from LEO to GEO: IUS.

3.1.2.2 Orbit and Mission Parameters

- LEO circular, 444 km. Inclination 56°.
  - Orbital period: 93.4 minutes
  - Time in sun: 57.5 minutes, minimum
  - Time in eclipse: 35.9 minutes, maximum
  - Number of sclipses: 56.311 Ten Years
- GEO circular, equatorial, 35,786 km
  - Orbital period: 24 hours
  - Time in Sun: 23.8 hours, minimum
  - Time in Eclipse*: 1.2 hours, maximum
  - Number of Eclipses: 44 per season, 88 per year
  - Total Eclipse: 81 hours of eclipse per year

3.1.2.3 Electrical

The following requirements are those imposed on the electrical power subsystems entity consisting of the GaAsSAS, the ESS and the PDCS. Requirements (which derive from this requirement) on each of these subsystems are specified in Section 3.2.1.

---

*This is an effective value to account for umbra and penumbra.

3.1.2.3.1 LEO Mission

- 250 kW continuous from BOL to EOL shall be provided to the loads, consisting of the User Systems. A maximum overload of 50% is to be provided to the loads for one orbit maximum. Rapid restoration of energy balance will be effected during ensuing orbits through operational scheduling.
- The bus voltage and power levels for the loads shall be:
  - small experiment projects and low power subsystems: 30 VDC/50 kW.
  - astonomy, communications, earth sensing and high power subsystems: 100-250 VDC/75 kW.
  - manufacturing processes experiments, materials processing, propulsion testing: 1000 VDC/125 kW.

3.1.2.3.2 GEO Mission

- 50 kW continuous, from BOL to EOL, shall be provided to the loads consisting of User Systems. A maximum overload of 10% is to be provided to the loads for one orbit maximum. Rapid restoration of energy balance will be effected during ensuing orbits through operational scheduling.
- The bus voltage and power levels for the loads shall be:
  - Astonomy - Provide 25 kW, 100 to 250 VDC, continuous power to an astronomical sensor such as optical telescope with vidicon sensor, video recording capability, and binary encoding for communications relay to earth.
  - Communications - Provide 10 kW, 28 to 30 VDC, continuous power to wide-band PCM transmitter (2200 MHZ) for data transmission.
  - Earth Resources - Provide 15 kW, 100 to 250 VDC continous to infrared and visible earth resources sensors, encoders and associated processing equipment for communications relay to earth. Power to be provided at 30 VDC.
  - Subsystems - Provide 5 kW, 28 to 30 VDC continuous to SSPS Subsystems.

3.2 Subsystem Performance and Interface Requirements and Constraints

3.2.1 Electrical Performance and Interface Requirements

The following requirements are imposed on the GaAs SAS subsystem performance, and on the electrical interfaces with the ESS and PDCS.

3.2.1.1 GaAs SAS/ESS/PDCS Interfaces

- The GaAs SAS shall provide adequate electrical power and energy to the ESS and to the PDCS at EOL to meet the User Systems and SSPS subsystem requirements specified in Section 3.1.2.4. The block diagram of Exhibit 3-3 specifies the efficiencies presently allocated to the interfaces involved.

3.2.1.2 Power Losses

The total power losses of the array shall not exceed 10%. These losses include:

- assembly factor
- diode drop
- wiring (cell, module panel inter-connections and main buses)
- slip rings.

3.2.1.3 Degradation Compensation

The GaAs SAS shall be designed to achieve a constant electrical power output by varying the angle of incidence of the sun vector on the plane of the array over the 10 year life in LEO, or 5 year life in GEO.

3.2.1.4 Environmental Degradation

The GaAs SAS shall not exceed 50% degradation over the operational life of BOL maximum power output (at slip-ring output) under the environments specified in Section 3.2.7. This applies to both LEO and GEO missions.

3.2.2 Structural/Mechanical/Thermal Performance and Interface Requirements and Constraints

3.2.2.1 GaAs SAS Structural/Mechanical Performance

- The GaAs SAS shall be capable of withstanding orbit changes of altitude and inclination.

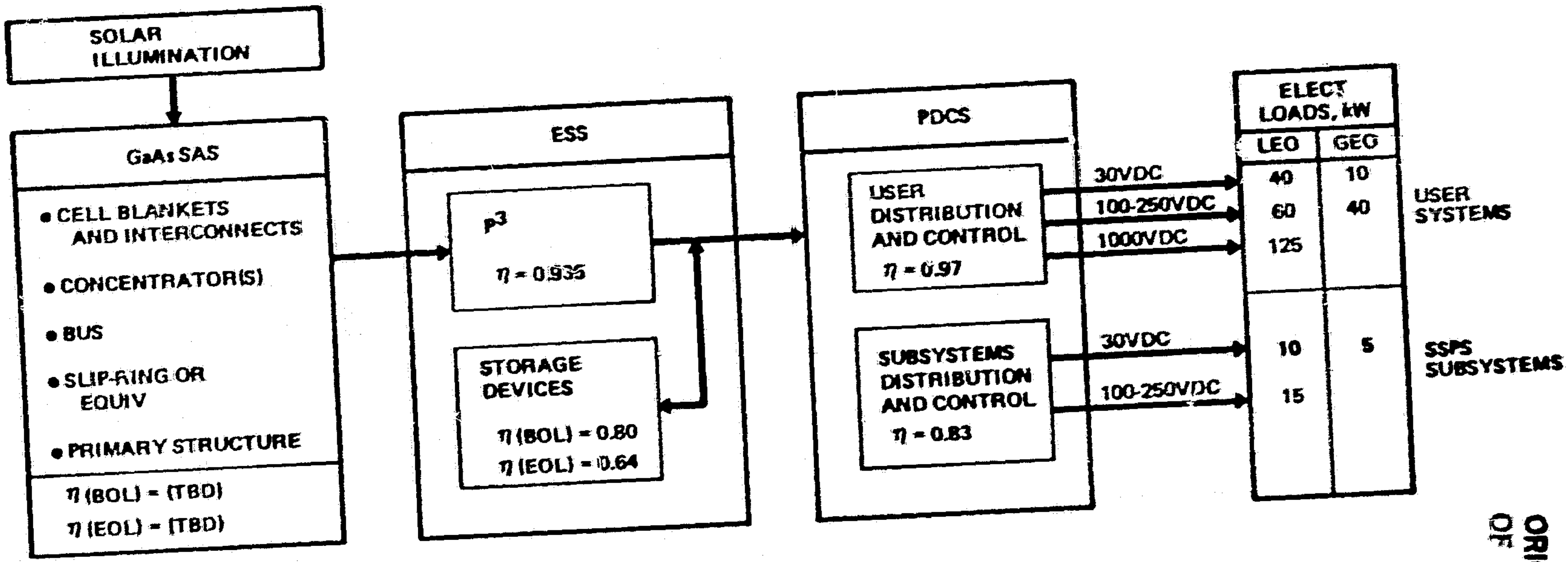

EXHIBIT 3-3. GaAs SAS PERFORMANCE AND INTERFACE REQUIREMENTS

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- Loads:
  - Perpendicular to plane of array: 0.01 G
  - Parallel to plane of array: 0.01 G
- The array shall be held within ± 10 degrees of planar except during orbit maintenance thrusting.

3.2.2.2 GaAs SAS/SMS Interface

The SAS interfaces with the SMS shall be:

- Structural Attachment: The SMS shall provide the mounting assembly which secures the GaAs SAS to the SMS structure, at the GaAs SAS two axis drive/slip ring assembly.
- Attitude Control Drive Interface: The SMS shall provide the drive power required to implement GaAs SAS attitude commands received from the CDS. The interface shall be the two-axis drive assembly shaft at the SMS drive power source. Maximum angular velocity and acceleration required of the SMS drive power source shall be $\omega = 1\ °/sec$, and $\dot{\omega} = 1\ °/sec^2$ about the axes of pitch and roll, where pitch is motion about the SAS boom axis.

3.2.2.3 GaAs SAS/PDCS Interface

- This mechanical interface shall be the electrical interconnects between the 2 axis drive/slip ring assembly output and the ESS/PDCS.

3.2.2.4 GaAs SAS/PCS Interface

- Thruster induced loads shall be consistent with structural/mechanical requirements of Section 3.2.3.1.
- Contaminant and charged particle constraints and tolerances shall be TBD.

3.2.2.5 GaAs SAS/TCS Interface

The SAS thermal control requirements and mechanical interfaces shall be: TBD

3.2.2.6 GaAs SAS/CDS Interface

- The GaAs SAS shall provide mechanical accommodations for command and data instruments which shall be components of the CDS. The CDS shall provide electrical power for command and data channels which interface with the GaAs SAS.
- The command and data channel list for GaAs SAS shall be: (1)
- Communication requirements for space assembly, check-out, operations and maintenance activities will be: (1)

3.2.2.7 GaAs SAS/OMCS Interface

- This interface is covered in Section 3.2.7.

3.2.3 Transportation/Transportability

3.2.3.1 The GaAs SAS components shall be transportable to space by the Space Shuttle.

3.2.3.2 The GaAs SAS shall incorporate fold-up solar panels and concentrator(s) for space transportation.

3.2.3.3 The SAS design, as stowed for transportation shall meet the transportation environment specified in Section 3.2.7.

3.2.3.4 The maximum dimensions and total weight including containers, of a single-flight set or sub-set of GaAs SAS components (blankets, concentrator(s), structural components, electrical and mechanical interconnects, electrical buses, 2 axis drive/slip ring assembly) shall not exceed 4.57 meters in diameter, 18 meters in length, and 25,855 kg in weight. The CG limits shall be as specified in JSC 07700 Volume XIV.

3.2.4 Life and Reliability

3.2.4.1 • LEO Mission - The GaAS SAS shall be designed for a ten year operational period between blanket change-out with on-orbit scheduled and unscheduled maintenance performed by the OMCS. Over the

(1) Not required for the purposes of this study.

ten year period, the electrical output shall not degrade greater than 50% of BOL subsystem electrical power output (this defines a failure at the subsystem level).

- GEO Mission - The GaAs SAS shall be designed for a five year operational life. The electrical output shall not degrade greater than 50% of the BOL subsystem electrical power output (this defines a failure at the subsystem level).

3.2.4.2 The design shall be such that failures will be non-proliferating.

3.2.4.3 Reliability specifications shall be subject to the life cycle cost trade analyses.

3.2.4.4 The design shall provide that the number of panels whose output is $\leq$ 92% P_o (EOL) shall not exceed 5% of the array area at any one time over the 10 year blanket life for the LEO mission and five year life for the GEO mission.

3.2.4.5 The number of panels changed out for failure shall not exceed 12% of the array area over the ten year blanket life.

3.2.4.6 Storage life is TBD.

3.2.5 Safety

The GaAs SAS design and procedures for all phases of production, earth and space integration, transportation and O&M, shall assure the chance of serious injury or death over a ten year period is less than one in 10^7 man-hours.

3.2.6 Maintenance/Maintainability

3.2.6.1 Logistics and Spares

- LEO Mission - The normal supply mode shall be a set of on-hand (in space) spares and materials sufficient for ten year's operation. The spares set shall be delivered by the Space Shuttle.
  The OMCS personnel crew shall be changed out every three months.
  Transport mode shall be Space Shuttle.

- GEO Mission - Spares are required only to support pre-launch testing.

3.2.6.2 Overhaul

- LEO Mission - The GaAs SAS shall be designed for array blanket change-out every ten years.

- GEO Mission - No applicable.

3.2.6.3 Maintenance

- LEO Mission

  - The blanket shall be modularized for panel removal and replacement with a serviceable spare.

  - In space (on-array) repair shall be limited to the panel level or higher.

  - In-space, shop repair of panels at panel level or lower shall be: TBD

  - Panels shall be considered failed at 90% of expected P_O at any given time, and shall be changed out.

  - The SAS design shall enable repair/replacement (and checkout) time of 24 manhours per modular panel.

  - The SAS design shall permit automatic fault isolation to the failed panel(s).

  - The Solar Array Subsystem (SAS) shall be capable of assembly and checkout in space. Assembly will include hook-up and attachment to the SMS and other subsystems of the SSPS system.

3.2.7 Environment

3.2.7.1 Natural Environment

The design shall meet the requirements of this specification within the natural environment (worst case 20 year prognosis) of the earth orbit range of: 300 to 1900 km, all inclinations, for the LEO Mission, and 30,000 to 40,000 km for the GEO Mission. This environment shall include effects due to U.V. radiation, solar flares, trapped radiation and micrometeorites.

3.2.7.2 Transportation Induced

- Earth surface/air transport: TBD
- Launch and ascent to LEO
  - Axial acceleration of 5g
  - Lateral acceleration of 0.5g
  - Decaying sinusoidally of 7g at 16 Hz
  - Sinusoidal vibration (three mutually perpendicular directions) ±1g peak from 2 to 40 Hz
  - Random vibration (gaussian amplitude distribution) 0.1 g^2/Hz from 10 to 60 Hz, 0.4 g^2/Hz from 60 to 2,000 Hz
  - Acoustic noise (decibels Re: 0.0002 microbar) up to 150 db (3 minutes duration) 45 to 11,200 Hz
- Ascent Venting Profile - TBD
- Ascent from LEO to GEO - TBD

3.2.7.3 Operational Induced

- The induced operational environments shall be as specified in Section 3.2 interface requirements.
- Contaminants - TBD

3.3 Design & Construction

3.3.1 Materials Properties

3.3.1.1 Materials Compatibility

TBD

3.3.1.2 Outgassing

TBD

3.3.1.3 Insulation Resistance

TBD

3.3.1.4 Voltage Breakdown

TBD

3.3.1.5 Contaminants Sources

TBD

3.4 Verification Requirements

The requirements of this specification shall be as specified in Section 4.0, verification. (Section 4.0 is TBD)

3.5 Personnel & Training Requirements

(1)

(1) Not required for the purposes of this study.

Appendix B

DISCUSSION OF SOLAR ARRAY THERMAL MODELLING

APPENDIX B

Discussion of Solar Array Thermal Modelling

FOR THE
GAAS SOLAR ARRAY SUBSYSTEMS STUDY

CONTRACT NAS3-22667
LEWIS RESEARCH CENTER
JUNE 12, 1981

For a solar array, one of the most important technology relationships is the effect of solar array temperature on solar cell performance. The sources of heat which influence solar array temperature include solar illumination from the sun, albedo (reflected solar energy from earth cloud cover), earth planetary radiation (infrared), and heat exchange with the space platform. The basic equation involved is as follows:

$$\frac{A(60}{3600}\,\overline{M}\,\overline{C}_p(T)\,\frac{dT}{dt} = q_{ill} + q_{al} + q_{er} + q_{sp} - q_E(T)$$

where

dT = temperature ($^{\circ}K$) $AT = T_2 - T_1$

dt = time (min) $At = t_2 - t_1$

$\overline{m}\,\overline{cp}\,(T)$ = array thermal capacity @ $\overline{T} = \frac{T_1 + T_2}{2}$ (Average)

q_{ill} = heat absorbed as a result of solar illumination

q_{al} = heat absorbed as a result of albedo

q_{er} = heat absorbed as a result of earth radiation

q_{sp} = heat absorbed as a result of space platform

$q_E(T)$ = heat emitted @ $\overline{T} = \frac{T_1 + T_2}{2}$

The six basic cases for the above equation are as shown in Exhibit B-1 and the following table (for an orbit of 444 km altitude):

CASE	$\emptyset^{\circ}$	t(min)	q_{ill}	q_{al}	q_{er}
I	-20.8° to 0°	0 to 5.05	front	front	front
II	0° to 90°	5.05 to 26.86	front	back	back
III	90° to 180°	26.86 to 48.68	front	back	back
IV	180° to 200.8°	48.68 to 53.72	front	front	front
V	200.8° to 270°	53.72 to 70.49	--	--	front
VI	270° to 339.2°	70.49 to 87.26	--	--	front

The parameters involved in the above general equation are as follows:

1. solar illumination =

$$\overbrace{(\bar{\alpha}_S - F_P N_{op})\, A_F\, S_S \cos \Gamma_1}$$

2. earth albedo =

$$\overbrace{\bar{\alpha}\, A\, (.36\, S_S)\, \cos \Gamma_2}$$

3. earth planetary radiation =

$$\overbrace{\bar{\alpha}\, A\, S_P \cos \Gamma_3}$$

4. heat exchange with space platform =

$$\overbrace{(.75\, \varepsilon_{HB})\, \varepsilon_S\, F_{B-P}\, A_B\, \sigma\, (T_{A_{op}}^4 - T_{P_{op}}^4)}$$

5. front side emittance to space =

$$\overbrace{\bar{\varepsilon}_{HF}\, F_{F-S}\, A_F\, \sigma\, T_{A_{op}}^4}$$

6. back side emittance to space =

$$\overbrace{(.75\, \varepsilon_{HB})\, F_{B-S}\, A_B\, \sigma\, T_{A_{op}}^4}$$

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Where:

$\bar{\alpha}_S$ = average solar absorptance of front surface materials .73

F_P = solar cell packing factor .85.1%

N_{op} = solar cell operating efficiency at array operating temperature 18.1%

A_F = array front side area (m^2) 1 m^2 (unit area)

S_S = solar illumination (W/m^2) (See paragraph 6.2.1.2)

Γ_1 = angle of incidence of sunlight on array front side (varies with orbit)

Γ_2 = angle of incidence of albedo energy on array (varies with orbit)

S_p = earth planetary radiation (W/m^2)   188 (LEO); 5 (GEO)

Γ_3 = angle of incidence of earth planetary radiation on array (varies with orbit)

$\bar{\varepsilon}_{HF}$ = average hemispherical emittance of array front side materials .84

F_{F-S} = view factor of array front side to space   1 (Γ=0°)

σ = Stephan Boltzmann's constant ($w\ m^{-2}\ {}^oK^{-4}$) 5.81×10^{-8}

$T_{A_{op}}$ = array operating temperature (^oK) (See paragraph 6.2.1.6.3)

ε_{HB} = hemispherical emittance of array back side material .7

$\bar{\alpha}$ = absorptance of albedo and earth planetary radiation by array surface .73 Front; .3 Back

A = array area for albedo and earth planetary radiation ($1m^2$)

F_{B-S} = view factor of array front side to space   1 (Γ = 0°)

ε_S = hemispherical emittance of space platform material .05

F_{B-P} = view factor of array back side to space platform surface   .7071 (Γ = 45°)

$T_{P_{op}}$ = operating temperature of space platform surface (323°K)

From these relationships and parameters, the average operating temperature is calculated for a given solar illumination (max, min, and/or average). From this, a typical profile is as shown in Exhibit B-2. The time in orbit is measured from the 0^o axis in Exhibit B-1.

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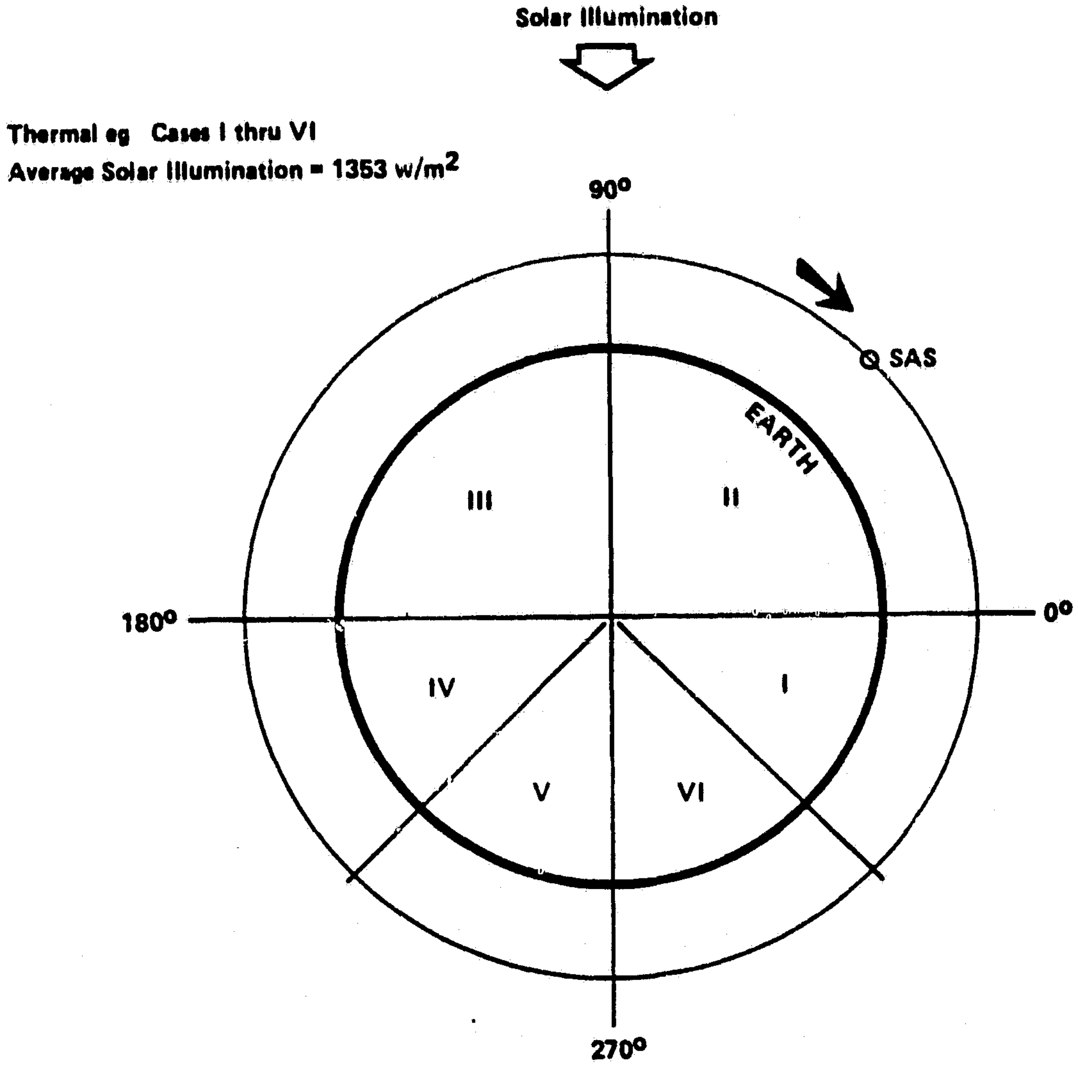

Exhibit B-1. Relationship of Sun, Earth and Solar Array Subsystem in Earth Orbit

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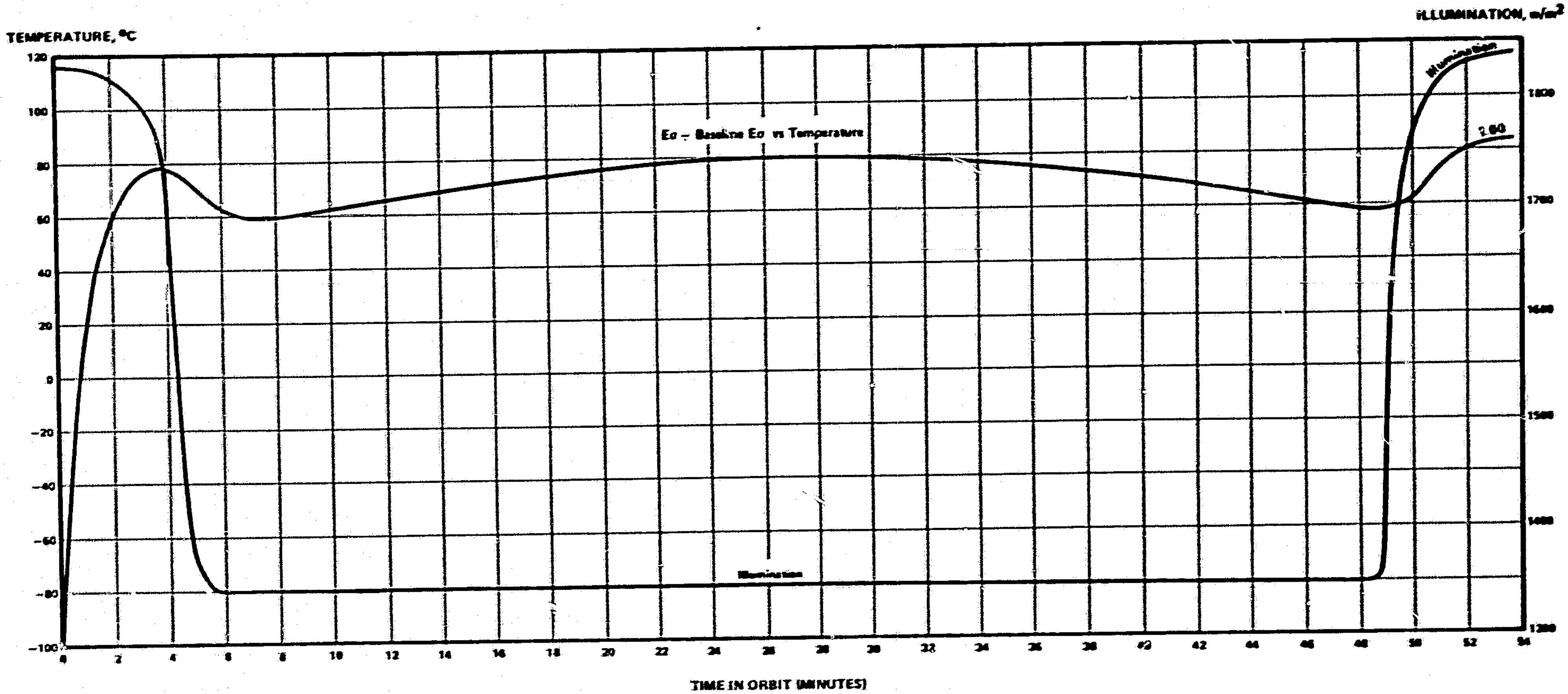

Exhibit B-2

Appendix C

DATA FOR
TECHNOLOGY VARIATIONS VS LCC

This appendix contains data printouts and curves which are discussed in Section 7.0 of the GaAs Solar Array Subsystems Study Final Report. The exhibits contained herein are as follows:

	GaAs SAS Parameter	Appendix C Exhibit #'s
1.	Cell Area (Ribbon)	1 [a - d]
2.	Cell Area (Square)	2 [a - d]
3.	Concentration Ratio	3 [a - b]
4.	Temperature (Average)	4 [a - d]
5.	Cell Efficiency	5 [a - d]
6.	Concentrator Degradation	6 [a - b]
7.	Cell Degradation	7 [a - d]
8.	Hardware Life	8 [a - d]
9.	Reliability (Built-In Spares)	9 [a - d]
10.	Spares/Maintenance	10 [a - b]
11.	Cell Cost	11 [a - d]

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LEO   250 KW Planar   GaAs SAS

ARRAY PERFORMANCE									
No. of Hardware Life Cycles	1	1	1	1	1	1	1	1	1
Total Cell Life Required (Yr)	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0
Total EOL Min. Power (KW)	650.3	651.8	651.9	651.1	650.2	654.6	655.1	652.3	653.0
Total EOL Min. Voltage (V)	194.0	193.0	215.0	215.0	215.0	215.0	215.0	215.0	215.0
BOL Cell Efficiency (%)	18.1	18.1	18.1	18.1	18.1	18.1	18.1	18.1	18.1
BOL Cell Max. Voltage (V)	.809	.809	.809	.809	.809	.809	.809	.809	.809
EOL Cell Power (MW)	64.0	127.0	191.0	254.0	318.0	382.0	446.0	509.0	574.0
EOL Cell Voltage (V)	.716	.714	.716	.715	.715	.715	.716	.715	.717
POWER FACTORS									
Radiation	.891	.891	.891	.891	.891	.891	.891	.891	.891
Temperature	.984	.983	.982	.981	.981	.981	.982	.981	.982
Main Bus	.971	.971	.975	.975	.975	.975	.976	.975	.975
	****	****	****	****	****	****	****	****	****
CUM. EOL FACTOR	.643	.642	.644	.643	.643	.643	.644	.643	.644
VOLTAGE FACTORS									
Radiation	.968	.968	.968	.968	.968	.968	.968	.968	.968
Temperature	.973	.970	.970	.968	.968	.968	.969	.968	.969
Main Bus	.971	.971	.975	.975	.975	.975	.976	.975	.975
	****	****	****	****	****	****	****	****	****
CUM. EOL FACTOR	.885	.882	.885	.884	.884	.884	.885	.884	.886
ILLUMINATION FACTORS									
Cover Degradation (EOL)	.870	.870	.870	.870	.870	.870	.870	.870	.870
Concentration Ratio (BOL)	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Concentrator Degrad. (EOL)	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
	*****	*****	*****	*****	*****	*****	*****	*****	*****
CUM. EOL FACTOR	.885	.885	.885	.885	.885	.885	.885	.885	.885
PHYSICAL CHARACTERISTICS									
Total Number of Cells	10160640	5132160	3412800	2563200	2044800	1713600	1468800	1281600	1137600
No. of Modules/Panel	15	15	15	15	15	15	15	15	15
No. of Panels/Blanket	36	36	24	24	24	24	24	24	24
Blanket Weight (Kg)	2032.0	2037.0	1951.0	1950.0	1939.0	1955.0	1954.0	1951.0	1941.0
Structure Weight (Kg)	2327.0	2316.0	2184.0	2182.0	2173.0	2189.0	2180.0	2176.0	2175.0
Total Array Weight (Kg)	10455.0	10464.0	9988.0	9982.0	9929.0	10009.0	9996.0	9980.0	9939.0
Solar Cell Area (cm2)	4.000	8.000	12.000	16.000	20.000	24.000	28.000	32.000	36.000
Module Area (M^2)	2.430	2.310	3.350	3.330	3.270	3.340	3.280	3.290	3.260
Concentrator Area (M^2)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Panel Area (M^2)	36.20	34.50	50.00	49.70	48.80	49.80	48.90	49.20	48.70
Blanket Area (M^2)	1337.0	1275.0	1227.0	1220.0	1199.0	1223.0	1202.0	1209.0	1196.0
Total Array Area (M^2)	5348.0	5100.0	4908.0	4880.0	4796.0	4892.0	4808.0	4836.0	4784.0
Power Density (W/M2)	121.59	127.80	132.82	133.41	135.58	133.81	136.25	134.89	136.49
Power/Weight Ratio (W/Kg)	62.20	62.29	65.26	65.22	65.49	65.40	65.57	65.37	65.70
LIFE CYCLE COST (1980$M)									
DDT&E	308.218	249.370	183.517	170.490	161.648	155.943	151.225	147.349	144.206
PRODUCTION	880.622	712.487	524.333	487.115	461.852	445.552	432.071	420.997	412.017
(Solar Cell - $/Cell)	(20.00)	(29.30)	(36.64)	(42.93)	(48.54)	(53.67)	(58.43)	(62.89)	(67.10)
OPERATIONS & MAINTENANCE	192.123	192.447	165.279	165.344	164.890	165.646	165.452	165.214	164.998
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TOTAL LIFE CYCLE COST	1380.963	1154.304	873.129	822.949	788.390	767.141	748.748	733.560	721.221

Exhibit 1a. Cell Area (Ribbon)

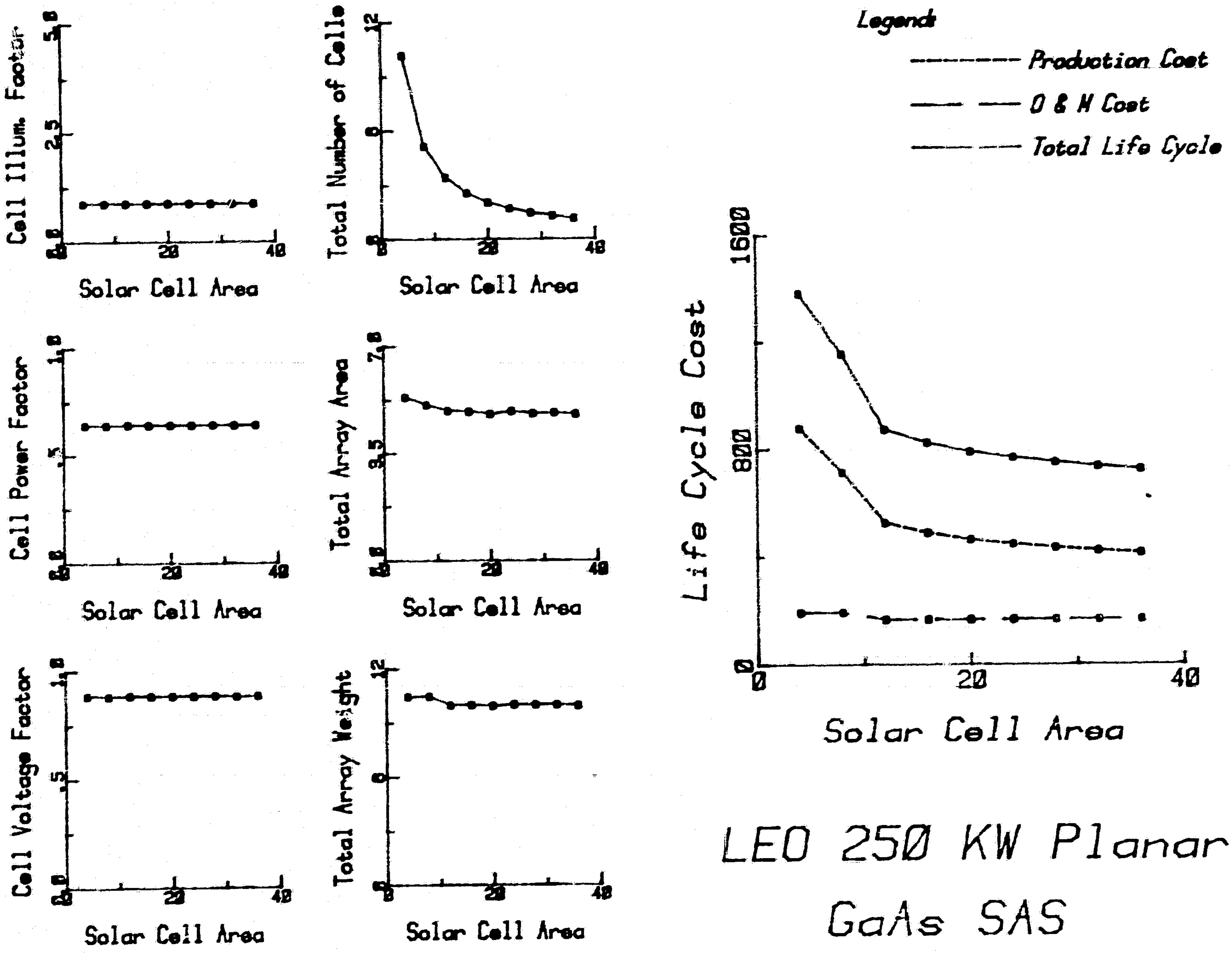

Exhibit 1a. Cell Area (Ribbon) Continued

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LEO 250 KW Conc. GaAs SAS

ARRAY PERFORMANCE									
No. of Hardware Life Cycles	1	1	1	1	1	1	1	1	1
Total Cell Life Required (Yr)	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0
Total EOL Min. Power (KW)	651.0	650.3	650.3	666.3	651.6	673.7	662.3	681.5	686.2
Total EOL Min. Voltage (V)	198.0	196.0	196.0	196.0	195.0	195.0	195.0	194.0	193.0
BOL Cell Efficiency (%)	18.1	18.1	18.1	18.1	18.1	18.1	18.1	18.1	18.1
BOL Cell Max. Voltage (V)	.843	.843	.843	.843	.843	.843	.843	.843	.843
EOL Cell Power (MW)	247.0	490.0	735.0	977.0	1219.0	1462.0	1711.0	1946.0	2190.0
EOL Cell Voltage (V)	.517	.511	.512	.510	.508	.507	.507	.505	.504
POWER FACTORS									
Radiation	.891	.891	.891	.891	.891	.891	.891	.891	.891
Temperature	.831	.826	.825	.825	.825	.826	.826	.826	.824
Main Bus	.928	.927	.927	.926	.925	.923	.925	.921	.925
	****	****	****	****	****	****	****	****	****
CUM. EOL FACTOR	.520	.516	.516	.514	.513	.513	.514	.512	.512
VOLTAGE FACTORS									
Radiation	.968	.968	.968	.968	.968	.968	.968	.968	.968
Temperature	.712	.704	.703	.702	.702	.704	.704	.704	.701
Main Bus	.928	.927	.927	.926	.925	.923	.925	.921	.925
	****	****	****	****	****	****	****	****	****
CUM. EOL FACTOR	.613	.606	.607	.605	.603	.601	.602	.599	.598
ILLUMINATION FACTORS									
Cover Degradation (EOL)	.870	.870	.870	.870	.870	.870	.870	.870	.870
Concentration Ratio (BOL)	5.000	5.000	5.000	5.000	5.000	5.000	5.000	5.000	5.000
Concentrator Degrad. (EOL)	.960	.960	.960	.960	.960	.960	.960	.960	.960
	*****	*****	*****	*****	*****	*****	*****	*****	*****
CUM. EOL FACTOR	4.247	4.247	4.247	4.247	4.247	4.247	4.247	4.247	4.247
PHYSICAL CHARACTERISTICS									
Total Number of Cells	2635776	1327104	884736	681984	534528	460800	387072	350208	313344
No. of Modules/Panel	8	8	8	8	8	8	8	8	8
No. of Panels/Blanket	48	48	48	48	48	48	48	48	48
Blanket Weight (Kg)	1495.0	1498.0	1498.0	1476.0	1481.0	1555.0	1506.0	1600.0	1490.0
Structure Weight (Kg)	1735.0	1741.0	1741.0	1729.0	1726.0	1814.0	1758.0	1866.0	1763.0
Total Array Weight (Kg)	7715.0	7733.0	7733.0	7633.0	7650.0	8034.0	7782.0	8266.0	7723.0
Solar Cell Area (cm2)	4.000	8.000	12.000	16.000	20.000	24.000	28.000	32.000	36.000
Module Area (M^2)	.880	.880	.880	.850	.860	.920	.880	.960	.850
Concentrator Area (M^2)	7.98	7.98	7.98	7.70	7.79	8.34	7.98	8.70	7.70
Panel Area (M^2)	35.50	35.50	35.50	34.00	34.70	37.00	35.50	38.60	34.00
Blanket Area (M^2)	1743.0	1743.0	1743.0	1667.0	1700.0	1813.0	1743.0	1893.0	1667.0
Total Array Area (M^2)	6972.0	6972.0	6972.0	6668.0	6800.0	7252.0	6972.0	7572.0	6668.0
Power Density (W/M2)	93.38	93.27	93.27	99.92	95.82	92.90	94.99	90.00	102.91
Power/Weight Ratio (W/Kg)	84.39	84.09	84.09	87.29	85.18	83.85	85.11	82.45	88.85
LIFE CYCLE COST (1980$M)									
DDT&E	184.642	169.312	163.218	160.075	157.506	157.189	155.139	155.584	153.650
PRODUCTION	527.549	483.748	466.336	457.358	450.018	449.110	443.255	444.525	439.000
(Solar Cell - $/Cell)	(20.00)	(29.30)	(36.64)	(42.93)	(48.54)	(53.67)	(58.43)	(62.89)	(67.10)
OPERATIONS & MAINTENANCE	183.166	183.327	183.327	182.461	182.456	186.281	183.811	188.566	183.290
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TOTAL LIFE CYCLE COST	895.357	836.387	812.881	799.894	789.980	792.580	782.205	788.675	775.940

Exhibit 1b. Cell Area (Ribbon)

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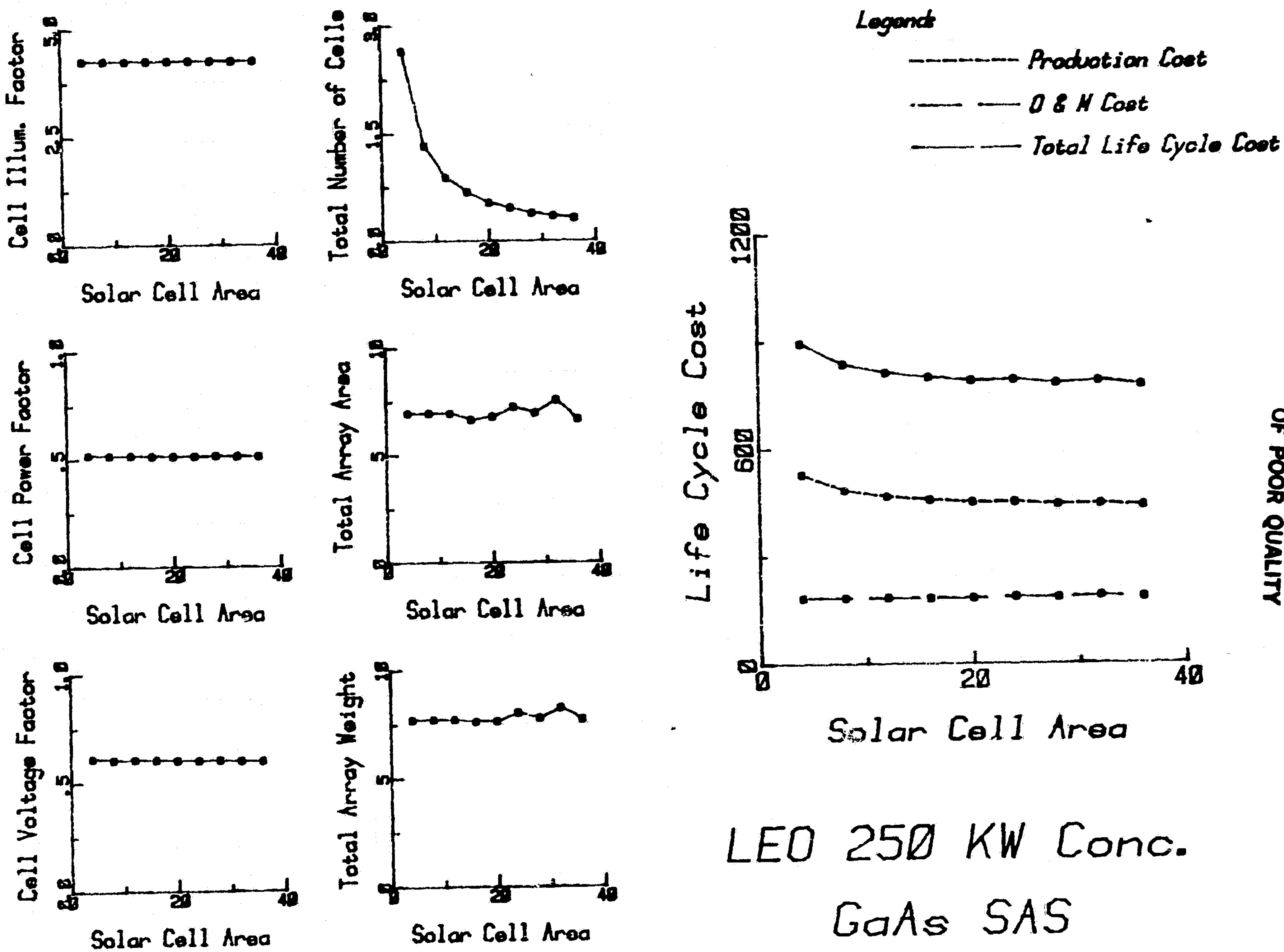

Exhibit 1b. Cell Area (Ribbon) Continued

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GEO 50 KW Planar GaAs SAS

ARRAY PERFORMANCE									
No. of Hardware Life Cycles	1	1	1	1	1	1	1	1	1
Total Cell Life Required (Yr)	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0
Total EOL Min. Power (KW)	70.6	70.8	70.6	71.0	71.5	72.1	72.2	70.9	72.1
Total EOL Min. Voltage (V)	193.0	192.0	192.0	192.0	192.0	192.0	192.0	192.0	192.0
BOL Cell Efficiency (%)	18.1	18.1	18.1	18.1	18.1	18.1	18.1	18.1	18.1
BOL Cell Max. Voltage (V)	.809	.809	.809	.809	.809	.809	.809	.809	.809
EOL Cell Power (MW)	55.0	109.0	163.0	217.6	271.0	325.0	380.0	433.0	488.0
EOL Cell Voltage (V)	.732	.729	.726	.726	.726	.726	.725	.725	.725
POWER FACTORS									
Radiation	.779	.779	.779	.779	.779	.779	.779	.779	.779
Temperature	.989	.987	.986	.986	.986	.985	.985	.985	.985
Main Bus	.989	.989	.988	.988	.988	.988	.988	.988	.988
	****	****	****	****	****	****	****	****	****
CUM. EOL FACTOR	.575	.574	.572	.572	.572	.571	.571	.571	.571
VOLTAGE FACTORS									
Radiation	.963	.963	.963	.963	.963	.963	.963	.963	.963
Temperature	.981	.978	.976	.976	.976	.975	.975	.975	.975
Main Bus	.589	.989	.988	.988	.988	.988	.988	.988	.988
	****	****	****	****	****	****	****	****	****
CUM. EOL FACTOR	.905	.901	.898	.897	.897	.897	.896	.896	.896
ILLUMINATION FACTORS									
Cover Degradation (EOL)	.870	.870	.870	.870	.870	.870	.870	.870	.870
Concentration Ratio (BOL)	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Concentrator Degrad. (EOL)	1.C90	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
	*****	*****	*****	*****	*****	*****	*****	*****	*****
CUM. EOL FACTOR	.885	.885	.885	.885	.885	.885	.885	.885	.885
PHYSICAL CHARACTERISTICS									
Total Number of Cells	1283040	649440	432960	327360	264000	221760	190080	163680	147840
No. of Modules/Panel	4	4	4	4	4	4	4	4	4
No. of Panels/Blanket	15	15	15	15	15	15	15	15	15
Blanket Weight (Kg)	298.0	300.0	300.0	301.0	303.0	304.0	304.0	299.0	304.0
Structure Weight (Kg)	285.0	287.0	287.0	288.0	289.0	290.0	290.0	286.0	290.0
Total Array Weight (Kg)	1477.0	1487.0	1487.0	1492.0	1501.0	1506.0	1506.0	1482.0	1506.0
Solar Cell Area (cm2)	4.000	8.000	12.000	16.000	20.000	24.000	28.000	32.000	36.000
Module Area (M^2)	2.690	2.610	2.610	2.610	2.590	2.610	2.590	2.570	2.600
Concentrator Area (M^2)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Panel Area (M^2)	10.80	10.40	10.50	10.40	10.40	10.50	10.40	10.30	10.40
Blanket Area (M^2)	171.0	166.0	166.0	166.0	165.0	166.0	165.0	163.0	165.0
Total Array Area (M^2)	684.0	664.0	664.0	664.0	660.0	664.0	660.0	652.0	660.0
Power Density (W/M2)	103.17	106.61	106.29	106.98	108.40	108.54	109.44	108.70	109.31
Power/Weight Ratio (W/Kg)	47.78	47.61	47.46	47.61	47.66	47.86	47.96	47.82	47.90
LIFE CYCLE COST (1980$M)									
DDT&E	54.026	46.636	43.654	42.071	41.050	40.326	39.718	39.106	38.845
PRODUCTION	154.360	133.245	124.725	120.203	117.287	115.216	113.481	111.732	110.986
(Solar Cell - $/Cell)	(20.00)	(29.30)	(36.64)	(42.93)	(48.54)	(53.67)	(58.43)	(62.89)	(67.10)
OPERATIONS & MAINTENANCE	.900	.900	.900	.900	.900	.900	.900	.900	.900
	-------	-------	-------	-------	-------	-------	-------	-------	-------
TOTAL LIFE CYCLE COST	209.286	180.781	169.279	163.174	159.237	156.442	154.099	151.738	150.731

Exhibit 1c. Cell Area (Ribbon)

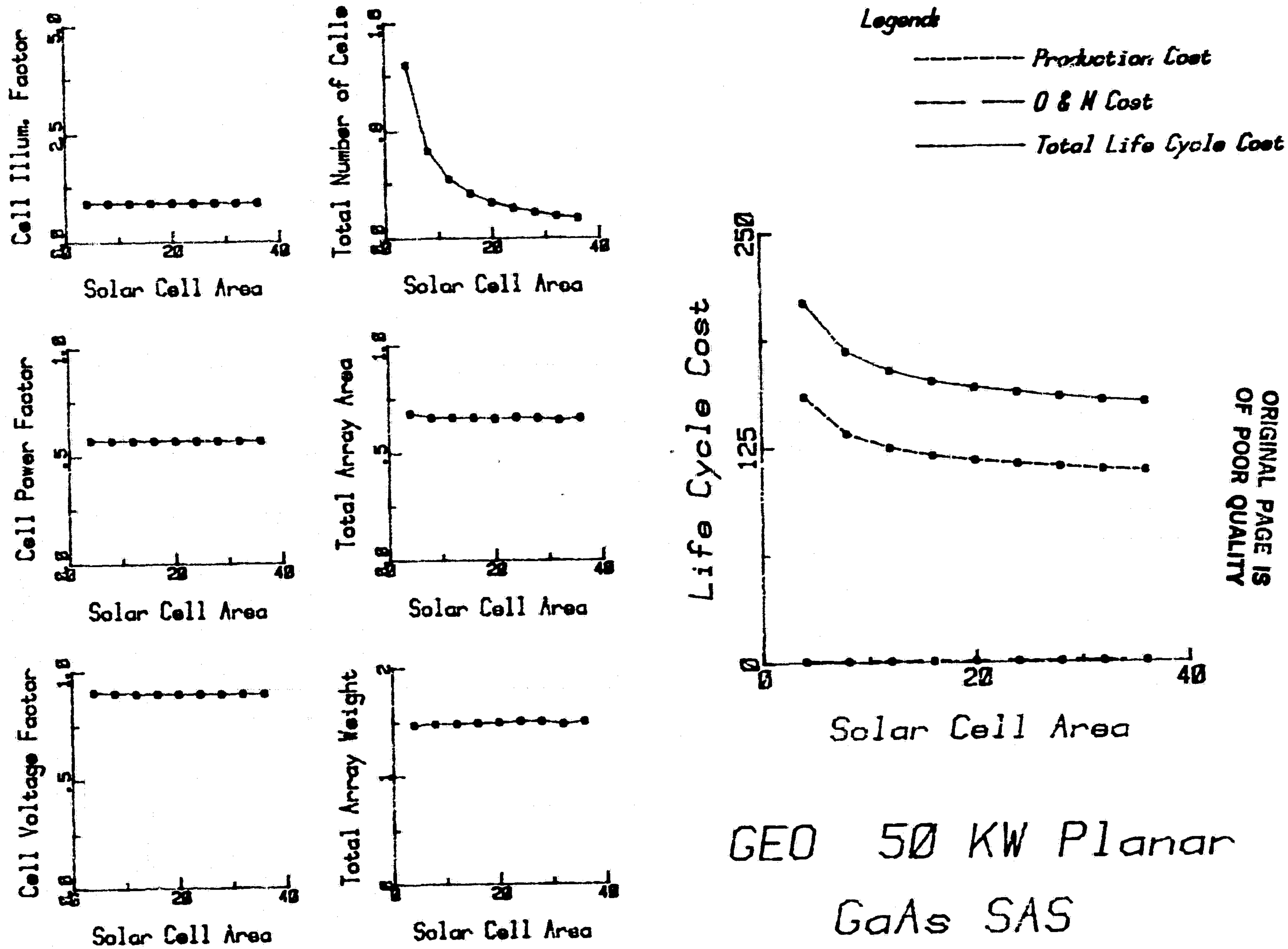

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Exhibit 1c. Cell Area (Ribbon) Continued

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GEO 50 KW Conc. GaAs SAS

ARRAY PERFORMANCE									
No. of Hardware Life Cycles	1	1	1	1	1	1	1	1	1
Total Cell Life Required (Yr)	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0
Total EOL Min. Power (KW)	71.9	72.9	74.0	75.5	72.6	78.3	71.0	81.2	78.2
Total EOL Min. Voltage (V)	183.0	182.0	182.0	181.0	181.0	181.0	181.0	181.0	181.0
BOL Cell Efficiency (%)	18.1	18.1	18.1	18.1	18.1	18.1	18.1	18.1	18.1
BOL Cell Max. Voltage (V)	.843	.843	.843	.843	.843	.843	.843	.843	.843
EOL Cell Power (MW)	218.0	434.0	648.0	864.0	1080.0	1295.0	1509.0	1727.0	1940.0
EOL Cell Voltage (V)	.546	.543	.541	.540	.540	.540	.539	.539	.539
POWER FACTORS									
Radiation	.779	.779	.779	.779	.779	.779	.779	.779	.779
Temperature	.839	.836	.835	.834	.834	.834	.834	.834	.834
Main Bus	.968	.967	.967	.967	.967	.967	.966	.966	.965
	****	****	****	****	****	****	****	****	****
CUM. EOL FACTOR	.478	.476	.474	.474	.474	.474	.473	.474	.473
VOLTAGE FACTORS									
Radiation	.963	.963	.963	.963	.963	.963	.963	.963	.963
Temperature	.726	.721	.719	.718	.718	.718	.717	.718	.718
Main Bus	.968	.967	.967	.967	.967	.967	.966	.966	.965
	****	****	****	****	****	****	****	****	****
CUM. EOL FACTOR	.648	.644	.642	.641	.641	.641	.639	.639	.639
ILLUMINATION FACTORS									
Cover Degradation (EOL)	.870	.870	.870	.870	.870	.870	.870	.870	.870
Concentration Ratio (BOL)	5.000	5.000	5.000	5.000	5.000	5.000	5.000	5.000	5.000
Concentrator Degrad. (EOL)	.960	.960	.960	.960	.960	.960	.960	.960	.960
	*****	*****	*****	*****	*****	*****	*****	*****	*****
CUM. EOL FACTOR	4.247	4.247	4.247	4.247	4.247	4.247	4.247	4.247	4.247
PHYSICAL CHARACTERISTICS									
Total Number of Cells	329280	168000	114240	87360	67200	60480	47040	47040	40320
No. of Modules/Panel	3	3	3	3	3	3	3	3	3
No. of Panels/Blanket	20	20	20	20	20	20	20	20	20
Blanket Weight (Kg)	227.0	224.0	225.0	226.0	224.0	237.0	232.0	251.0	255.0
Structure Weight (Kg)	223.0	221.0	222.0	224.0	220.0	235.0	228.0	248.0	251.0
Total Array Weight (Kg)	1131.0	1117.0	1122.0	1128.0	1116.0	1183.0	1154.6	1252.0	1271.0
Solar Cell Area (cm2)	4.000	8.000	12.000	16.000	20.000	24.000	28.000	32.000	36.000
Module Area (M^2)	.720	.690	.690	.690	.690	.740	.740	.810	.850
Concentrator Area (M^2)	6.53	6.25	6.25	6.25	6.25	6.71	6.71	7.34	7.70
Panel Area (M^2)	10.80	10.40	10.40	10.40	10.40	11.20	11.20	12.20	12.70
Blanket Area (M^2)	226.0	216.0	216.0	216.0	216.0	232.0	232.0	253.0	264.0
Total Array Area (M^2)	904.0	864.0	864.0	864.0	864.0	928.0	928.0	1012.0	1056.0
Power Density (W/M2)	79.41	84.39	85.68	87.36	84.00	84.40	76.49	80.28	74.07
Power/Weight Ratio (W/Kg)	63.47	65.27	65.98	66.91	65.03	66.21	61.51	64.89	61.54
LIFE CYCLE COST (1980$M)									
DDT&E	45.717	43.808	43.099	42.715	42.323	42.389	42.012	42.287	42.164
PRODUCTION	130.619	125.165	123.141	122.043	120.923	121.110	120.033	120.619	120.469
(Solar Cell - $/Cell)	(20.00)	(29.30)	(36.64)	(42.93)	(48.54)	(53.67)	(58.43)	(62.89)	(67.10)
OPERATIONS & MAINTENANCE	.900	.900	.900	.900	.900	.900	.900	.900	.900
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TOTAL LIFE CYCLE COST	177.236	169.873	167.140	165.658	164.146	164.399	162.945	164.006	163.533

Exhibit 1d. Cell Area (Ribbon)

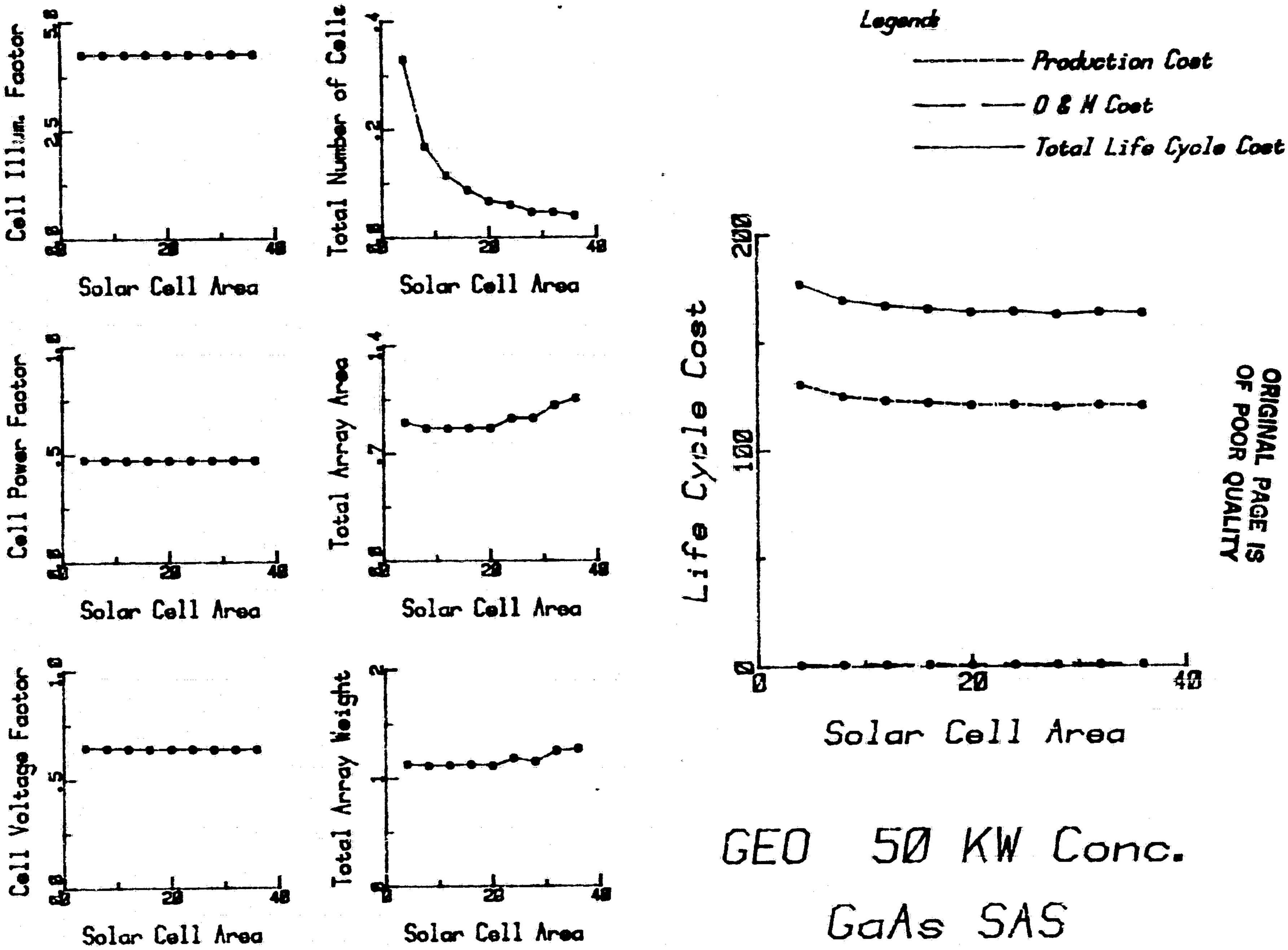

Exhibit 1d. Cell Area (Ribbon) Continued

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LEO 250 KW Planar GaAs SAS

ARRAY PERFORMANCE									
No. of Hardware Life Cycles	1	1	1	1	1	1	1	1	1
Total Cell Life Required (Yr)	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0
Total EOL Min. Power (KW)	650.3	650.5	651.1	653.4	653.0	652.3	661.0	668.2	663.1
Total EOL Min. Voltage (V)	194.0	193.0	215.0	214.0	215.0	214.0	214.0	214.0	214.0
BOL Cell Efficiency (%)	18.1	18.1	18.1	18.1	18.1	18.1	18.1	18.1	18.1
EOL Cell Max. Voltage (V)	.809	.809	.809	.809	.809	.809	.809	.809	.809
EOL Cell Power (MW)	64.0	143.0	254.0	398.0	574.0	781.0	1020.0	1289.0	1588.0
EOL Cell Voltage (V)	.716	.714	.715	.714	.715	.714	.714	.714	.712
POWER FACTORS									
Radiation	.891	.891	.891	.891	.891	.891	.891	.891	.891
Temperature	.984	.982	.981	.981	.980	.980	.980	.980	.979
Main Bus	.971	.971	.975	.976	.976	.977	.976	.975	.975
	****	****	****	****	****	****	****	****	****
CUM. EOL FACTOR	.643	.641	.643	.644	.644	.644	.644	.643	.642
VOLTAGE FACTORS									
Radiation	.968	.968	.968	.968	.968	.968	.968	.968	.968
Temperature	.973	.970	.968	.967	.967	.966	.966	.965	.964
Main Bus	.971	.971	.975	.976	.976	.977	.976	.975	.975
	****	****	****	****	****	****	****	****	****
CUM. EOL FACTOR	.885	.882	.884	.883	.884	.883	.883	.883	.880
ILLUMINATION FACTORS									
Cover Degradation (EOL)	.870	.870	.870	.870	.870	.870	.870	.870	.870
Concentration Ratio (BOL)	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Concentrator Degrad. (EOL)	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
	*****	*****	*****	*****	*****	*****	*****	*****	*****
CUM. EOL FACTOR	.885	.885	.885	.885	.885	.885	.885	.885	.885
PHYSICAL CHARACTERISTICS									
Total Number of Cells	10160640	4548960	2563200	1641600	1137600	835200	648000	518400	417600
No. of Modules/Panel	15	15	15	15	15	.15	15	15	15
No. of Panels/Blanket	36	36	24	24	24	24	24	24	24
Blanket Weight (Kg)	2032.0	2033.0	1953.0	1947.0	1940.0	1935.0	1962.0	1982.0	1969.0
Structure Weight (Kg)	2327.0	2311.0	2184.0	2167.0	2151.0	2144.0	2190.0	2220.0	2206.0
Total Array Weight (Kg)	10455.0	10443.0	9996.0	9955.0	9911.0	9884.0	10038.C	10148.0	10082.0
Solar Cell Area (cm2)	4.000	9.000	16.000	25.000	36.000	49.000	64.000	81.000	100.000
Module Area (M^2)	2.430	2.310	3.350	3.200	3.130	3.090	3.220	3.260	3.240
Concentrator Area (M^2)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Panel Area (M^2)	36.20	34.50	50.00	47.80	46.80	46.10	48.10	48.70	48.30
Blanket Area (M^2)	1337.0	1275.0	1227.0	1175.0	1150.0	1135.0	1183.0	1197.0	1187.0
Total Array Area (M^2)	5348.0	5100.0	4908.0	4700.0	4600.0	4540.0	4732.0	4788.0	4748.0
Power Density (W/M2)	121.59	127.55	132.65	139.01	141.95	143.68	139.68	139.56	139.67
Power/Weight Ratio (W/Kg)	62.20	62.29	65.13	65.63	65.88	65.99	65.85	65.85	65.78
LIFE CYCLE COST (1980$M)									
DDT&E	308.218	241.513	170.508	154.442	144.145	137.106	132.671	129.246	125.836
PRODUCTION	880.622	690.036	487.165	441.263	411.843	391.730	379.059	369.275	359.532
(Solar Cell - $/Cell)	(20.00)	(31.27)	(42.93)	(54.89)	(67.10)	(79.53)	(92.13)	(104.90)	(117.81)
OPERATIONS & MAINTENANCE	192.123	192.220	165.408	164.998	164.588	164.393	166.013	167.288	166.726
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TOTAL LIFE CYCLE COST	1380.963	1123.769	823.081	760.703	720.576	693.229	677.743	665.809	652.094

Exhibit 2a. Cell Area (Square)

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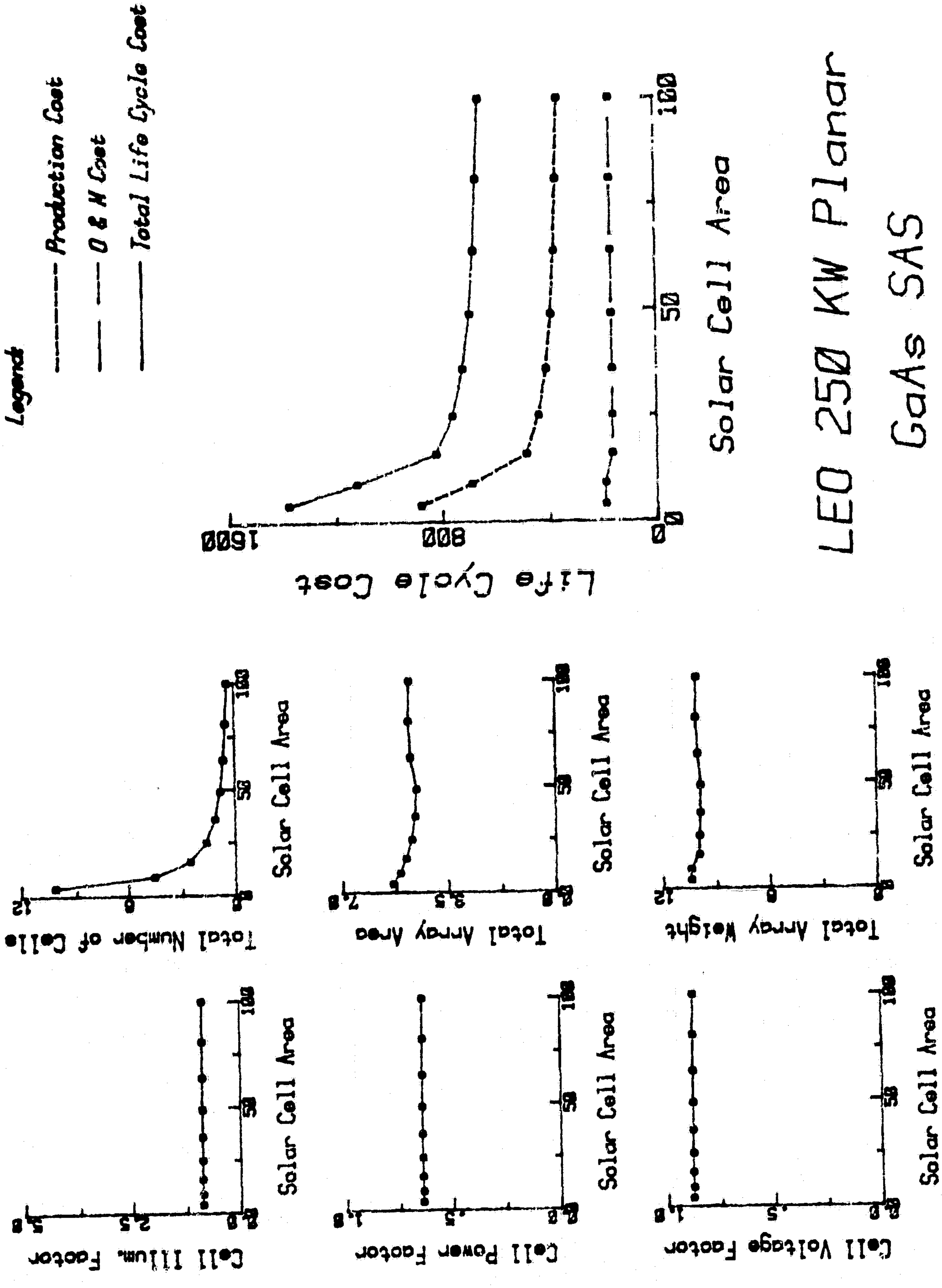

Exhibit 2a. Cell Area (Square) Continued

LEO 250 KW Conc. GaAs SAS

ARRAY PERFORMANCE									
No. of Hardware Life Cycles	1	1	1	1	1	1	1	1	1
Total Cell Life Required (Yr)	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0
Total EOL Min. Power (KW)	651.0	651.2	663.6	674.2	686.2	662.0	719.0	725.7	675.0
Total EOL Min. Voltage (V)	198.0	196.0	195.0	193.0	193.0	193.0	193.0	193.0	193.0
BOL Cell Efficiency (%)	18.1	18.1	18.1	18.1	18.1	18.1	18.1	18.1	18.1
BOL Cell Max. Voltage (V)	.843	.843	.843	.843	.843	.843	.843	.843	.843
EOL Cell Power (MW)	247.0	552.0	973.0	1524.0	2190.0	2993.0	3901.0	4928.0	6104.0
EOL Cell Voltage (V)	.517	.511	.507	.503	.502	.503	.502	.502	.503
POWER FACTORS									
Radiation	.891	.891	.891	.891	.891	.891	.891	.891	.891
Temperature	.831	.827	.824	.824	.824	.834	.823	.823	.823
Main Bus	.928	.927	.924	.926	.924	.928	.926	.925	.927
	****	****	****	****	****	****	****	****	****
CUM. EOL FACTOR	.520	.516	.512	.513	.512	.514	.513	.512	.514
VOLTAGE FACTORS									
Radiation	.968	.968	.968	.968	.968	.968	.968	.968	.968
Temperature	.712	.706	.700	.701	.700	.700	.700	.699	.699
Main Bus	.928	.927	.924	.926	.924	.928	.926	.925	.927
	****	****	****	****	****	****	****	****	****
CUM. EOL FACTOR	.613	.606	.601	.597	.595	.597	.595	.596	.597
ILLUMINATION FACTORS									
Cover Degradation (EOL)	.870	.870	.870	.870	.870	.870	.870	.870	.870
Concentration Ratio (BOL)	5.000	5.000	5.000	5.000	5.000	5.000	5.000	5.000	5.000
Concentrator Degrad. (EOL)	.960	.960	.960	.960	.960	.960	.960	.960	.960
	*****	*****	*****	*****	*****	*****	*****	*****	*****
CUM. EOL FACTOR	4.247	4.247	4.247	4.247	4.247	4.247	4.247	4.247	4.247
PHYSICAL CHARACTERISTICS									
Total Number of Cells	2635776	1179648	681984	442368	313344	221184	184320	147456	110592
No. of Modules/Panel	8	8	8	8	8	8	8	8	8
No. of Panels/Blanket	48	48	48	48	48	48	48	48	48
Blanket Weight (Kg)	1495.0	1445.0	1508.0	1441.0	1522.0	1381.0	1488.0	1527.0	1495.0
Structure Weight (Kg)	1735.0	1689.0	1762.0	1706.0	1795.0	1638.0	1783.0	1828.0	1758.0
Total Array Weight (Kg)	7715.0	7469.0	7794.0	7470.0	7883.0	7162.0	7735.0	7936.0	7738.0
Solar Cell Area (cm2)	4.000	9.000	16.000	25.000	36.000	49.000	64.000	81.000	100.000
Module Area (M^2)	.880	.830	.880	.810	.880	.760	.830	.860	.860
Concentrator Area (M^2)	7.98	7.52	7.98	7.34	7.98	6.89	7.52	7.79	7.79
Panel Area (M^2)	35.50	33.30	35.50	32.60	35.50	30.40	33.30	34.70	34.70
Blanket Area (M^2)	1743.0	1633.0	1743.0	1598.0	1743.0	1494.0	1633.0	1700.0	1700.0
Total Array Area (M^2)	6972.0	6532.0	6972.0	6392.0	6972.0	5976.0	6532.0	6800.0	6800.0
Power Density (W/M2)	93.38	99.69	95.18	105.47	98.43	110.78	110.08	106.86	99.27
Power/Weight Ratio (W/Kg)	84.39	87.18	85.14	90.25	87.05	92.43	92.96	91.56	87.24
LIFE CYCLE COST (1980$M)									
DDT&E	184.642	166.799	160.420	155.628	153.993	150.185	150.683	150.053	148.302
PRODUCTION	527.549	476.568	458.342	444.650	439.980	429.099	430.522	428.724	423.720
(Solar Cell - $/Cell)	(20.00)	(31.27)	(42.93)	(54.89)	(67.10)	(79.53)	(92.13)	(104.90)	(117.81)
OPERATIONS & MAINTENANCE	183.166	180.834	183.972	180.843	184.802	177.894	183.438	185.221	183.286
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TOTAL LIFE CYCLE COST	895.357	824.201	802.734	781.121	778.775	757.178	764.643	763.998	755.308

Exhibit 2b. Cell Area (Square)

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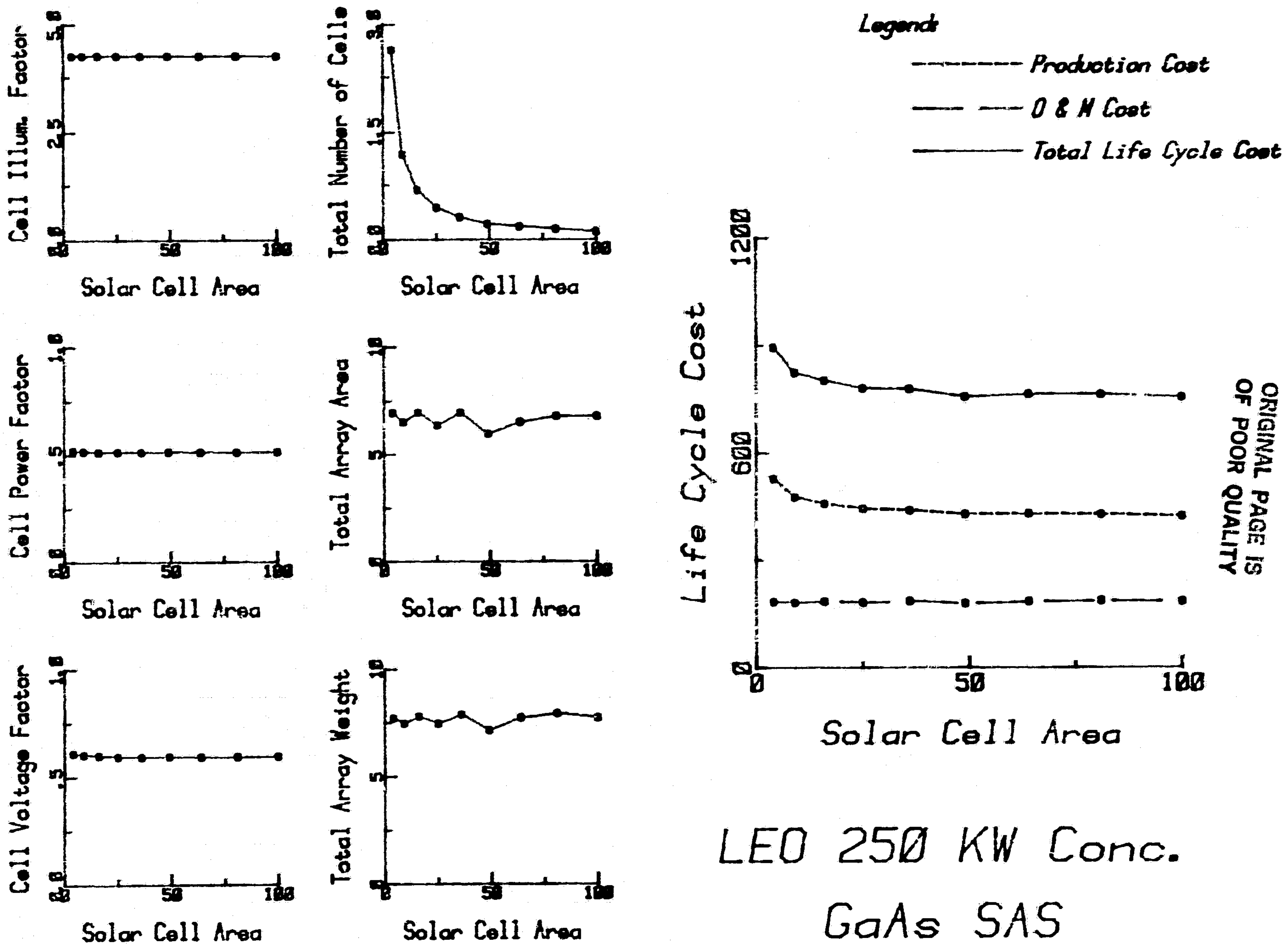

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Exhibit 2b. Cell Area (Square) Continued

GEO 50 KW Planar GaAs SAS

ARRAY PERFORMANCE									
No. of Hardware Life Cycles	1	1	1	1	1	1	1	1	1
Total Cell Life Required (Yr)	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0
Total EOL Min. Power (KW)	70.6	70.8	71.0	71.6	72.3	73.7	73.4	75.4	71.5
Total EOL Min. Voltage (V)	193.0	193.0	192.0	192.0	192.0	192.0	192.0	192.0	192.0
EOL Cell Efficiency (%)	18.1	18.1	18.1	18.1	18.1	18.1	18.1	18.1	18.1
EOL Cell Max. Voltage (V)	.809	.809	.809	.809	.809	.809	.809	.809	.809
EOL Cell Power (MW)	55.0	123.0	217.0	339.0	489.0	665.0	869.0	1098.0	1354.0
EOL Cell Voltage (V)	.732	.730	.728	.726	.726	.726	.725	.725	.725
POWER FACTORS									
Radiation	.779	.779	.779	.779	.779	.779	.779	.779	.779
Temperature	.989	.987	.986	.985	.984	.984	.984	.983	.983
Main Bus	.989	.989	.989	.989	.989	.989	.989	.988	.989
	****	****	****	****	****	****	****	****	****
CUM. EOL FACTOR	.575	.574	.573	.572	.572	.572	.572	.571	.571
VOLTAGE FACTORS									
Radiation	.963	.963	.963	.963	.963	.963	.963	.963	.963
Temperature	.981	.978	.976	.974	.973	.973	.972	.972	.972
Main Bus	.989	.989	.989	.989	.989	.989	.989	.988	.989
	****	****	****	****	****	****	****	****	****
CUM. EOL FACTOR	.905	.902	.900	.898	.897	.897	.896	.896	.896
ILLUMINATION FACTORS									
Cover Degradation (EOL)	.870	.870	.870	.870	.870	.870	.870	.870	.870
Concentration Ratio (EOL)	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Concentrator Degrad. (EOL)	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
	*****	*****	*****	*****	*****	*****	*****	*****	*****
CUM. EOL FACTOR	.885	.885	.885	.885	.885	.885	.885	.885	.885
PHYSICAL CHARACTERISTICS									
Total Number of Cells	1283040	575520	327360	211200	147840	110880	84480	68640	52800
No. of Modules/Panel	4	4	4	4	4	4	4	4	4
No. of Panels/Blanket	15	15	15	15	15	15	15	15	15
Blanket Weight (Kg)	298.0	299.0	301.0	301.0	303.0	306.0	306.0	312.0	301.0
Structure Weight (Kg)	285.0	285.0	286.0	287.0	288.0	294.0	292.0	300.0	287.0
Total Array Weight (Kg)	1477.0	1481.0	1490.0	1491.0	1500.0	1518.0	1516.0	1548.0	1491.0
Solar Cell Area (cm2)	4.000	9.000	16.000	25.000	36.000	49.000	64.000	81.000	100.000
Module Area (M^2)	2.690	2.570	2.540	2.440	2.480	2.610	2.480	2.720	2.360
Concentrator Area (M^2)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Panel Area (M^2)	10.80	10.30	10.20	9.80	9.90	10.40	9.90	10.90	9.40
Blanket Area (M^2)	171.0	164.0	162.0	156.0	158.0	166.0	158.0	172.0	151.0
Total Array Area (M^2)	684.0	656.0	648.0	624.0	632.0	664.0	632.0	688.0	604.0
Power Density (W/M2)	103.17	107.91	109.62	114.74	114.39	111.05	116.16	109.54	118.36
Power/Weight Ratio (W/Kg)	47.78	47.80	47.67	48.02	48.20	48.58	48.42	48.69	47.95
LIFE CYCLE COST (1980$M)									
DDT&E	54.026	45.634	42.067	40.077	38.834	38.064	37.355	37.001	36.309
PRODUCTION	154.360	130.382	120.190	114.507	110.954	108.754	106.729	105.717	103.741
(Solar Cell - $/Cell)	(20.00)	(31.27)	(42.93)	(54.89)	(67.10)	(79.53)	(92.13)	(104.90)	(117.81)
OPERATIONS & MAINTENANCE	.900	.900	.900	.900	.900	.900	.900	.900	.900
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TOTAL LIFE CYCLE COST	209.286	176.916	163.157	155.484	150.688	147.718	144.984	143.618	140.950

Exhibit 2c. Cell Area (Square)

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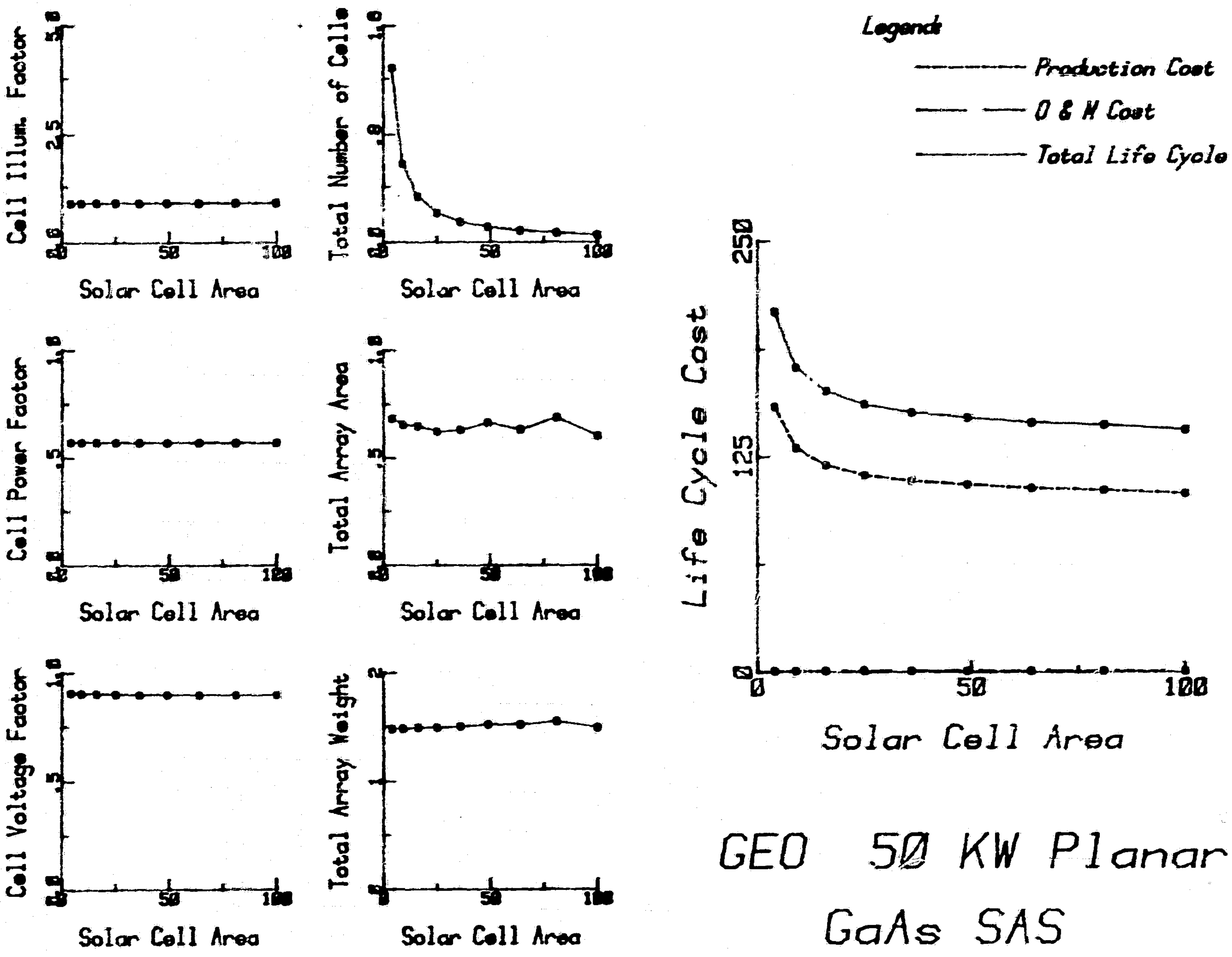

Exhibit 2c. Cell Area (Square) Continued

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GEO 50 KW Conc. GaAs SAS

ARRAY PERFORMANCE									
No. of Hardware Life Cycles	1	1	1	1	1	1	1	1	1
Total Cell Life Required (Yr)	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0
Total EOL Min. Power (KW)	71.8	72.0	75.5	72.4	78.2	71.0	92.5	93.9	77.4
Total EOL Min. Voltage (V)	183.0	182.0	181.0	181.0	181.0	180.0	180.0	193.0	192.0
BOL Cell Efficiency (%)	18.1	18.1	18.1	18.1	18.1	18.1	18.1	18.1	18.1
BOL Cell Max. Voltage (V)	.843	.843	.843	.843	.843	.843	.843	.843	.843
EOL Cell Power (MW)	218.0	487.0	864.0	1347.0	1940.0	2641.0	3441.0	4346.0	5374.0
EOL Cell Voltage (V)	.546	.541	.540	.538	.538	.537	.536	.535	.534
POWER FACTORS									
Radiation	.779	.779	.779	.779	.779	.779	.779	.779	.779
Temperature	.839	.835	.833	.832	.831	.831	.830	.830	.830
Main Bus	.968	.968	.968	.968	.968	.968	.967	.965	.967
	****	****	****	****	****	****	****	****	****
CUM. EOL FACTOR	.478	.475	.474	.473	.473	.473	.472	.471	.472
VOLTAGE FACTORS									
Radiation	.963	.963	.963	.963	.963	.963	.963	.963	.963
Temperature	.726	.720	.717	.714	.713	.712	.712	.711	.710
Main Bus	.968	.968	.968	.968	.968	.968	.967	.965	.967
	****	****	****	****	****	****	****	****	****
CUM. EOL FACTOR	.648	.642	.640	.638	.638	.637	.636	.635	.634
ILLUMINATION FACTORS									
Cover Degradation (EOL)	.870	.870	.870	.870	.870	.870	.870	.870	.870
Concentration Ratio (BOL)	5.000	5.000	5.000	5.000	5.000	5.000	5.000	5.000	5.000
Concentrator Degrad. (EOL)	.960	.960	.960	.960	.960	.960	.960	.960	.960
	*****	*****	*****	*****	*****	*****	*****	*****	*****
CUM. EOL FACTOR	4.247	4.247	4.247	4.247	4.247	4.247	4.247	4.247	4.247
PHYSICAL CHARACTERISTICS									
Total Number of Cells	329280	147840	87360	53760	40320	26880	26880	21600	14400
No. of Modules/Panel	3	3	3	3	3	3	3	3	3
No. of Panels/Blanket	20	20	20	20	20	20	20	20	20
Blanket Weight (Kg)	227.0	216.0	230.0	211.0	224.0	213.0	262.0	267.0	227.0
Structure Weight (Kg)	223.0	214.0	227.0	209.0	223.0	210.0	263.0	268.0	224.0
Total Array Weight (Kg)	1131.0	1078.0	1147.0	1053.0	1119.0	1062.0	1311.0	1336.0	1132.0
Solar Cell Area (cm2)	4.000	9.000	16.000	25.000	36.000	49.000	64.000	81.000	100.000
Module Area (M^2)	.720	.660	.720	.620	.670	.640	.830	.860	.690
Concentrator Area (M^2)	6.53	5.98	6.53	5.62	6.07	5.80	7.52	7.79	6.25
Panel Area (M^2)	10.80	9.80	10.80	9.40	10.10	9.60	12.50	13.00	10.40
Blanket Area (M^2)	226.0	205.0	226.0	196.0	211.0	201.0	259.0	269.0	216.0
Total Array Area (M^2)	904.0	820.0	904.0	784.0	844.0	804.0	1036.0	1076.0	864.0
Power Density (W/M2)	79.41	87.80	83.50	92.36	92.68	88.30	89.28	87.24	89.57
Power/Weight Ratio (W/Kg)	63.47	66.79	65.81	68.77	69.90	66.85	70.55	70.26	68.36
LIFE CYCLE COST (1980$M)									
DDT&E	45.713	43.463	42.759	41.958	41.862	41.395	42.000	41.909	41.206
PRODUCTION	130.619	124.181	122.169	119.879	119.606	118.272	120.000	119.740	117.731
(Solar Cell - $/Cell)	(20.00)	(31.27)	(42.93)	(54.89)	(67.10)	(79.53)	(92.13)	(104.90)	(117.81)
OPERATIONS & MAINTENANCE	.900	.900	.900	.900	.900	.900	.900	.900	.900
	-------	-------	-------	-------	-------	-------	-------	-------	-------
TOTAL LIFE CYCLE COST	177.236	168.544	165.828	162.737	162.368	160.567	162.900	162.549	159.837

Exhibit 2d. Cell Area (Square)

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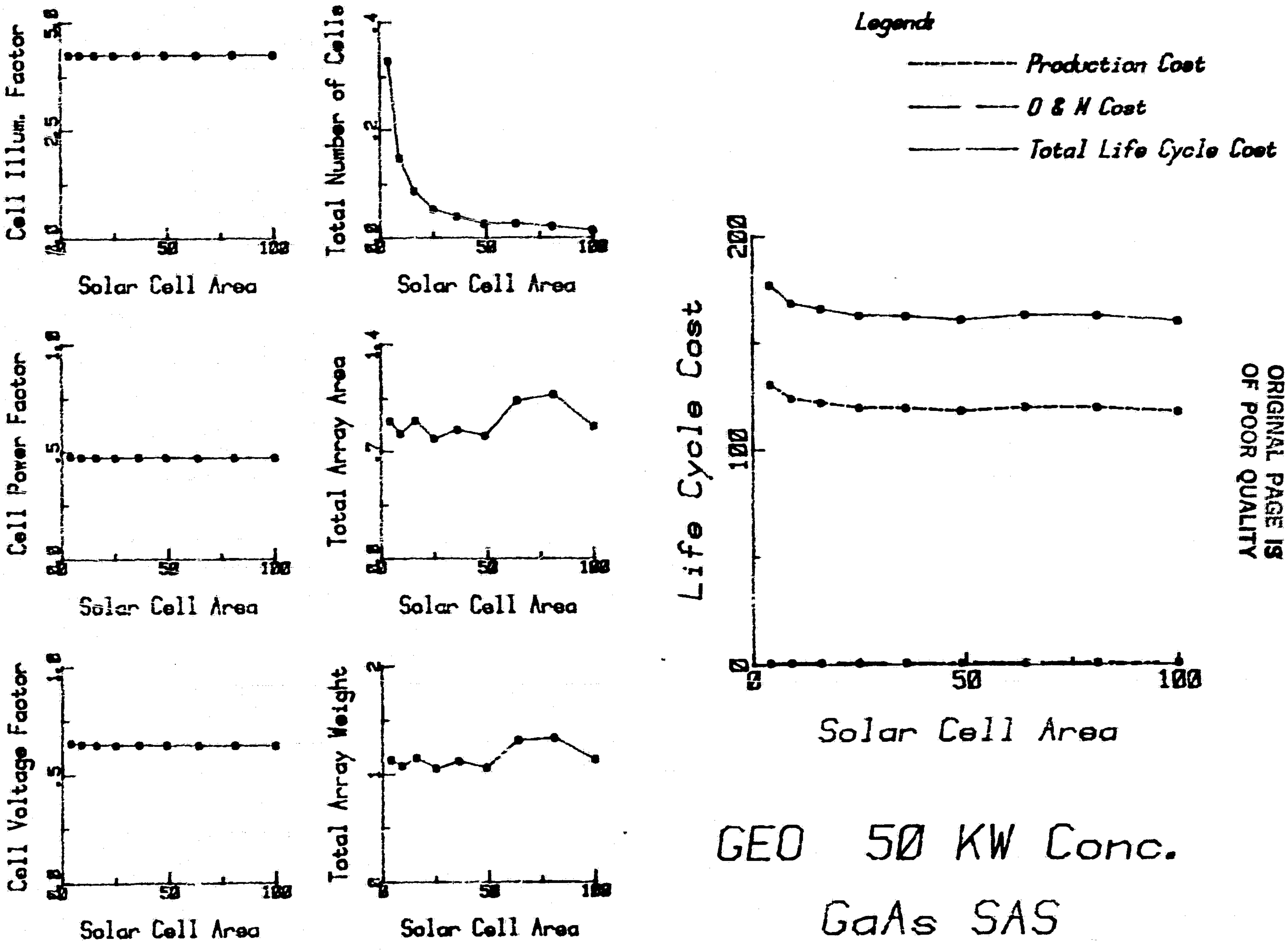

Exhibit 2d. Cell Area (Square) Continued

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LEO 250 KW Conc. GaAs SAS

ARRAY PERFORMANCE									
No. of Hardware Life Cycles	1	1	1	1	1	1	1	1	1
Total Cell Life Required (Yr)	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0
Total EOL Min. Power (KW)	650.3	650.8	653.2	652.9	652.5	654.1	654.0	656.6	655.9
Total EOL Min. Voltage (V)	311.0	227.0	183.0	243.0	210.0	202.0	195.0	210.0	203.0
BOL Cell Efficiency (%)	18.1	18.1	18.1	18.1	18.1	18.1	18.1	18.1	18.1
BOL Cell Max. Voltage (V)	.809	.813	.817	.822	.826	.830	.835	.839	.843
EOL Cell Power (MW)	128.0	177.0	225.0	277.0	320.0	364.0	407.0	450.0	488.0
EOL Cell Voltage (V)	.722	.676	.634	.614	.582	.560	.542	.524	.507
POWER FACTORS									
Radiation	.891	.891	.891	.891	.891	.891	.891	.891	.891
Temperature	.983	.952	.926	.905	.886	.869	.854	.841	.828
Main Bus	.982	.968	.950	.956	.941	.936	.931	.929	.921
	****	****	****	****	****	****	****	****	****
CUM. EOL FACTOR	.649	.620	.592	.582	.561	.547	.535	.526	.513
VOLTAGE FACTORS									
Radiation	.968	.968	.968	.968	.968	.968	.968	.968	.968
Temperature	.970	.919	.875	.838	.806	.778	.752	.729	.708
Main Bus	.982	.968	.950	.956	.941	.936	.931	.929	.921
	****	****	****	****	****	****	****	****	****
CUM. EOL FACTOR	.892	.831	.776	.747	.705	.675	.649	.625	.602
ILLUMINATION FACTORS									
Cover Degradation (EOL)	.870	.870	.870	.870	.870	.870	.870	.870	.870
Concentration Ratio (BOL)	1.000	1.500	2.000	2.500	3.000	3.500	4.000	4.500	5.000
Concentrator Degrad. (EOL)	1.000	.960	.960	.960	.960	.960	.960	.960	.960
	*****	*****	*****	*****	*****	*****	*****	*****	*****
CUM. EOL FACTOR	.885	1.274	1.699	2.123	2.548	2.973	3.398	3.822	4.247
PHYSICAL CHARACTERISTICS									
Total Number of Cells	5080320	3677184	2903040	2356992	2039040	1797120	1607040	1459200	1344000
No. of Modules/Panel	18	14	12	11	10	9	9	8	8
No. of Panels/Blanket	72	72	72	72	72	60	60	60	60
Blanket Weight (Kg)	2256.0	2263.0	2008.0	1822.0	1768.0	1620.0	1568.0	1495.0	1510.0
Structure Weight (Kg)	2315.0	2422.0	2302.0	2013.0	2028.0	1883.0	1837.0	1756.0	1775.0
Total Array Weight (Kg)	11339.0	11474.0	10334.0	9301.0	9100.0	8363.0	8109.0	7736.0	7815.0
Solar Cell Area (cm2)	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000
Module Area (M^2)	.960	.880	.810	.720	.720	.810	.720	.720	.690
Concentrator Area (M^2)	0.00	2.39	2.94	3.26	3.92	5.14	5.22	5.87	6.25
Panel Area (M^2)	17.30	18.50	19.30	19.80	21.60	25.50	26.00	26.00	27.70
Blanket Area (M^2)	1283.0	1375.0	1435.0	1467.0	1598.0	1565.0	1599.0	1593.0	1697.0
Total Array Area (M^2)	5172.0	5500.0	5740.0	5868.0	6392.0	6260.0	6396.0	6372.0	6788.0
Power Density (W/M2)	125.73	118.34	113.80	111.26	102.08	104.49	102.26	103.05	96.62
Power/Weight Ratio (W/Kg)	57.35	56.72	63.21	70.19	71.70	78.22	80.66	84.88	83.92
LIFE CYCLE COST (1980$M)									
DDT&E	399.707	338.349	303.154	281.504	266.091	218.420	214.073	203.216	201.079
PRODUCTION	1142.021	966.712	866.153	804.298	760.259	624.056	611.636	580.618	574.510
(Solar Cell - $/Cell)	(29.30)	(29.30)	(29.30)	(29.30)	(29.30)	(29.30)	(29.30)	(29.30)	(29.30)
OPERATIONS & MAINTENANCE	272.038	275.006	260.994	250.559	247.422	215.226	212.006	208.825	209.044
	--------	--------	--------	--------	--------	--------	--------	--------	--------
TOTAL LIFE CYCLE COST	1813.766	1580.067	1430.301	1336.361	1273.772	1057.702	1037.715	992.659	984.633

Exhibit 3a. Concentration Ratio

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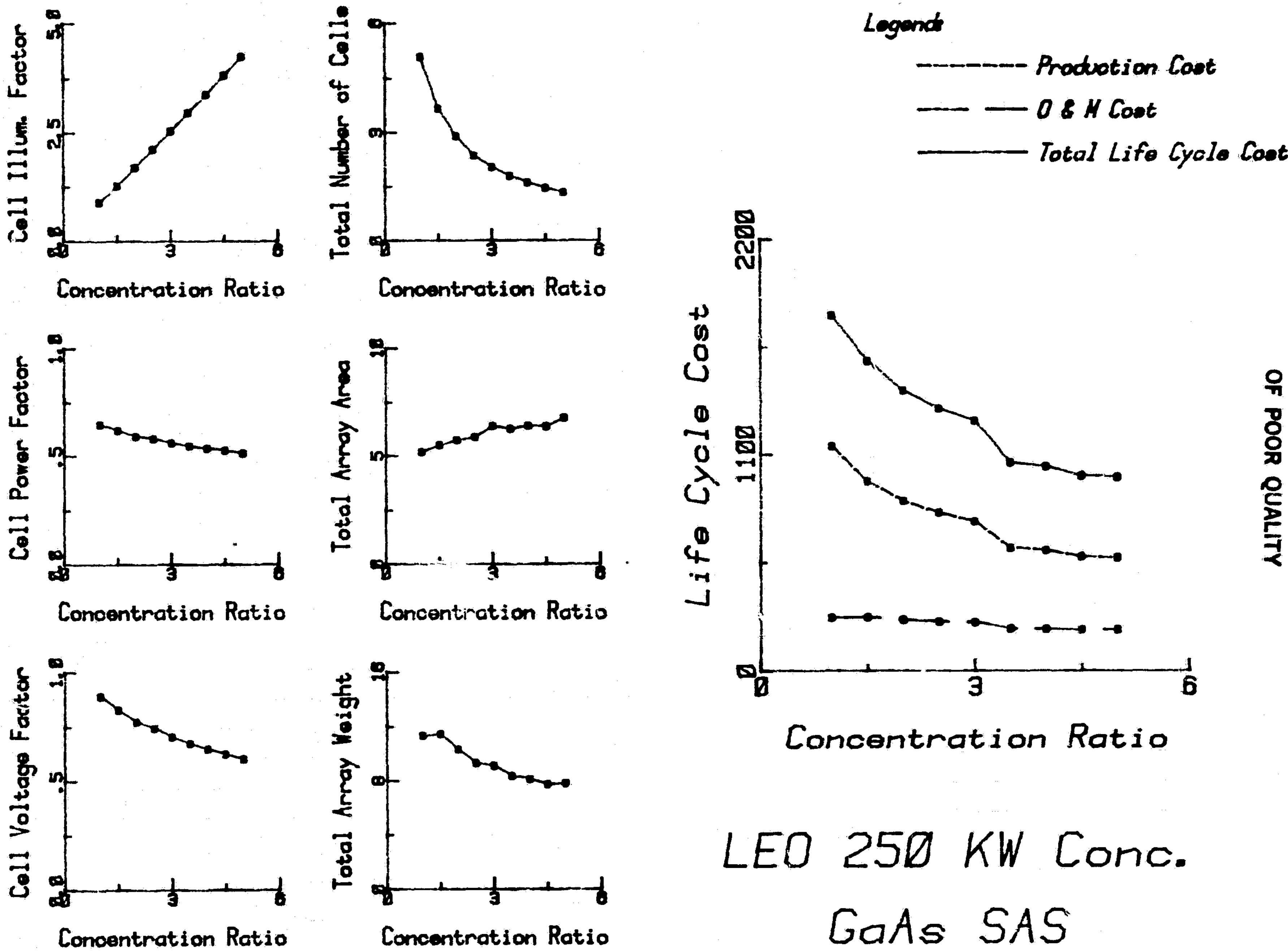

Exhibit 3a. Concentration Ratio Continued

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GEO 50 KW Conc. GaAs SAS

ARRAY PERFORMANCE									
No. of Hardware Life Cycles	1	1	1	1	1	1	1	1	1
Total Cell Life Required (Yr)	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0
Total EOL Min. Power (KW)	70.9	71.1	71.1	71.9	72.0	71.6	72.2	71.9	72.9
Total EOL Min. Voltage (V)	210.0	208.0	190.0	262.0	183.0	194.0	193.0	187.0	183.0
BOL Cell Efficiency (%)	18.1	18.1	18.1	18.1	18.1	18.1	18.1	18.1	18.1
BOL Cell Max. Voltage (V)	.809	.813	.817	.822	.826	.830	.835	.839	.843
EOL Cell Power (MW)	109.0	152.0	196.0	239.0	279.0	319.0	358.0	396.0	434.0
EOL Cell Voltage (V)	.729	.692	.659	.633	.609	.588	.574	.557	.544
POWER FACTORS									
Radiation	.779	.779	.779	.779	.779	.779	.779	.779	.779
Temperature	.987	.958	.932	.910	.892	.876	.861	.848	.836
Main Bus	.988	.985	.980	.979	.973	.972	.970	.970	.968
	****	****	****	****	****	****	****	****	****
CUM. EOL FACTOR	.573	.555	.537	.524	.511	.500	.491	.483	.476
VOLTAGE FACTORS									
Radiation	.963	.963	.963	.963	.963	.963	.963	.963	.963
Temperature	.978	.928	.884	.848	.817	.788	.764	.741	.721
Main Bus	.986	.985	.980	.979	.973	.972	.970	.970	.968
	****	****	****	****	****	****	****	****	****
CUM. EOL FACTOR	.901	.851	.806	.770	.737	.709	.687	.664	.645
ILLUMINATION FACTORS									
Cover Degradation (EOL)	.870	.870	.870	.870	.870	.870	.870	.870	.870
Concentration Ratio (BOL)	1.000	1.500	2.000	2.500	3.000	3.500	4.000	4.500	5.000
Concentrator Degrad. (EOL)	1.000	.960	.960	.960	.960	.960	.960	.960	.960
	*****	*****	*****	*****	*****	*****	*****	*****	*****
CUM. EOL FACTOR	.885	1.274	1.699	2.123	2.548	2.973	3.398	3.822	4.247
PHYSICAL CHARACTERISTICS									
Total Number of Cells	650880	468000	362880	300800	258000	224400	201600	181440	168000
No. of Modules/Panel	6	5	4	4	3	3	3	3	3
No. of Panels/Blanket	30	30	30	25	25	25	20	20	20
Blanket Weight (Kg)	330.0	333.0	288.0	266.0	248.0	236.0	227.0	220.0	224.0
Structure Weight (Kg)	312.0	313.0	278.0	256.0	245.0	232.0	223.0	217.0	221.0
Total Array Weight (Kg)	1632.0	1645.0	1430.0	1320.0	1237.0	1176.0	1131.0	1057.0	1117.0
Solar Cell Area (cm2)	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000
Module Area (M^2)	.880	.770	.720	.720	.850	.720	.810	.720	.690
Concentrator Area (M^2)	0.00	2.09	2.61	3.26	4.62	4.57	5.87	5.87	6.25
Panel Area (M^2)	5.30	5.70	5.70	7.20	7.60	7.60	9.70	9.70	10.40
Blanket Area (M^2)	169.0	182.0	181.0	188.0	197.0	197.0	203.0	203.0	216.0
Total Array Area (M^2)	676.0	728.0	724.0	752.0	788.0	788.0	812.0	812.0	864.0
Power Density (W/M2)	104.95	97.71	98.24	95.60	91.35	90.85	88.88	88.49	84.39
Power/Weight Ratio (W/Kg)	43.47	43.24	49.74	54.46	58.19	60.87	63.81	65.50	65.27
LIFE CYCLE COST (1980$M)									
DDT&E	82.591	75.763	69.945	58.770	55.031	54.227	44.522	44.046	43.808
PRODUCTION	235.974	216.467	199.844	167.913	157.230	154.934	127.207	125.847	125.165
(Solar Cell – $/Cell)	(29.30)	(29.30)	(29.30)	(29.30)	(29.30)	(29.30)	(29.30)	(29.30)	(29.30)
OPERATIONS & MAINTENANCE	.900	.900	.900	.900	.900	.900	.900	.900	.900
	--------	--------	--------	--------	--------	--------	--------	--------	--------
TOTAL LIFE CYCLE COST	319.465	293.130	270.689	227.583	213.161	210.061	172.629	170.793	169.873

Exhibit 3b. Concentration Ratio

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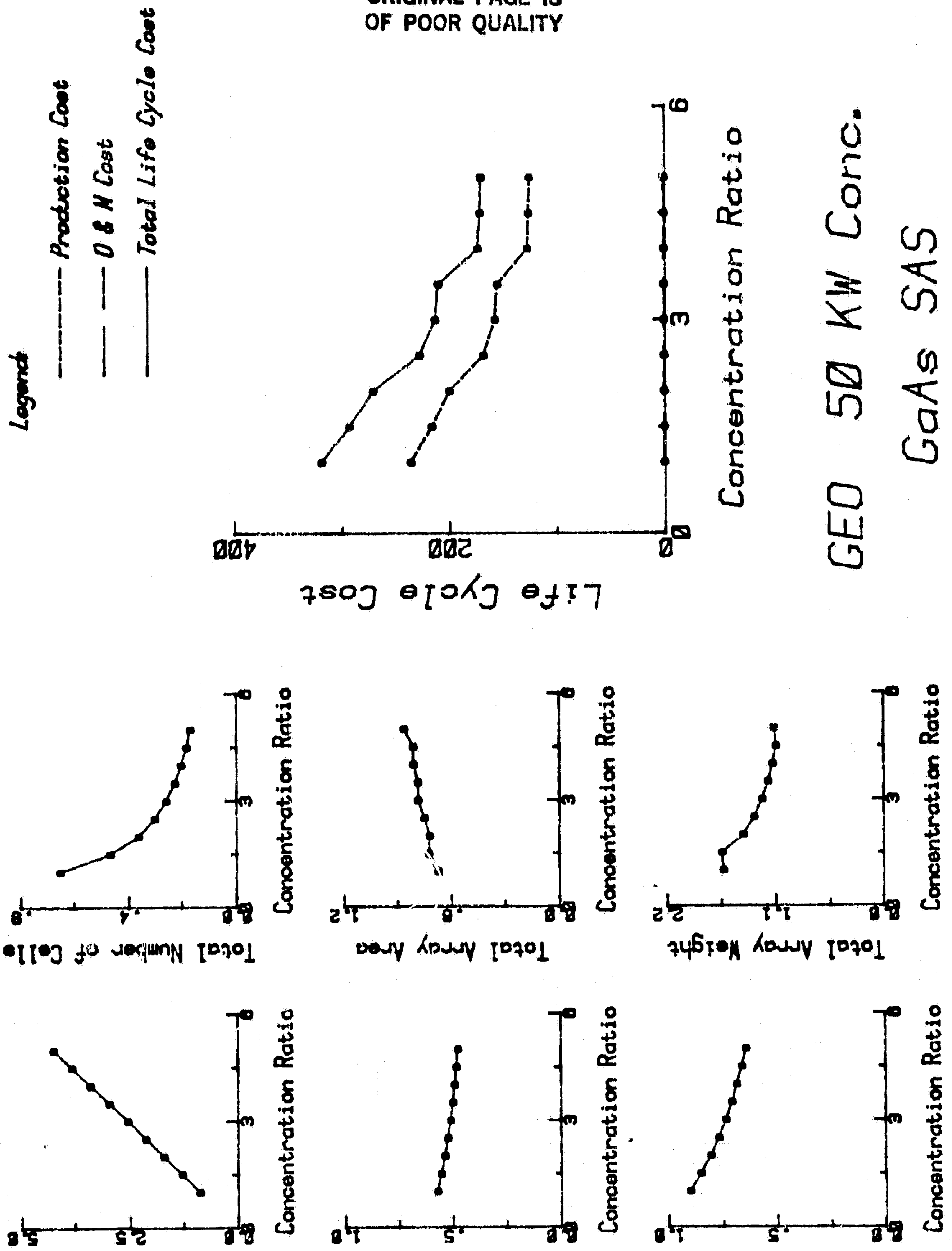

Exhibit 3b. Concentration Ratio Continued

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LEO 250 KW Planar GaAs SAS

ARRAY PERFORMANCE									
No. of Hardware Life Cycles	1	1	1	1	1	1	1	1	1
Total Cell Life Required (Yr)	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0
Total EOL Min. Power (KW)	653.3	650.9	653.5	650.3	651.3	652.3	653.9	653.5	650.3
Total EOL Min. Voltage (V)	306.0	219.0	210.0	201.0	191.0	183.0	233.0	221.0	210.0
BOL Cell Efficiency (%)	18.1	18.1	18.1	18.1	18.1	18.1	18.1	18.1	18.1
BOL Cell Max. Voltage (V)	.810	.810	.810	.810	.810	.810	.810	.810	.810
EOL Cell Power (mW)	139.0	135.0	132.0	128.0	125.0	121.0	119.0	116.0	112.0
EOL Cell Voltage (V)	.849	.809	.777	.742	.708	.675	.647	.615	.582
Avg. Temp. (Deg-K @ Min Ill)	208.1	238.4	266.6	293.5	319.8	345.7	371.3	396.8	422.2
POWER FACTORS									
Radiation	.891	.891	.891	.891	.891	.891	.891	.891	.891
Temperature	1.089	1.059	1.031	1.004	.978	.952	.927	.901	.876
Main Bus	.960	.963	.961	.961	.960	.959	.967	.966	.965
	****	****	****	****	****	****	****	****	****
CUM. EOL FACTOR	.703	.685	.667	.649	.632	.614	.602	.585	.568
VOLTAGE FACTORS									
Radiation	.968	.968	.968	.968	.968	.968	.968	.968	.968
Temperature	1.152	1.101	1.053	1.007	.963	.919	.875	.832	.789
Main Bus	.960	.963	.961	.961	.960	.959	.967	.966	.965
	****	****	****	****	****	****	****	****	****
CUM. EOL FACTOR	1.048	.999	.959	.916	.874	.833	.799	.759	.719
ILLUMINATION FACTORS									
Cover Degradation (EOL)	.870	.870	.870	.870	.870	.870	.870	.870	.870
Concentration Ratio (BOL)	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Concentrator Degrad. (EOL)	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
	*****	*****	*****	*****	*****	*****	*****	*****	*****
CUM. EOL FACTOR	.885	.885	.885	.885	.885	.885	.885	.885	.885
PHYSICAL CHARACTERISTICS									
Total Number of Cells	4700160	4821120	4950720	5080320	5209920	5391360	5495040	5633280	5806080
No. of Modules/Panel	15	15	15	15	15	15	15	15	15
No. of Panels/Blanket	36	36	36	36	36	36	36	36	36
Blanket Weight (Kg)	2103.0	2151.0	2210.0	2261.0	2323.0	2398.0	2442.0	2505.0	2581.0
Structure Weight (Kg)	2889.0	3121.0	3221.0	3313.0	3427.0	3555.0	3443.0	3552.0	3679.0
Total Array Weight (Kg)	11301.0	11725.0	12061.0	12357.0	12719.0	13147.0	13211.0	13572.0	14003.0
Solar Cell Area (cm2)	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000
Module Area (M^2)	2.410	2.450	2.520	2.570	2.650	2.730	2.780	2.860	2.950
Concentrator Area (M^2)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Panel Area (M^2)	34.30	34.90	36.00	36.70	37.90	39.00	39.70	40.90	42.20
Blanket Area (M^2)	1257.0	1278.0	1320.0	1347.0	1389.0	1431.0	1457.0	1499.0	1546.0
Total Array Area (M^2)	5028.0	5112.0	5280.0	5388.0	5556.0	5724.0	5823.0	5996.0	6184.0
Power Density (W/M2)	129.94	127.32	123.76	120.69	117.23	113.96	112.20	108.98	105.16
Power/Weight Ratio (W/Kg)	57.81	55.51	54.18	52.63	51.21	49.62	49.50	48.15	46.44
LIFE CYCLE COST (1980$M)									
DDT&E	240.857	243.994	247.184	250.329	253.553	257.970	260.244	263.652	267.887
PRODUCTION	683.163	697.125	706.241	715.227	724.436	737.058	743.555	753.293	765.391
(Solar Cell - $/Cell)	(29.30)	(29.30)	(29.30)	(29.30)	(29.30)	(29.30)	(29.30)	(29.30)	(29.30)
OPERATIONS & MAINTENANCE	185.317	187.650	190.274	192.769	195.458	199.055	201.096	203.915	207.381
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TOTAL LIFE CYCLE COST	1114.338	1128.769	1143.699	1158.325	1173.447	1194.083	1204.895	1220.860	1240.659

Exhibit 4a. Temperature (Average)

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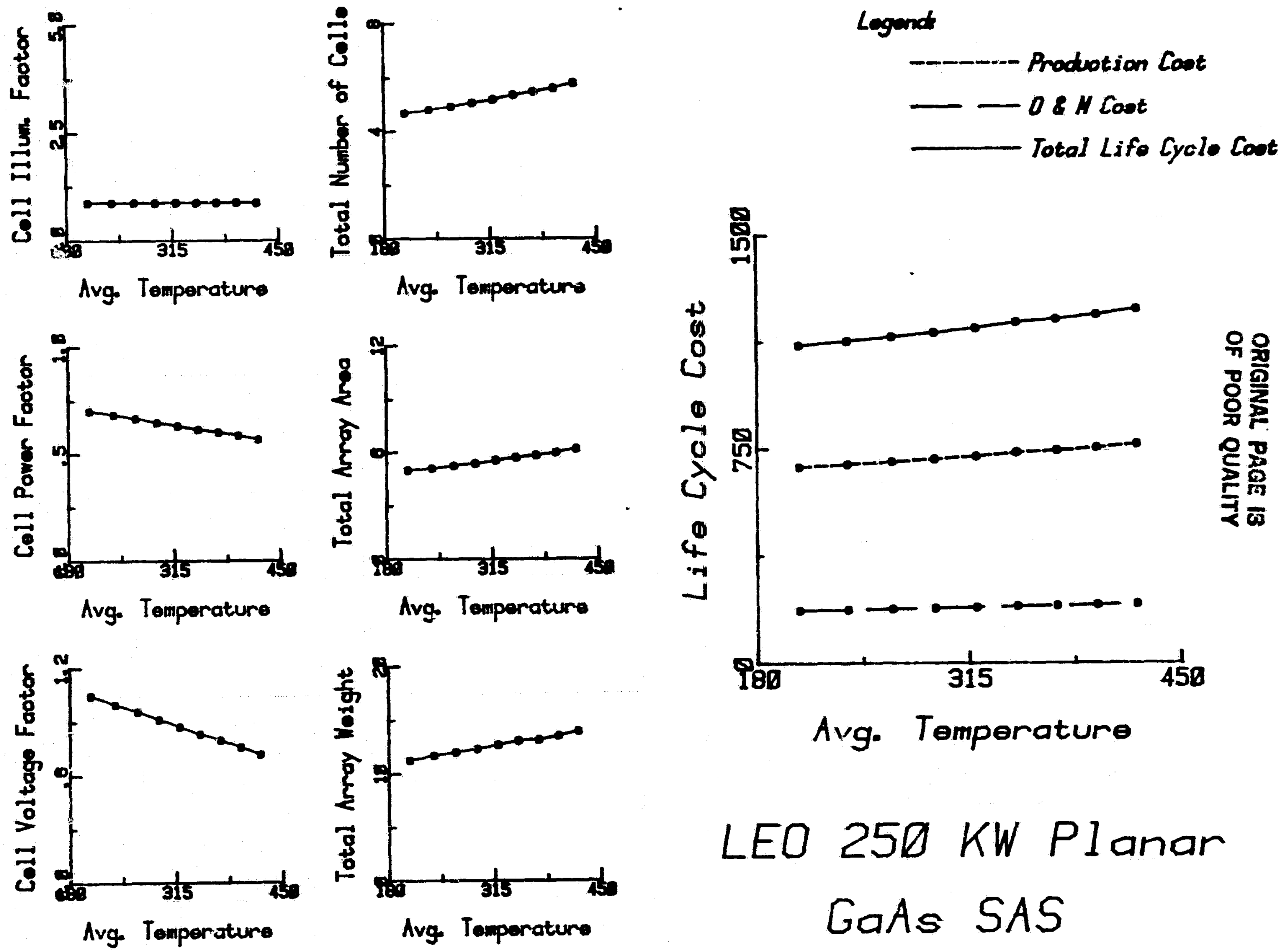

Exhibit 4a. Temperature (Average) Continued

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LEO 250 KW Conc. GaAs SAS

ARRAY PERFORMANCE									
No. of Hardware Life Cycles	1	1	1	1	1	1	1	1	1
Total Cell Life Required (Yr)	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0
Total EOL Min. Power (KW)	660.7	651.6	654.2	662.6	656.9	656.6	651.4	661.2	651.6
Total EOL Min. Voltage (V)	225.0	216.0	203.0	193.0	183.0	221.0	208.0	195.0	182.0
BOL Cell Efficiency (%)	18.1	18.1	18.1	18.1	18.1	18.1	18.1	18.1	18.1
BOL Cell Max. Voltage (V)	.810	.810	.810	.810	.810	.810	.810	.810	.810
EOL Cell Power (MW)	512.0	505.0	484.0	469.0	455.0	450.0	435.0	420.0	404.0
EOL Cell Voltage (V)	.703	.676	.634	.603	.570	.552	.519	.487	.454
Avg. Temp. (Deg-K @ Min 111)	298.0	323.0	348.0	373.0	398.0	423.0	448.0	473.0	498.0
POWER FACTORS									
Radiation	.779	.779	.779	.779	.779	.779	.779	.779	.779
Temperature	1.000	.975	.950	.925	.900	.875	.850	.825	.800
Main Bus	.923	.927	.911	.907	.903	.920	.914	.909	.905
	****	****	****	****	****	****	****	****	****
CUM. EOL FACTOR	.539	.532	.510	.494	.479	.474	.458	.442	.426
VOLTAGE FACTORS									
Radiation	.963	.963	.963	.963	.963	.963	.963	.963	.963
Temperature	1.000	.958	.915	.873	.830	.788	.745	.703	.660
Main Bus	.923	.927	.911	.907	.903	.920	.914	.909	.905
	****	****	****	****	****	****	****	****	****
CUM. EOL FACTOR	.868	.835	.783	.744	.704	.681	.641	.601	.561
ILLUMINATION FACTORS									
Cover Degradation (EOL)	.870	.870	.870	.870	.870	.870	.870	.870	.870
Concentration Ratio (BOL)	5.000	5.000	5.000	5.000	5.000	5.000	5.000	5.000	5.000
Concentrator Degrad. (EOL)	.960	.960	.960	.960	.960	.960	.960	.960	.960
	*****	*****	*****	*****	*****	*****	*****	*****	*****
CUM. EOL FACTOR	4.247	4.247	4.247	4.247	4.247	4.247	4.247	4.247	4.247
PHYSICAL CHARACTERISTICS									
Total Number of Cells	1290240	1290240	1351680	1413120	1443840	1459200	1497600	1574400	1612800
No. of Modules/Panel	8	8	8	8	8	8	8	8	8
No. of Panels/Blanket	48	48	60	60	60	60	60	60	60
Blanket Weight (Kg)	2143.0	2143.0	2447.0	2465.0	2474.0	2479.0	2555.0	1640.0	2651.0
Structure Weight (Kg)	3600.0	3011.0	5599.0	5682.0	5733.0	5647.0	6227.0	6805.0	6877.0
Total Array Weight (Kg)	11572.0	11583.0	15387.0	15542.0	15629.0	15563.0	16447.0	17365.0	17481.0
Solar Cell Area (cm2)	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000
Module Area (M^2)	.980	.980	.900	.900	.900	.900	.940	.980	.980
Concentrator Area (M^2)	8.88	8.88	8.16	8.16	8.16	8.16	8.52	8.88	8.83
Panel Area (M^2)	38.70	38.70	35.60	35.60	35.60	35.60	37.20	38.70	38.70
Blanket Area (M^2)	1897.0	1897.0	2180.0	2180.0	2180.0	2180.0	2277.0	2367.0	2367.0
Total Array Area (M^2)	7588.0	7588.0	8720.0	8720.0	8720.0	8720.0	9108.0	9468.0	9468.0
Power Density (W/M2)	87.07	85.86	75.03	75.99	75.33	75.30	71.52	69.84	68.82
Power/Weight Ratio (W/Kg)	57.09	56.26	42.52	42.64	42.03	42.19	39.60	38.08	37.27
LIFE CYCLE COST (1980$M)									
DDT&E	172.972	172.987	210.622	212.131	212.899	213.135	215.200	218.139	219.107
PRODUCTION	494.205	494.249	601.776	606.089	608.282	608.957	614.858	623.254	626.021
(Solar Cell - $/Cell)	(29.30)	(29.30)	(29.30)	(29.30)	(29.30)	(29.30)	(29.30)	(29.30)	(29.30)
OPERATIONS & MAINTENANCE	187.536	187.586	222.180	223.274	223.793	224.081	227.197	231.004	231.696
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TOTAL LIFE CYCLE COST	854.763	854.822	1034.577	1041.494	1044.973	1046.173	1057.255	1072.397	1076.824

Exhibit 4b. Temperature (Average)

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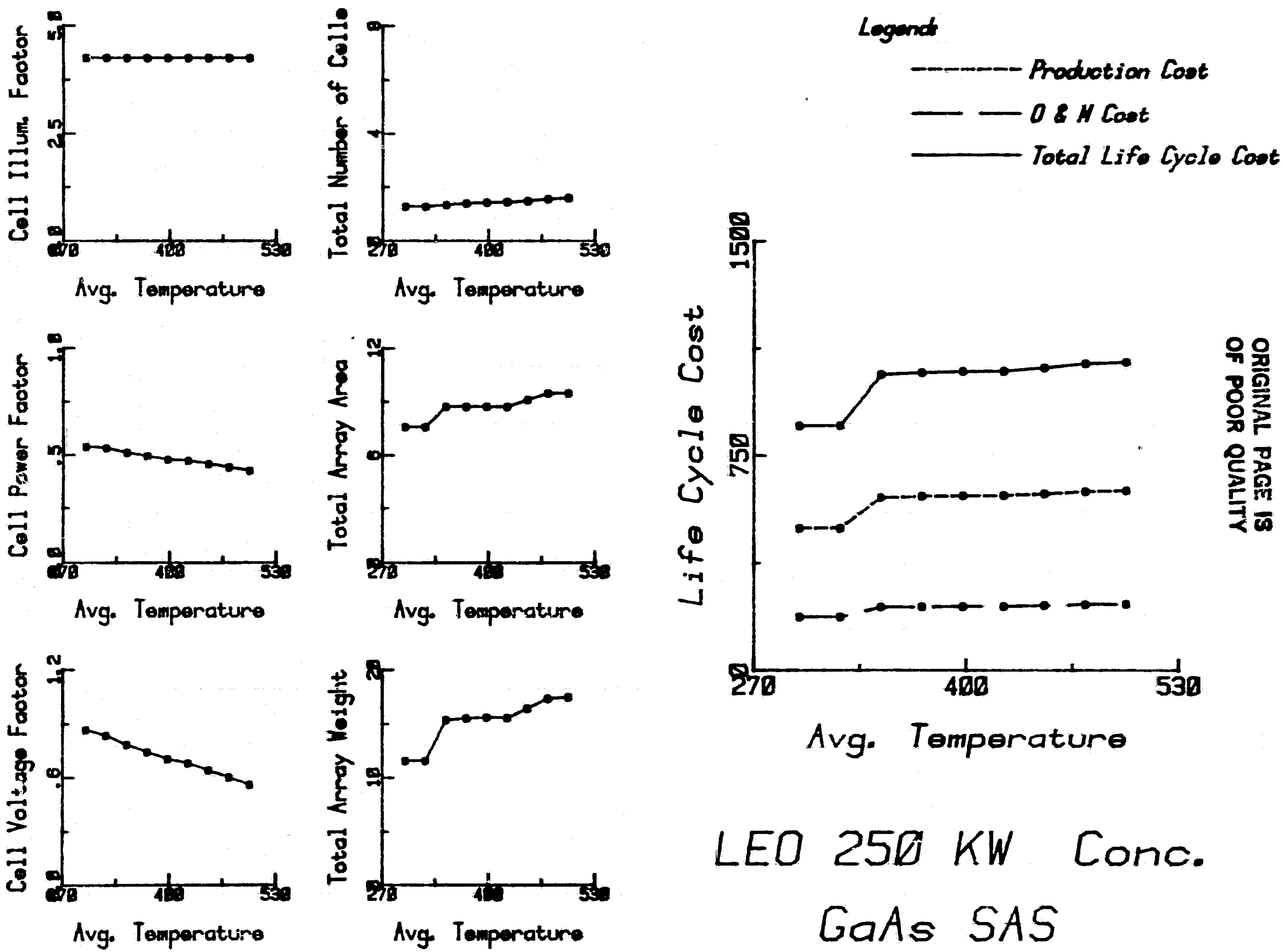

Exhibit 4b. Temperature (Average) Continued

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GEO 50 KW Planar GaAs SAS

ARRAY PERFORMANCE									
No. of Hardware Life Cycles	1	1	1	1	1	1	1	1	1
Total Cell Life Required (Yr)	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0
Total EOL Min. Power (KW)	71.8	71.5	71.1	71.4	71.7	71.3	71.6	71.1	71.8
Total EOL Min. Voltage (V)	206.0	198.0	190.0	182.0	196.0	188.0	199.0	189.0	198.0
BOL Cell Efficiency (%)	18.1	18.1	18.1	18.1	18.1	18.1	18.1	18.1	18.1
BOL Cell Max. Voltage (V)	.810	.810	.810	.810	.810	.810	.810	.810	.810
EOL Cell Power (MW)	136.0	133.0	130.0	126.0	123.0	120.0	117.0	114.0	111.0
EOL Cell Voltage (V)	.856	.824	.792	.759	.727	.695	.663	.630	.599
Avg. Temp. (Deg-K @ Min III)	223.0	248.0	273.0	298.0	323.0	348.0	373.0	398.0	423.0
POWER FACTORS									
Radiation	.891	.891	.891	.891	.891	.891	.891	.891	.891
Temperature	1.075	1.050	1.025	1.000	.975	.950	.925	.900	.875
Main Bus	.992	.991	.991	.991	.992	.991	.992	.992	.992
	****	****	****	****	****	****	****	****	****
CUM. EOL FACTOR	.717	.699	.683	.666	.650	.633	.617	.600	.583
VOLTAGE FACTORS									
Radiation	.968	.968	.968	.968	.968	.968	.968	.968	.968
Temperature	1.128	1.085	1.043	1.000	.958	.915	.873	.830	.788
Main Bus	.992	.991	.991	.991	.992	.991	.992	.992	.992
	****	****	****	****	****	****	****	****	****
CUM. EOL FACTOR	1.057	1.017	.978	.937	.898	.858	.819	.778	.739
ILLUMINATION FACTORS									
Cover Degradation (EOL)	.870	.870	.870	.870	.870	.870	.870	.870	.870
Concentration Ratio (BOL)	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Concentrator Degrad. (EOL)	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
	*****	*****	*****	*****	*****	*****	*****	*****	*****
CUM. EOL FACTOR	.885	.885	.885	.885	.885	.885	.885	.885	.885
PHYSICAL CHARACTERISTICS									
Total Number of Cells	528000	537600	547200	566400	583200	594000	612000	624000	646800
No. of Modules/Panel	15	15	15	15	15	15	15	15	15
No. of Panels/Blanket	5	5	5	5	5	5	5	5	5
Blanket Weight (Kg)	288.0	295.0	301.0	311.0	319.0	326.0	334.0	338.0	352.0
Structure Weight (Kg)	77.0	78.0	78.0	79.0	78.0	79.0	78.0	79.0	79.0
Total Array Weight (Kg)	1229.0	1258.0	1282.0	1323.0	1354.0	1383.0	1414.0	1431.0	1487.0
Solar Cell Area (cm2)	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000
Module Area (M^2)	1.940	1.980	2.030	2.110	2.150	2.190	2.240	2.280	2.360
Concentrator Area (M^2)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Panel Area (M^2)	27.60	28.10	28.30	30.00	30.60	31.10	31.90	32.40	33.60
Blanket Area (M^2)	149.0	152.0	156.0	162.0	165.0	168.0	172.0	175.0	181.0
Total Array Area (M^2)	596.0	608.0	624.0	648.0	660.0	672.0	688.0	700.0	724.0
Power Density (W/M2)	120.47	117.60	114.01	110.12	108.70	106.07	104.07	101.63	99.17
Power/Weight Ratio (W/kg)	58.42	56.84	55.49	53.94	52.98	51.54	50.64	49.71	48.29
LIFE CYCLE COST (1980$M)									
DDT&E	31.849	32.088	32.323	32.784	33.181	33.447	33.870	34.150	34.704
PRODUCTION	90.997	91.681	92.351	93.670	94.804	95.562	96.773	97.572	99.155
(Solar Cell - $/Cell)	(29.30)	(29.30)	(29.30)	(29.30)	(29.30)	(29.30)	(29.30)	(29.30)	(29.30)
OPERATIONS & MAINTENANCE	.900	.900	.900	.900	.900	.900	.900	.900	.900
	-------	-------	-------	-------	-------	-------	-------	-------	-------
TOTAL LIFE CYCLE COST	123.746	124.670	125.574	127.354	128.885	129.909	131.543	132.622	134.760

Exhibit 4c. Temperature (Average)

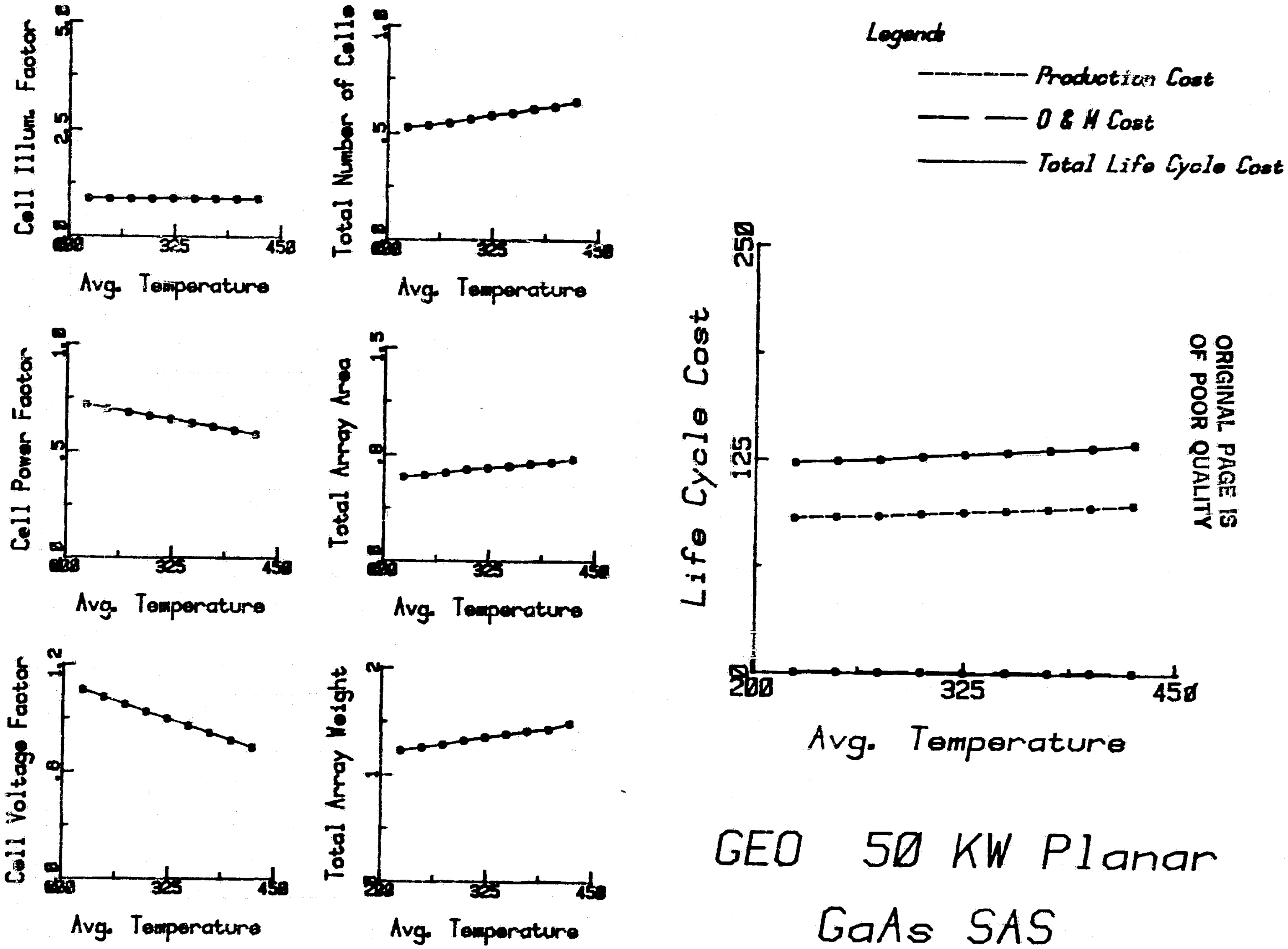

Exhibit 4c. Temperature (Average) Continued

GLO 50 KW Conc. GaAs SAS

ARRAY PERFORMANCE									
No. of Hardware Life Cycles	1	1	1	1	1	1	1	1	1
Total Cell Life Required (Yr)	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0
Total EOL Min. Power (KW)	71.9	75.4	73.6	72.6	70.7	74.3	71.9	74.8	70.8
Total EOL Min. Voltage (V)	197.0	188.0	180.0	187.0	193.0	183.0	187.0	189.0	189.0
BOL Cell Efficiency (%)	18.1	18.1	18.1	18.1	18.1	18.1	18.1	18.1	18.1
BOL Cell Max. Voltage (V)	.810	.810	.810	.810	.810	.810	.810	.810	.810
EOL Cell Power (MW)	524.0	510.0	498.0	485.0	472.0	458.0	446.0	433.0	419.0
EOL Cell Voltage (V)	.746	.714	.682	.650	.620	.587	.556	.524	.492
Avg. Temp. (Deg-K @ Min Ill)	298.0	323.0	348.0	373.0	398.0	423.0	448.0	473.0	498.0
POWER FACTORS									
Radiation	.779	.779	.779	.779	.779	.779	.779	.779	.779
Temperature	1.000	.975	.950	.925	.900	.875	.850	.825	.800
Main Bus	.979	.978	.978	.979	.980	.978	.979	.979	.979
	****	****	****	****	****	****	****	****	****
CUM. EOL FACTOR	.575	.560	.546	.532	.518	.503	.489	.475	.460
VOLTAGE FACTORS									
Radiation	.963	.963	.963	.963	.963	.963	.963	.963	.963
Temperature	1.000	.958	.915	.873	.830	.788	.745	.703	.660
Main Bus	.979	.978	.978	.979	.980	.978	.979	.979	.979
	****	****	****	****	****	****	****	****	****
CUM. EOL FACTOR	.921	.882	.842	.803	.765	.725	.686	.647	.608
ILLUMINATION FACTORS									
Cover Degradation (EOL)	.870	.870	.870	.870	.870	.870	.870	.870	.870
Concentration Ratio (BOL)	5.000	5.000	5.000	5.000	5.000	5.000	5.000	5.000	5.000
Concentrator Degrad. (EOL)	.960	.960	.960	.960	.960	.960	.960	.960	.960
	*****	*****	*****	*****	*****	*****	*****	*****	*****
CUM. EOL FACTOR	4.247	4.247	4.247	4.247	4.247	4.247	4.247	4.247	4.247
PHYSICAL CHARACTERISTICS									
Total Number of Cells	137280	147840	147840	149760	149760	162240	161280	172800	168960
No. of Modules/Panel	6	6	6	6	6	6	6	6	6
No. of Panels/Blanket	10	10	10	10	10	10	10	10	10
Blanket Weight (Kg)	325.0	336.0	336.0	337.0	337.0	353.0	353.0	376.0	375.0
Structure Weight (Kg)	75.0	76.0	76.0	76.0	75.0	76.0	76.0	78.0	77.0
Total Array Weight (Kg)	1375.0	1420.0	1420.0	1424.0	1423.0	1488.0	1488.0	1582.0	1577.0
Solar Cell Area (cm2)	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000
Module Area (M^2)	.740	.770	.770	.770	.770	.830	.830	.900	.900
Concentrator Area (M^2)	6.71	6.98	6.98	6.98	6.98	7.52	7.52	8.16	8.16
Panel Area (M^2)	21.90	23.00	23.00	23.00	23.00	24.50	24.50	26.70	26.70
Blanket Area (M^2)	233.0	244.0	244.0	244.0	244.0	260.0	260.0	283.0	283.0
Total Array Area (M^2)	932.0	976.0	976.0	976.0	976.0	1040.0	1040.0	1132.0	1132.0
Power Density (W/M2)	77.17	77.25	75.45	74.43	72.42	71.46	69.15	66.11	62.54
Power/Weight Ratio (W/Kg)	52.31	53.10	51.86	51.01	49.67	49.95	48.33	47.31	44.90
LIFE CYCLE COST (1980$M)									
DDT&E	30.547	30.848	30.848	30.894	30.892	31.282	31.261	31.669	31.580
PRODUCTION	87.276	88.137	88.137	88.268	88.264	89.378	89.319	90.484	90.229
(Solar Cell - $/Cell)	(29.30)	(29.30)	(29.30)	(29.30)	(29.30)	(29.30)	(29.30)	(29.30)	(29.30)
OPERATIONS & MAINTENANCE	.900	.900	.900	.900	.900	.900	.900	.900	.900
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TOTAL LIFE CYCLE COST	118.722	119.885	119.885	120.062	120.056	121.561	121.480	123.053	122.710

Exhibit 4d. Temperature (Average)

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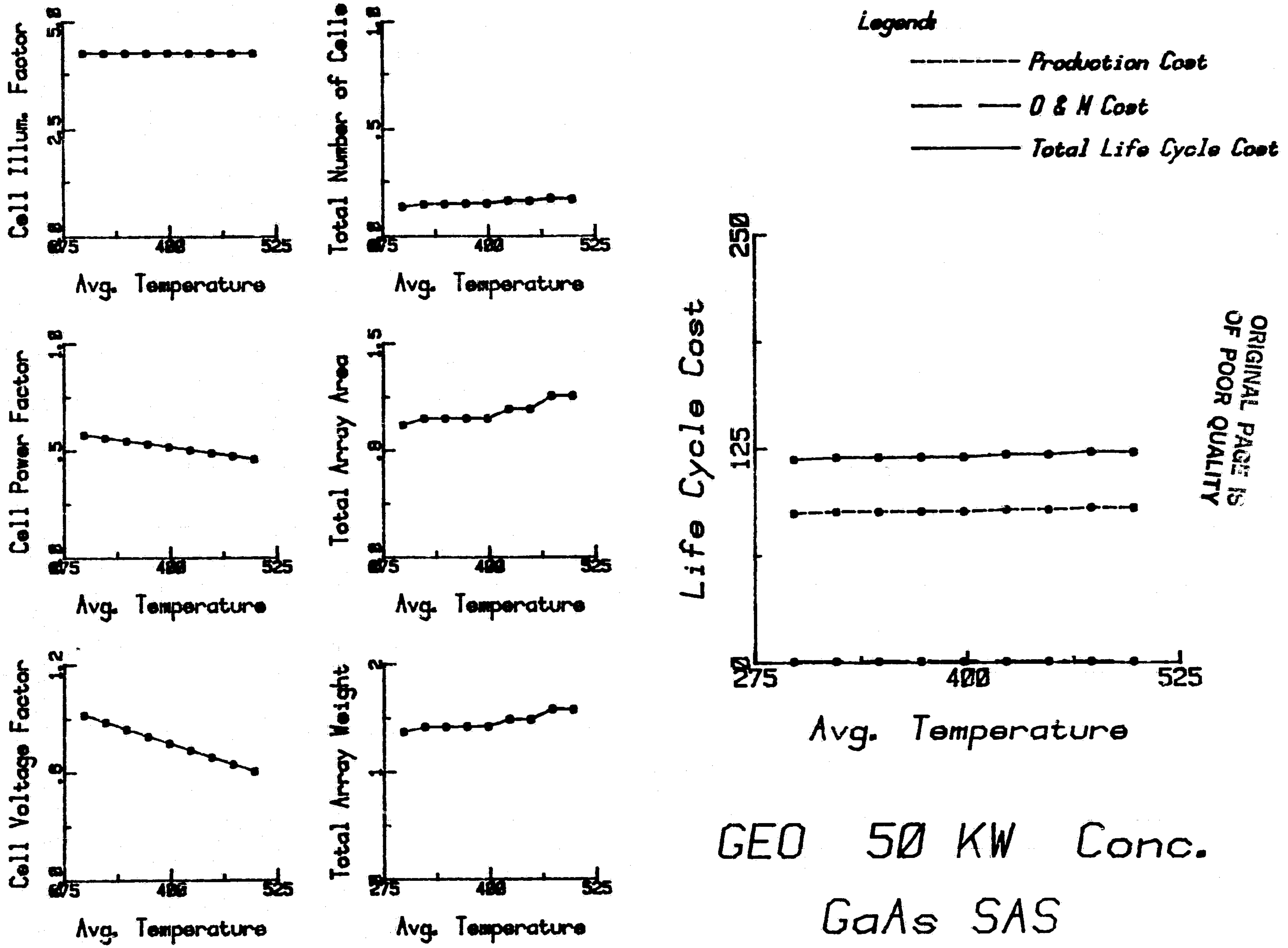

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Exhibit 4d. Temperature (Average) Continued

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LEO 250 KW Planar GaAs SAS

ARRAY PERFORMANCE									
No. of Hardware Life Cycles	1	1	1	1	1	1	1	1	1
Total Cell Life Required (Yr)	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0
Total EOL Min. Power (KW)	652.0	650.3	651.1	650.3	650.4	650.3	651.5	651.3	653.5
Total EOL Min. Voltage (V)	256.0	254.0	254.0	190.0	190.0	191.0	191.0	191.0	191.0
BOL Cell Efficiency (%)	11.1	12.1	13.1	14.1	15.1	16.1	17.1	18.1	19.1
BOL Cell Max. Voltage (V)	.810	.810	.810	.810	.810	.810	.810	.810	.810
EOL Cell Power (MW)	77.0	84.0	91.0	98.0	105.0	112.0	118.0	125.0	132.0
EOL Cell Voltage (V)	.710	.708	.708	.703	.703	.706	.706	.706	.705
POWER FACTORS									
Radiation	.891	.891	.891	.891	.891	.891	.891	.891	.891
Temperature	.980	.980	.980	.980	.981	.981	.981	.981	.981
Main Bus	.969	.968	.966	.964	.963	.961	.961	.960	.959
	****	****	****	****	****	****	****	****	****
CUM. EOL FACTOR	.638	.638	.636	.635	.635	.634	.634	.634	.633
VOLTAGE FACTORS									
Radiation	.968	.968	.968	.968	.968	.968	.968	.968	.968
Temperature	.965	.966	.966	.967	.967	.967	.968	.968	.968
Main Bus	.969	.968	.966	.964	.963	.961	.961	.960	.959
	****	****	****	****	****	****	****	****	****
CUM. EOL FACTOR	.876	.874	.874	.868	.868	.872	.872	.871	.870
ILLUMINATION FACTORS									
Cover Degradation (EOL)	.870	.870	.870	.870	.870	.870	.870	.870	.870
Concentration Ratio (BOL)	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Concentrator Degrad. (EOL)	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
	*****	*****	*****	*****	*****	*****	*****	*****	*****
CUM. EOL FACTOR	.885	.885	.885	.885	.885	.885	.885	.885	.885
PHYSICAL CHARACTERISTICS									
Total Number of Cells	8467200	7741440	7153920	6635520	6194880	5806080	5520960	5209920	4950720
No. of Modules/Panel	15	15	15	15	15	15	15	15	15
No. of Panels/Blanket	48	48	48	36	36	36	36	36	36
Blanket Weight (Kg)	3718.0	3413.0	3160.0	2932.0	2741.0	2581.0	2450.0	2323.0	2210.0
Structure Weight (Kg)	10893.0	10064.0	9371.0	4191.0	3954.0	3749.0	3588.0	3427.0	3286.0
Total Array Weight (Kg)	25765.0	23716.0	22011.0	15919.0	14918.0	14073.0	13388.0	12719.0	12126.0
Solar Cell Area (cm2)	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000
Module Area (M^2)	3.200	2.950	2.730	3.330	3.110	2.950	2.780	2.650	2.520
Concentrator Area (M^2)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Panel Area (M^2)	45.80	42.20	39.00	47.60	44.50	42.20	39.70	37.90	36.00
Blanket Area (M^2)	2231.0	2057.0	1903.0	1746.0	1631.0	1546.0	1457.0	1389.0	1320.0
Total Array Area (M^2)	8924.0	8228.0	7612.0	6984.0	6524.0	6184.0	5828.0	5556.0	5280.0
Power Density (W/M2)	73.06	79.04	85.53	93.11	99.70	105.16	111.78	117.23	123.76
Power/Weight Ratio (W/Kg)	25.31	27.42	29.58	40.85	43.60	46.21	48.66	51.21	53.89
LIFE CYCLE COST (1980$M)									
DDT&E	380.071	362.077	347.454	288.014	277.349	267.983	261.037	253.553	247.274
PRODUCTION	1085.918	1034.504	992.725	822.898	792.425	765.667	745.821	724.436	706.497
(Solar Cell - $/Cell)	(29.30)	(29.30)	(29.30)	(29.30)	(29.30)	(29.30)	(29.30)	(29.30)	(29.30)
OPERATIONS & MAINTENANCE	287.221	272.792	261.041	223.841	215.028	207.381	201.549	195.458	190.274
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TOTAL LIFE CYCLE COST	1753.209	1669.373	1601.220	1334.752	1284.801	1241.032	1208.408	1173.447	1144.045

Exhibit 5a. Cell Efficiency

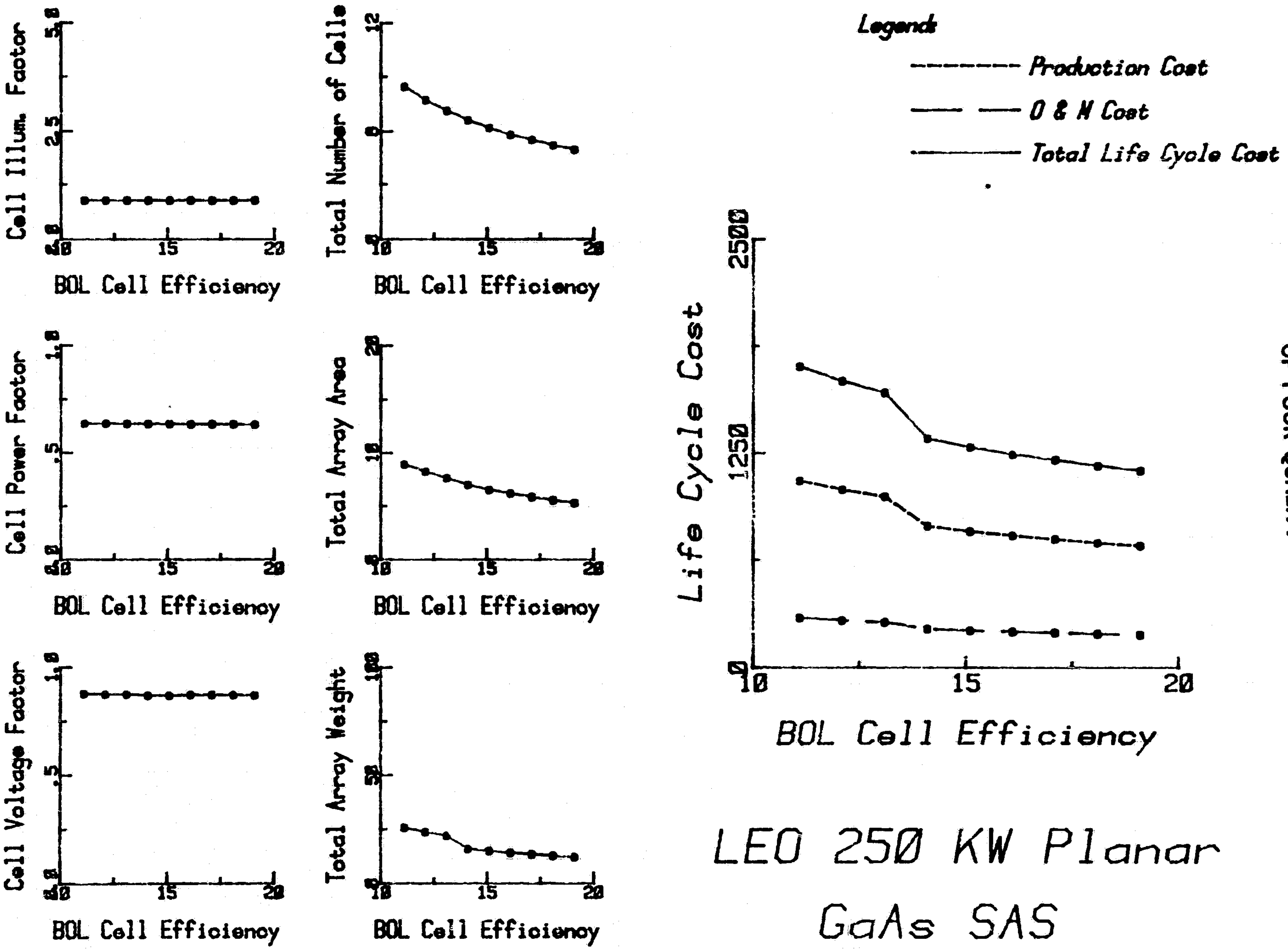

Exhibit 5a. Cell Efficiency Continued

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LEO 250 KW Conc. GaAs SAS

ARRAY PERFORMANCE									
No. of Hardware Life Cycles	1	1	1	1	1	1	1	1	1
Total Cell Life Required (Yr)	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0
Total EOL Min. Power (KW)	663.6	652.8	662.6	656.9	661.2	659.5	665.0	661.2	661.9
Total EOL Min. Voltage (V)	269.0	237.0	213.0	213.0	181.0	224.0	224.0	191.0	191.0
BOL Cell Efficiency (%)	11.1	12.1	13.1	14.1	15.1	16.1	17.1	18.1	19.1
BOL Cell Max. Voltage (V)	.810	.810	.810	.810	.810	.810	.810	.810	.810
EOL Cell Power (MW)	250.0	271.0	302.0	325.0	345.0	367.0	390.0	420.0	442.0
EOL Cell Voltage (V)	.467	.463	.474	.474	.470	.468	.468	.475	.475
POWER FACTORS									
Radiation	.779	.779	.779	.779	.779	.779	.779	.779	.779
Temperature	.825	.825	.825	.825	.825	.825	.825	.825	.825
Main Bus	.883	.877	.905	.905	.897	.895	.894	.909	.908
	****	****	****	****	****	****	****	****	****
CUM. EOL FACTOR	.429	.427	.440	.440	.436	.435	.435	.442	.441
VOLTAGE FACTORS									
Radiation	.963	.963	.963	.963	.963	.963	.963	.963	.963
Temperature	.702	.702	.702	.702	.702	.702	.703	.703	.703
Main Bus	.883	.877	.905	.905	.897	.895	.894	.909	.908
	****	****	****	****	****	****	****	****	****
CUM. EOL FACTOR	.576	.572	.585	.585	.580	.578	.578	.587	.587
ILLUMINATION FACTORS									
Cover Degradation (EOL)	.870	.870	.870	.870	.870	.870	.870	.870	.870
Concentration Ratio (BOL)	5.000	5.000	5.000	5.000	5.000	5.000	5.000	5.000	5.000
Concentrator Degrad. (EOL)	.960	.960	.960	.960	.960	.960	.960	.960	.960
	*****	*****	*****	*****	*****	*****	*****	*****	*****
CUM. EOL FACTOR	4.247	4.247	4.247	4.247	4.247	4.247	4.247	4.247	4.247
PHYSICAL CHARACTERISTICS									
Total Number of Cells	2654208	2408448	2193408	2021376	1916928	1797120	1704960	1574400	1497600
No. of Modules/Panel	8	8	8	8	8	8	8	8	8
No. of Panels/Blanket	108	96	84	84	72	72	72	60	60
Blanket Weight (Kg)	4503.0	4128.0	3651.0	3424.0	3156.0	3045.0	2941.0	2640.0	2555.0
Structure Weight (Kg)	58976.0	40542.0	24401.0	20282.0	13673.0	12323.0	11145.0	6819.0	6279.0
Total Array Weight (Kg)	76988.0	57054.0	39005.0	33978.0	26297.0	24503.0	22909.0	17379.0	16499.0
Solar Cell Area (cm2)	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000
Module Area (M^2)	.940	.980	.980	.900	.980	.940	.900	.980	.940
Concentrator Area (M^2)	8.52	8.88	8.88	8.16	8.88	8.52	8.16	8.88	8.52
Panel Area (M^2)	37.20	38.70	38.70	35.60	38.70	37.20	35.60	38.70	37.20
Blanket Area (M^2)	4086.0	3777.0	3307.0	3045.0	2837.0	2729.0	2613.0	2367.0	2277.0
Total Array Area (M^2)	16344.0	15108.0	13228.0	12180.0	11348.0	10916.0	10452.0	9468.0	9108.0
Power Density (W/M2)	40.60	43.21	50.09	53.93	58.27	60.42	63.62	69.84	72.67
Power/Weight Ratio (W/Kg)	8.62	11.44	16.99	19.33	25.15	26.92	29.03	38.05	40.12
LIFE CYCLE COST (1980$M)									
DDT&E	436.598	377.420	320.464	310.523	267.988	263.082	259.033	218.158	215.270
PRODUCTION	1247.422	1078.344	915.612	887.209	765.680	751.663	740.095	623.307	615.056
(Solar Cell - $/Cell)	(29.30)	(29.30)	(29.30)	(29.30)	(29.30)	(29.30)	(29.30)	(29.30)	(29.30)
OPERATIONS & MAINTENANCE	399.309	360.982	318.785	308.850	275.494	270.406	265.838	231.004	227.197
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TOTAL LIFE CYCLE COST	2083.328	1816.746	1554.861	1506.583	1309.162	1285.151	1264.966	1072.469	1057.523

Exhibit 5b. Cell Efficiency

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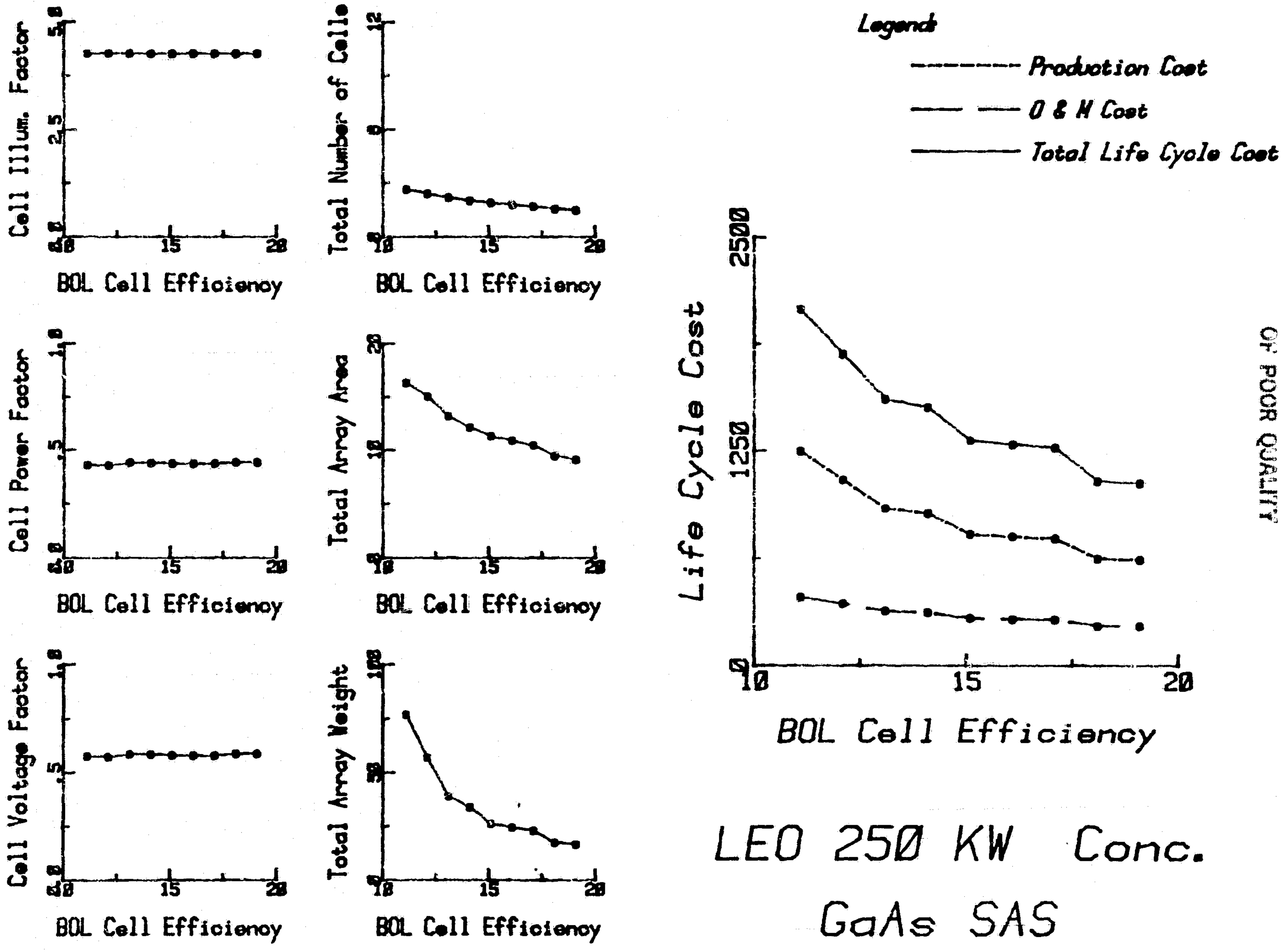

Exhibit 5b. Cell Efficiency Continued

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GEO 50 KW Planar GaAs SAS

ARRAY PERFORMANCE									
No. of Hardware Life Cycles	1	1	1	1	1	1	1	1	1
Total Cell Life Required (Yr)	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0
Total EOL Min. Power (KW)	71.1	70.7	71.3	71.0	71.1	70.7	71.4	71.6	71.3
Total EOL Min. Voltage (V)	220.0	220.0	220.0	220.0	220.0	199.0	199.0	199.0	199.0
BOL Cell Efficiency (%)	11.1	12.1	13.1	14.1	15.1	16.1	17.1	18.1	19.1
BOL Cell Max. Voltage (V)	.810	.810	.810	.810	.810	.810	.810	.810	.810
EOL Cell Power (MW)	76.0	83.0	90.0	97.0	104.0	111.0	118.0	125.0	132.0
EOL Cell Voltage (V)	.733	.734	.733	.734	.734	.735	.735	.735	.735
POWER FACTORS									
Radiation	.891	.891	.891	.891	.891	.891	.891	.891	.891
Temperature	.985	.986	.986	.986	.986	.986	.987	.987	.987
Main Bus	.991	.990	.990	.989	.989	.992	.992	.992	.991
	****	****	****	****	****	****	****	****	****
CUM. EOL FACTOR	.656	.656	.656	.655	.655	.657	.658	.658	.657
VOLTAGE FACTORS									
Radiation	.968	.968	.968	.968	.968	.968	.968	.968	.968
Temperature	.975	.976	.976	.976	.977	.977	.977	.978	.978
Main Bus	.991	.990	.990	.989	.989	.992	.992	.992	.991
	****	****	****	****	****	****	****	****	****
CUM. EOL FACTOR	.905	.906	.905	.906	.906	.908	.908	.908	.908
ILLUMINATION FACTORS									
Cover Degradation (EOL)	.870	.870	.870	.870	.870	.870	.870	.870	.870
Concentration Ratio (BOL)	1.000	1.000	1.000	1.000	1.000	1.000	1.090	1.000	1.000
Concentrator Degrad. (EOL)	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
	*****	*****	*****	*****	*****	*****	*****	*****	*****
CUM. EOL FACTOR	.885	.885	.885	.885	.885	.885	.885	.885	.885
PHYSICAL CHARACTERISTICS									
Total Number of Cells	936000	852000	792000	732000	684000	637200	604800	572400	540000
No. of Modules/Panel	15	15	15	15	15	15	15	15	15
No. of Panels/Blanket	10	10	10	10	10	5	5	5	5
Blanket Weight (Kg)	461.0	424.0	393.0	368.0	344.0	349.0	332.0	312.0	295.0
Structure Weight (Kg)	100.0	98.0	96.0	95.0	93.0	79.0	78.0	78.0	77.0
Total Array Weight (Kg)	1944.0	1794.0	1668.0	1567.0	1469.0	1475.0	1406.0	1326.0	1257.0
Solar Cell Area (cm2)	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000
Module Area (M^2)	1.730	1.600	1.490	1.400	1.320	2.360	2.240	2.110	1.980
Concentrator Area (M^2)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Panel Area (M^2)	24.50	22.70	21.00	19.70	18.50	33.60	31.90	30.00	28.10
Blanket Area (M^2)	256.0	236.0	218.0	205.0	193.0	181.0	172.0	162.0	152.0
Total Array Area (M^2)	1024.0	944.0	872.0	820.0	772.0	724.0	688.0	648.0	608.0
Power Density (W/M2)	69.45	74.92	81.74	86.59	92.12	97.68	103.72	110,43	117.24
Power/Weight Ratio (W/Kg)	36.58	39.42	42.73	45.31	48.41	47.95	50.75	53.97	56.71
LIFE CYCLE COST (1980$M)									
DDT&E	58.804	56.818	55.380	53.968	52.820	34.484	33.706	32.917	32.139
PRODUCTION	168.012	162.338	158.229	154.194	150.916	98.525	96.303	94.050	91.826
(Solar Cell - $/Cell)	(29.30)	(29.30)	(29.30)	(29.30)	(29.30)	(29.30)	(29.30)	(29.30)	(29.30)
OPERATIONS & MAINTENANCE	.900	.900	.900	.900	.900	.900	.900	.900	.900
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TOTAL LIFE CYCLE COST	227.716	220.056	214.509	209.062	204.636	133.909	130.908	127.867	124.865

Exhibit 5c. Cell Efficiency

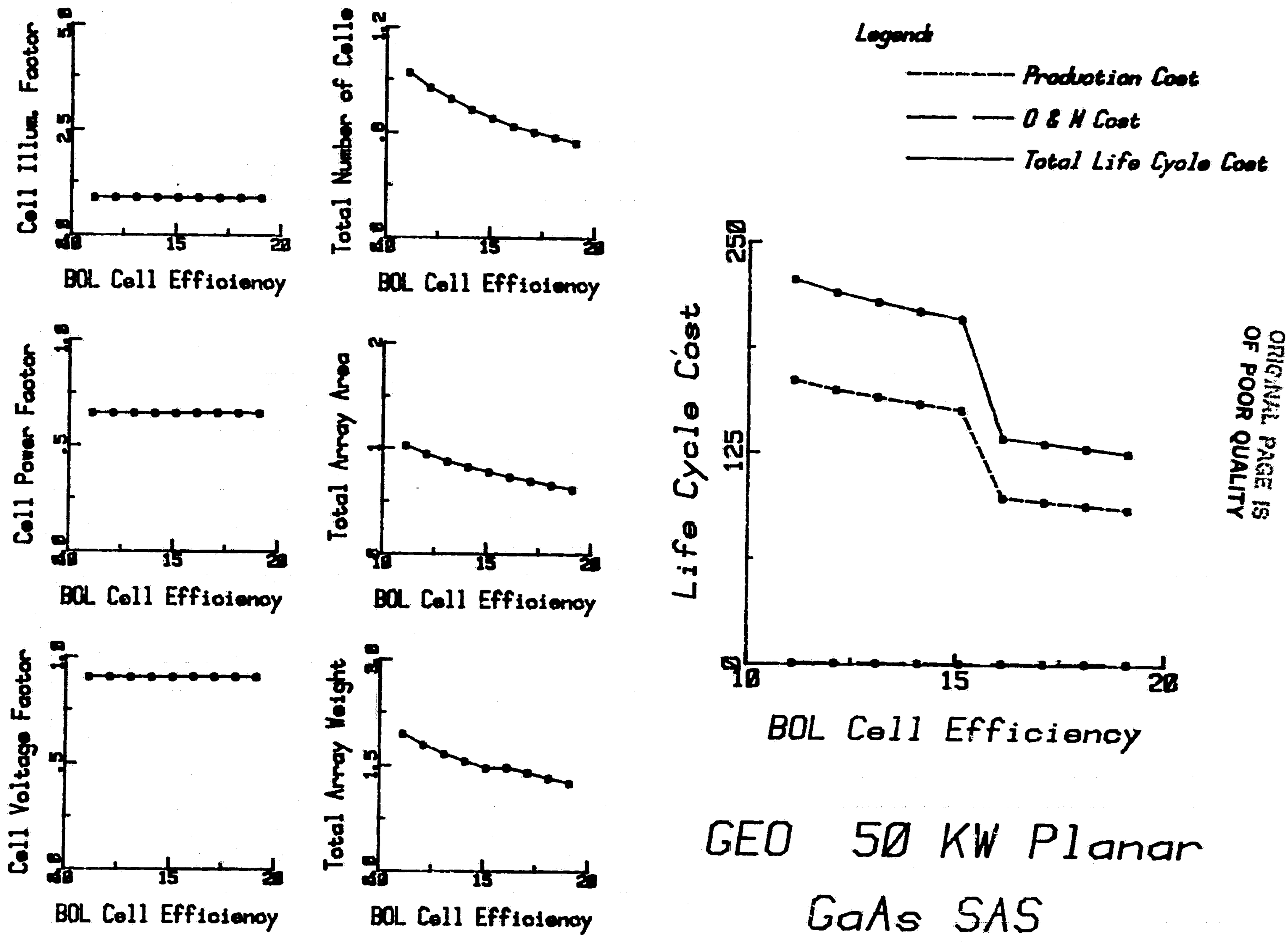

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Exhibit 5c. Cell Efficiency Continued

GEO 50 KW Conc. GaAs SAS

ARRAY PERFORMANCE									
No. of Hardware Life Cycles	1	1	1	1	1	1	1	1	1
Total Cell Life Required (Yr)	11.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0
Total EOL Min. Power (KW)	73.3	71.5	72.8	73.4	73.6	72.8	71.4	75.5	73.2
Total EOL Min. Voltage (V)	189.0	189.0	189.0	189.0	189.0	189.0	189.0	189.0	189.0
BOL Cell Efficiency (%)	11.1	12.1	13.1	14.1	15.1	16.1	17.1	18.1	19.1
BOL Cell Max. Voltage (V)	.810	.810	.810	.810	.810	.810	.810	.810	.810
EOL Cell Power (MW)	268.0	292.0	316.0	340.0	365.0	389.0	413.0	437.0	462.0
EOL Cell Voltage (V)	.524	.524	.524	.524	.526	.526	.526	.526	.526
POWER FACTORS									
Radiation	.779	.779	.779	.779	.779	.779	.779	.779	.779
Temperature	.834	.834	.834	.834	.834	.834	.834	.834	.834
Main Bus	.978	.978	.977	.977	.979	.979	.979	.979	.979
	****	****	****	****	****	****	****	****	****
CUM. EOL FACTOR	.479	.479	.479	.479	.480	.480	.480	.480	.480
VOLTAGE FACTORS									
Radiation	.963	.963	.963	.963	.963	.963	.963	.963	.563
Temperature	.717	.718	.718	.718	.718	.718	.718	.718	.718
Main Bus	.978	.978	.977	.977	.979	.979	.979	.979	.979
	****	****	****	****	****	****	****	****	****
CUM. EOL FACTOR	.647	.647	.647	.647	.649	.649	.649	.649	.649
ILLUMINATION FACTORS									
Cover Degradation (EOL)	.870	.870	.870	.870	.870	.870	.870	.870	.870
Concentration Ratio (BOL)	5.000	5.000	5.000	5.000	5.000	5.000	5.000	5.000	5.000
Concentrator Degrad. (EOL)	.960	.960	.960	.960	.960	.960	.960	.960	.960
	*****	*****	*****	*****	*****	*****	*****	*****	*****
CUM. EOL FACTOR	4.247	4.247	4.247	4.247	4.247	4.247	4.247	4.247	4.247
PHYSICAL CHARACTERISTICS									
Total Number of Cells	273600	244800	230400	216000	201600	187200	172800	172800	158400
No. of Modules/Panel	6	6	6	6	6	6	6	6	6
No. of Panels/Blanket	15	15	15	15	10	10	10	10	10
Blanket Weight (Kg)	529.0	494.0	485.0	457.0	403.0	388.0	376.0	376.0	352.0
Structure Weight (Kg)	99.0	94.0	92.0	90.0	80.0	79.0	78.0	78.0	76.0
Total Array Weight (Kg)	2215.0	2070.0	2032.0	1918.0	1692.0	1631.0	1582.0	1582.0	1484.0
Solar Cell Area (cm2)	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000
Module Area (M^2)	.900	.830	.810	.740	.980	.940	.900	.900	.830
Concentrator Area (M^2)	8.16	7.52	7.34	6.71	8.88	8.52	8.16	8.16	7.52
Panel Area (M^2)	26.70	24.50	24.00	21.90	29.00	27.90	26.70	26.70	24.50
Blanket Area (M^2)	418.0	385.0	377.0	344.0	306.0	295.0	283.0	283.0	260.0
Total Array Area (M^2)	1672.0	1540.0	1508.0	1376.0	1224.0	1180.0	1132.0	1132.0	1040.0
Power Density (W/M2)	43.85	46.40	48.26	53.37	60.13	61.73	63.04	66.71	70.38
Power/Weight Ratio (W/Kg)	33.10	34.52	35.82	38.29	43.50	44.66	45.11	47.74	49.33
LIFE CYCLE COST (1980$M)									
DDT&E	46.783	45.916	45.538	45.017	32.477	32.067	31.669	31.669	31.195
PRODUCTION	133.666	131.189	130.108	128.621	92.791	91.620	90.484	90.484	89.128
(Solar Cell - $/Cell)	(29.30)	(29.30)	(29.30)	(29.30)	(29.30)	(29.30)	(29.30)	(29.30)	(29.30)
OPERATIONS & MAINTENANCE	.900	.900	.900	.900	.900	.900	.900	.900	.900
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TOTAL LIFE CYCLE COST	181.348	178.006	176.546	174.539	126.168	124.587	123.053	123.053	121.223

Exhibit 5d. Cell Efficiency

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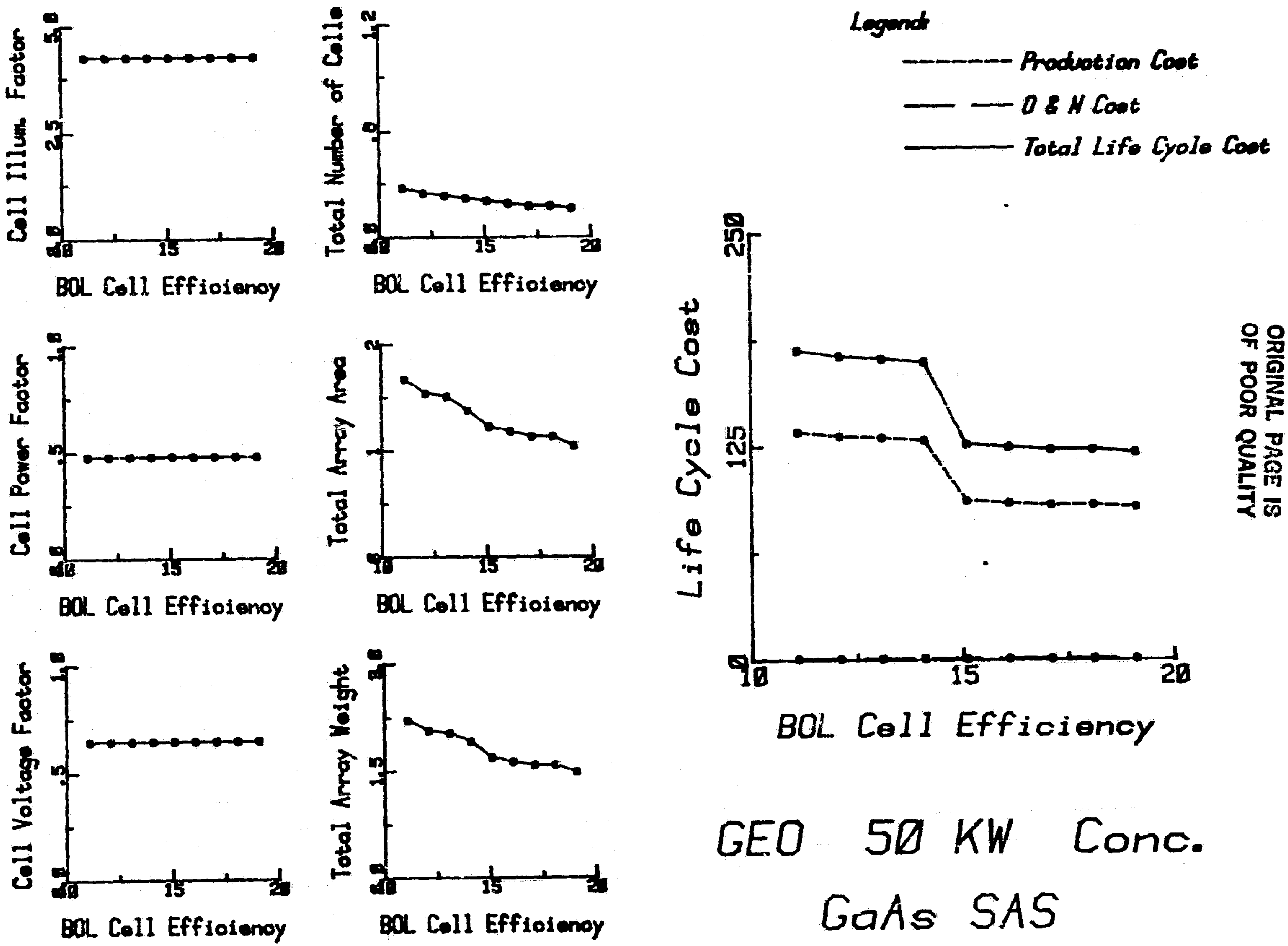

Exhibit 5d. Cell Efficiency Continued

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LEO 250 KW Conc. GaAs SAS

ARRAY PERFORMANCE									
No. of Hardware Life Cycles	1	1	1	1	1	1	1	1	1
Total Cell Life Required (Yr)	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0
Total EOL Min. Power (KW)	658.3	650.3	654.7	652.8	653.2	650.3	655.5	653.5	651.9
Total EOL Min. Voltage (V)	193.0	195.0	199.0	200.0	202.0	206.0	217.0	221.0	224.0
BOL Cell Efficiency (%)	18.1	18.1	18.1	18.1	18.1	18.1	18.1	18.1	18.1
BOL Cell Max. Voltage (V)	.845	.843	.842	.841	.838	.836	.834	.831	.829
EOL Cell Power (MW)	503.0	490.0	480.0	466.0	443.0	420.0	397.0	374.0	347.0
EOL Cell Voltage (V)	.504	.509	.518	.521	.525	.537	.541	.551	.560
POWER FACTORS									
Radiation	.891	.891	.891	.891	.891	.891	.891	.891	.891
Temperature	.824	.828	.832	.834	.843	.847	.857	.865	.873
Main Bus	.925	.925	.929	.930	.928	.930	.927	.927	.915
	****	****	****	****	****	****	****	****	****
CUM. EOL FACTOR	.513	.515	.521	.523	.526	.530	.535	.539	.540
VOLTAGE FACTORS									
Radiation	.968	.968	.968	.968	.968	.958	.968	.968	.968
Temperature	.700	.708	.714	.717	.732	.741	.757	.770	.784
Main Bus	.925	.925	.929	.930	.928	.930	.927	.927	.915
	****	****	****	****	****	****	****	****	****
CUM. EOL FACTOR	.596	.604	.615	.619	.625	.642	.649	.663	.676
ILLUMINATION FACTORS									
Cover Degradation (EOL)	.870	.870	.870	.870	.870	.870	.870	.870	.870
Concentration Ratio (BOL)	5.000	5.000	5.000	5.000	5.000	5.000	5.000	5.000	5.000
Concentrator Degrad. (EOL)	.990	.960	.930	.900	.850	.800	.750	.700	.650
	*****	*****	*****	*****	*****	*****	*****	*****	*****
CUM. EOL FACTOR	4.380	4.247	4.114	3.982	3.760	3.539	3.318	3.097	2.876
PHYSICAL CHARACTERISTICS									
Total Number of Cells	1308672	1327104	1363968	1400832	1474560	1548288	1651200	1747200	1881600
No. of Modules/Panel	8	8	8	8	8	8	8	8	8
No. of Panels/Blanket	48	48	48	48	48	48	60	60	60
Blanket Weight (Kg)	1460.0	1498.0	1508.0	1519.0	1621.0	1664.0	1802.0	1870.0	2008.0
Structure Weight (Kg)	1710.0	1743.0	1751.0	1762.0	1862.0	1899.0	2057.0	2124.0	2261.0
Total Array Weight (Kg)	7550.0	7735.0	7783.0	7838.0	8346.0	8555.0	9265.0	9604.0	10293.0
Solar Cell Area (cm2)	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000
Module Area (M^2)	.850	.880	.880	.880	.960	.980	.850	.880	.960
Concentrator Area (M^2)	7.70	7.98	7.98	7.98	8.70	8.88	7.70	7.98	8.70
Panel Area (M^2)	34.00	35.50	35.50	35.50	38.60	39.40	34.00	35.50	38.60
Blanket Area (M^2)	1667.0	1743.0	1743.0	1743.0	1893.0	1928.0	2079.0	2174.0	2362.0
Total Array Area (M^2)	6668.0	6972.0	6972.0	6972.0	7572.0	7712.0	8316.0	8696.0	9448.0
Power Density (W/M2)	98.72	93.27	93.90	93.63	86.27	84.32	78.83	75.14	69.11
Power/Weight Ratio (W/Kg)	87.19	84.07	84.12	83.29	78.27	76.01	70.75	68.04	63.43
LIFE CYCLE COST (1980$M)									
DDT&E	168.547	169.315	170.164	171.023	173.606	175.536	210.399	213.057	217.260
PRODUCTION	481.563	483.756	486.184	488.638	496.017	501.531	601.139	608.735	620.742
(Solar Cell - $/Cell)	(29.30)	(29.30)	(29.30)	(29.30)	(29.30)	(29.30)	(29.30)	(29.30)	(29.30)
OPERATIONS & MAINTENANCE	181.493	183.327	183.972	184.640	189.857	192.151	224.337	227.925	235.223
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TOTAL LIFE CYCLE COST	831.603	836.398	840.320	844.301	859.480	869.218	1035.875	1049.717	1073.225

Exhibit 6a. Concentrator Degradation

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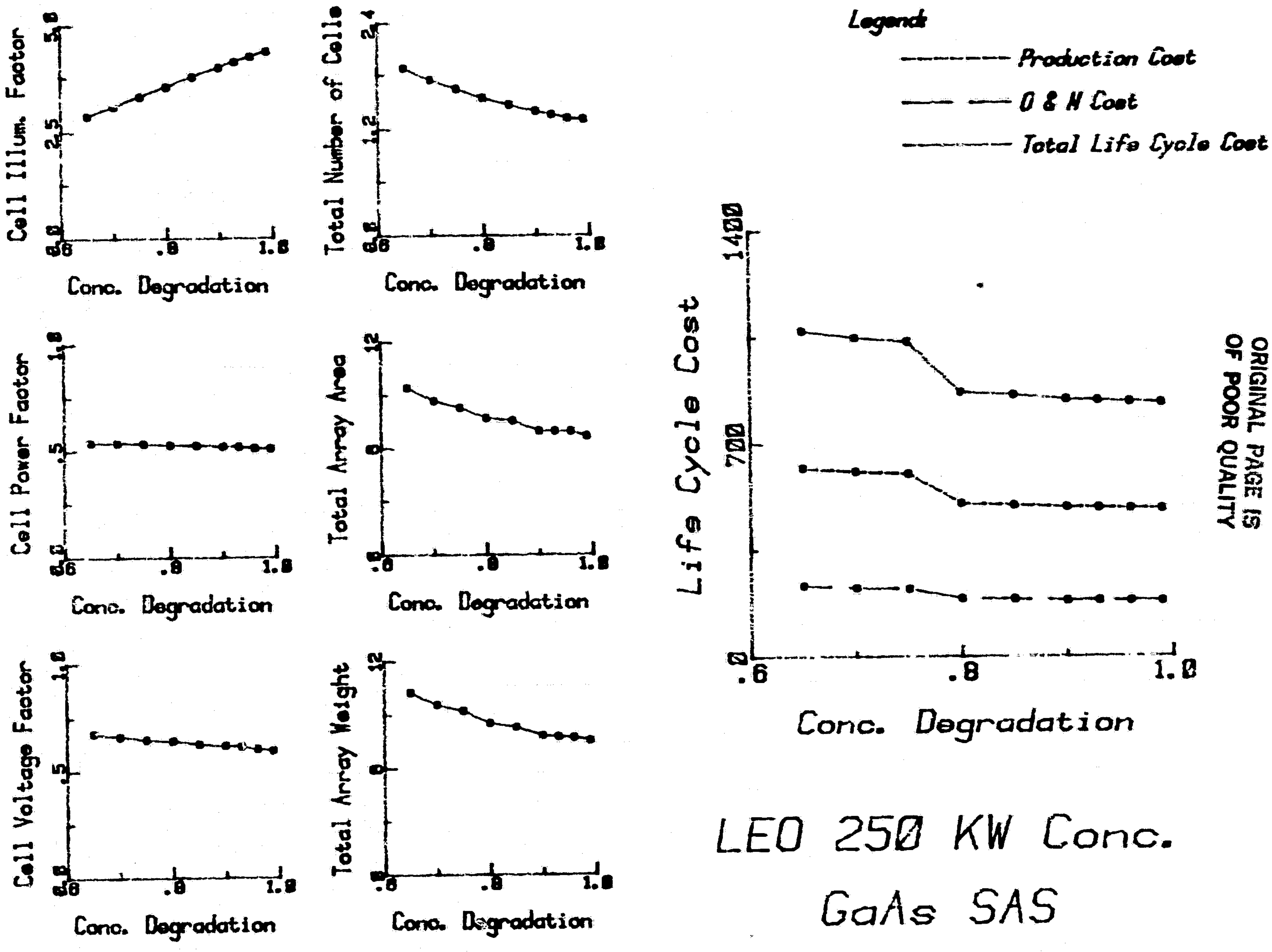

Exhibit 6a. Concentrator Degradation Continued

GEO 50 KW Conc. GaAs SAS

ARRAY PERFORMANCE									
No. of Hardware Life Cycles	1	1	1	1	1	1	1	1	1
Total Cell Life Required (Yr)	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0
Total EOL Min. Power (KW)	71.5	72.9	70.7	71.8	70.9	72.3	70.6	72.1	71.6
Total EOL Min. Voltage (V)	181.0	182.0	183.0	186.0	187.0	191.0	193.0	182.0	185.0
BOL Cell Efficiency (%)	18.1	18.1	18.1	18.1	18.1	18.1	18.1	18.1	18.1
BOL Cell Max. Voltage (V)	.845	.843	.842	.841	.838	.836	.834	.831	.829
EOL Cell Power (MW)	445.0	434.0	421.0	411.0	391.0	371.0	350.0	330.0	310.0
EOL Cell Voltage (V)	.539	.543	.546	.553	.558	.568	.575	.583	.592
POWER FACTORS									
Radiation	.779	.779	.779	.779	.779	.779	.779	.779	.779
Temperature	.832	.836	.839	.844	.850	.857	.864	.872	.880
Main Bus	.967	.968	.968	.969	.969	.968	.968	.969	.970
	****	****	****	****	****	****	****	****	****
CUM. EOL FACTOR	.473	.476	.477	.481	.484	.488	.491	.497	.502
VOLTAGE FACTORS									
Radiation	.963	.963	.963	.963	.963	.963	.963	.963	.963
Temperature	.715	.721	.727	.734	.744	.757	.768	.782	.795
Main Bus	.967	.968	.968	.969	.969	.968	.968	.969	.970
	****	****	****	****	****	****	****	****	****
CUM. EOL FACTOR	.638	.644	.649	.657	.666	.679	.689	.701	.714
ILLUMINATION FACTORS									
Cover Degradation (EOL)	.870	.870	.870	.870	.870	.870	.870	.870	.870
Concentration Ratio (BOL)	5.000	5.000	5.000	5.000	5.000	5.000	5.000	5.000	5.000
Concentrator Degrad. (EOL)	.990	.960	.930	.900	.850	.800	.750	.700	.650
	*****	*****	*****	*****	*****	*****	*****	*****	*****
CUM. EOL FACTOR	4.380	4.247	4.114	3.982	3.760	3.539	3.318	3.097	2.876
PHYSICAL CHARACTERISTICS									
Total Number of Cells	161280	168000	168000	174720	181440	194880	201600	218400	230880
No. of Modules/Panel	3	3	3	3	3	3	3	3	3
No. of Panels/Blanket	20	20	20	20	20	20	20	20	20
Blanket Weight (Kg)	215.0	224.0	224.0	230.0	231.0	253.0	255.0	273.0	290.0
Structure Weight (Kg)	212.0	221.0	220.0	225.0	226.0	245.0	246.0	264.0	279.0
Total Array Weight (Kg)	1072.0	1117.0	1116.0	1145.0	1150.0	1257.0	1266.0	1356.0	1439.0
Solar Cell Area (cm2)	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000
Module Area (M^2)	.660	.690	.690	.720	.720	.810	.810	.880	.960
Concentrator Area (M^2)	5.98	6.25	6.25	6.53	6.53	7.34	7.34	7.98	8.70
Panel Area (M^2)	9.80	10.40	10.40	10.80	10.80	12.20	12.20	13.30	14.50
Blanket Area (M^2)	205.0	216.0	216.0	226.0	226.0	253.0	253.0	276.0	300.0
Total Array Area (M^2)	820.0	864.0	864.0	904.0	904.0	1012.0	1012.0	1104.0	1200.0
Power Density (W/M2)	87.52	84.39	81.86	79.43	78.48	71.44	69.72	65.28	59.64
Power/Weight Ratio (W/Kg)	66.95	65.27	63.38	62.71	61.69	57.52	55.73	53.13	49.74
LIFE CYCLE COST (1980$M)									
DDT&E	43.590	43.808	43.806	44.008	44.158	44.633	44.788	45.303	45.724
PRODUCTION	124.544	125.165	125.161	125.736	126.166	127.522	127.966	129.437	130.639
(Solar Cell - $/Cell)	(29.30)	(29.30)	(29.30)	(29.30)	(29.30)	(29.30)	(29.30)	(29.30)	(29.30)
OPERATIONS & MAINTENANCE	.900	.900	.900	.900	.900	.900	.900	.900	.900
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TOTAL LIFE CYCLE COST	169.034	169.873	169.867	170.644	171.224	173.055	173.654	175.640	177.263

Exhibit 6b. Concentrator Degradation

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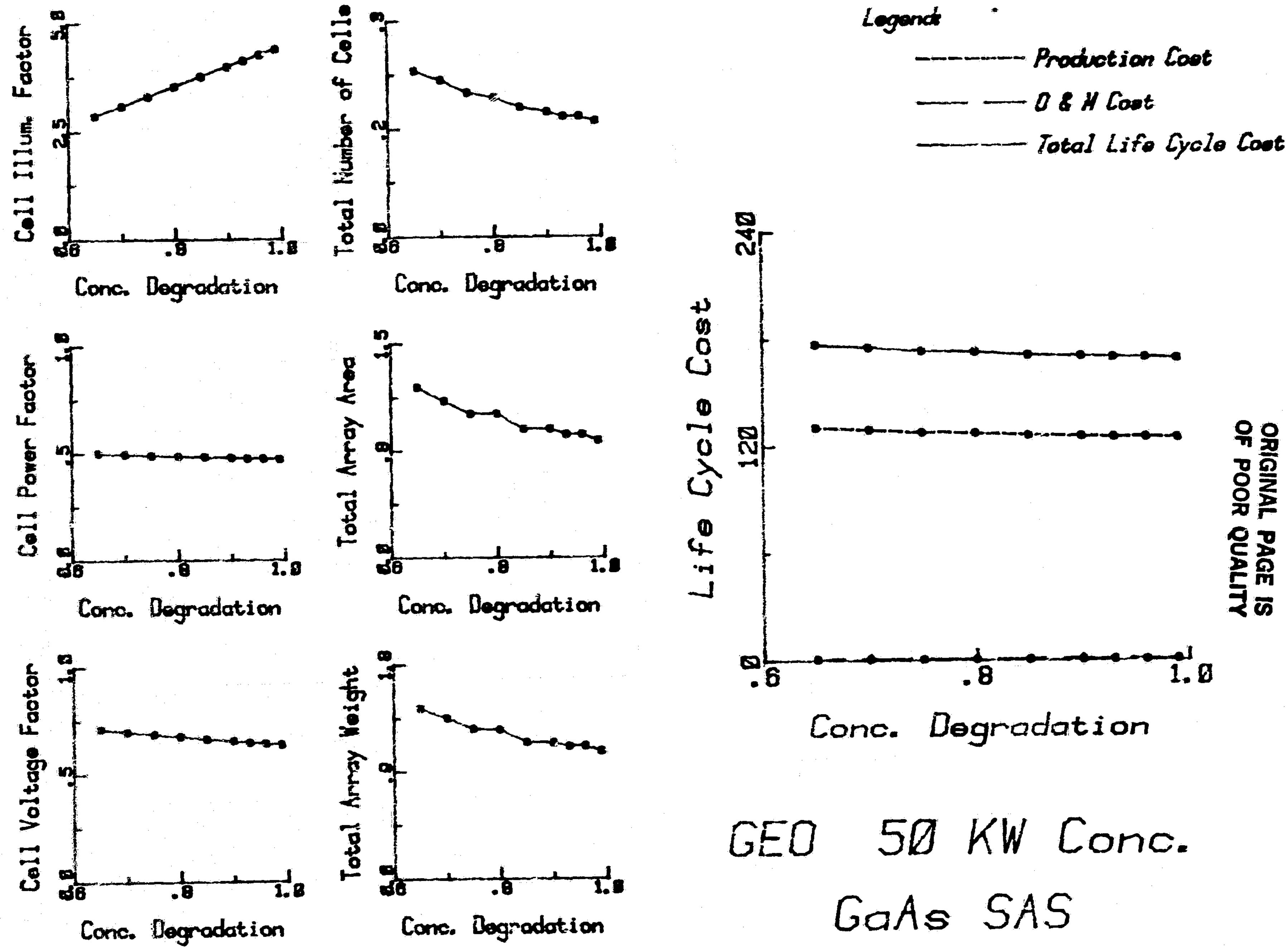

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Exhibit 6b. Concentrator Degradation Continued

LEO 250 KW Planar GaAs SAS

ARRAY PERFORMANCE									
No. of Hardware Life Cycles	1	1	1	1	1	1	1	1	1
Total Cell Life Required (Yr)	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0
Total EOL Min. Power (KW)	652.2	653.0	651.3	653.2	652.9	650.4	651.1	650.3	650.7
Total EOL Min. Voltage (V)	196.0	194.0	191.0	188.0	184.0	180.0	234.0	229.0	223.0
BOL Cell Efficiency (%)	18.1	18.1	18.1	18.1	18.1	18.1	18.1	18.1	18.1
BOL Cell Max. Voltage (V)	.810	.810	.810	.810	.810	.810	.810	.810	.810
EOL Cell Power (MW)	139.0	134.0	125.0	120.0	110.0	102.0	91.0	84.0	70.0
EOL Cell Voltage (V)	.727	.718	.706	.696	.680	.668	.649	.638	.619
POWER FACTORS									
Radiation	.990	.950	.891	.850	.779	.725	.650	.600	.500
Temperature	.982	.982	.981	.981	.980	.979	.978	.978	.976
Main Bus	.959	.960	.960	.961	.961	.961	.963	.964	.966
	****	****	****	****	****	****	****	****	****
CUM. EOL FACTOR	.704	.676	.634	.605	.554	.515	.462	.427	.356
VOLTAGE FACTORS									
Radiation	.997	.985	.968	.956	.935	.919	.897	.883	.853
Temperature	.970	.969	.968	.967	.965	.964	.962	.962	.959
Main Bus	.959	.960	.960	.961	.961	.961	.963	.964	.966
	****	****	****	****	****	****	****	****	****
CUM. EOL FACTOR	.898	.886	.871	.859	.839	.825	.801	.788	.764
ILLUMINATION FACTORS									
Cover Degradation (EOL)	.870	.870	.870	.870	.870	.870	.870	.870	.870
Concentration Ratio (BOL)	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Concentrator Degrad. (EOL)	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
	*****	*****	*****	*****	*****	*****	*****	*****	*****
CUM. EOL FACTOR	.885	.885	.885	.885	.885	.885	.885	.885	.885
PHYSICAL CHARACTERISTICS									
Total Number of Cells	4691520	4872960	5209920	5443200	5935680	6376320	7153920	7741440	9296640
No. of Modules/Panel	15	15	15	15	15	15	15	15	15
No. of Panels/Blanket	36	36	36	36	36	36	48	48	48
Blanket Weight (Kg)	2100.0	2174.0	2323.0	2413.0	2631.0	2820.0	3160.0	3413.0	4065.0
Structure Weight (Kg)	3128.0	3230.0	3427.0	3555.0	3844.0	4097.0	9463.0	10187.0	12022.0
Total Array Weight (Kg)	11528.0	11926.0	12719.0	13207.0	14368.0	15377.0	22103.0	23839.0	28282.0
Solar Cell Area (cm2)	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000
Module Area (M^2)	2.410	2.480	2.650	2.730	2.990	3.200	2.730	2.950	3.480
Concentrator Area (M^2)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Panel Area (M^2)	34.30	35.40	37.90	39.00	42.80	45.80	39.00	42.20	49.90
Blanket Area (M^2)	1257.0	1299.0	1389.0	1431.0	1567.0	1678.0	1903.0	2057.0	2434.0
Total Array Area (M^2)	5028.0	5196.0	5556.0	5724.0	6268.0	6712.0	7612.0	8228.0	9736.0
Power Density (W/M2)	129.71	125.68	117.23	114.11	104.16	96.91	85.53	79.04	66.83
Power/Weight Ratio (W/Kg)	56.57	54.76	51.21	49.46	45.44	42.30	29.46	27.28	23.01
LIFE CYCLE COST (1980$M)									
DDT&E	240.987	245.362	253.550	259.150	271.124	281.801	347.572	362.236	400.864
PRODUCTION	688.534	701.034	724.429	740.429	774.641	805.147	993.063	1034.959	1145.327
(Solar Cell - $/Cell)	(29.30)	(29.30)	(29.30)	(29.30)	(29.30)	(29.30)	(29.30)	(29.30)	(29.30)
OPERATIONS & MAINTENANCE	185.157	188.689	195.460	199.964	209.878	218.659	261.044	272.795	303.596
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TOTAL LIFE CYCLE COST	1114.678	1135.085	1173.439	1199.543	1255.643	1305.607	1601.679	1669.990	1849.787

Exhibit 7a. Cell Degradation

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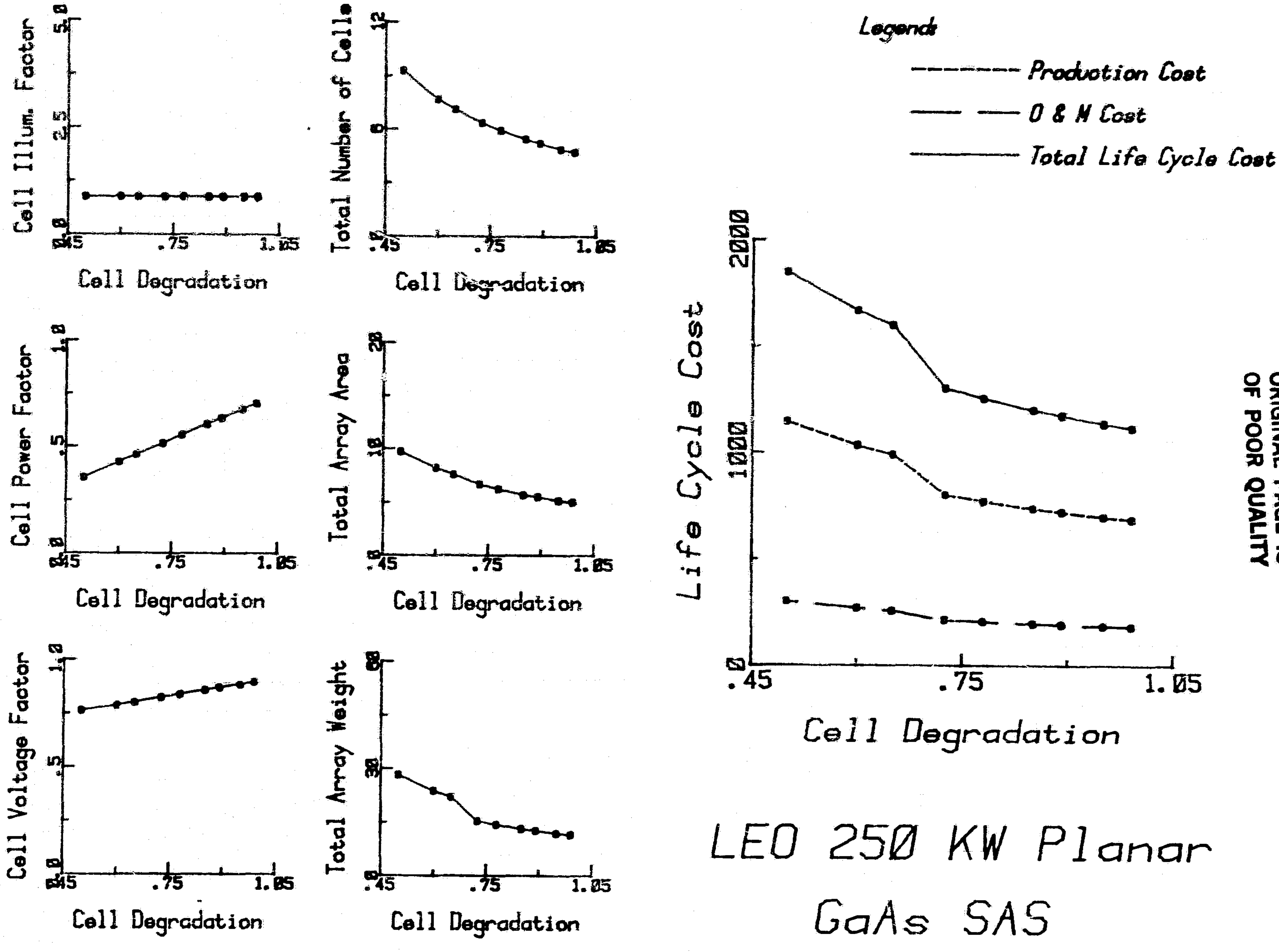

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Exhibit 7a. Cell Degradation Continued

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LEO 250 KW Conc. GaAs SAS

ARRAY PERFORMANCE									
No. of Hardware Life Cycles	1	1	1	1	1	1	1	1	1
Total Cell Life Required (Yr)	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0
Total EOL Min. Power (KW)	656.8	663.4	662.2	650.6	658.1	665.0	659.2	654.5	651.3
Total EOL Min. Voltage (V)	193.0	190.0	192.0	190.0	185.0	218.0	212.0	190.0	211.0
BOL Cell Efficiency (%)	18.1	18.1	18.1	18.1	18.1	18.1	18.1	18.1	18.1
BOL Cell Max. Voltage (V)	.810	.810	.810	.810	.810	.810	.810	.810	.810
EOL Cell Power (MW)	540.0	518.0	479.0	458.0	418.0	390.0	349.0	317.0	265.0
EOL Cell Voltage (V)	.501	.495	.480	.473	.461	.454	.441	.426	.412
POWER FACTORS									
Radiation	.990	.950	.891	.850	.779	.725	.650	.600	.500
Temperature	.829	.828	.827	.826	.825	.824	.823	.822	.821
Main Bus	.917	.918	.907	.908	.906	.911	.911	.895	.899
	****	****	****	****	****	****	****	****	****
CUM. EOL FACTOR	.569	.546	.505	.482	.440	.411	.368	.334	.279
VOLTAGE FACTORS									
Radiation	.997	.985	.968	.956	.935	.919	.897	.883	.853
Temperature	.708	.707	.706	.705	.703	.700	.699	.698	.696
Main Bus	.917	.918	.907	.908	.906	.911	.911	.895	.899
	****	****	****	****	****	****	****	****	****
CUM. EOL FACTOR	.619	.611	.592	.584	.569	.560	.545	.526	.509
ILLUMINATION FACTORS									
Cover Degradation (EOL)	.870	.870	.870	.870	.870	.870	.870	.870	.870
Concentration Ratio (BOL)	5.000	5.000	5.000	5.000	5.000	5.000	5.000	5.000	5.000
Concentrator Degrad. (EOL)	.960	.960	.960	.960	.960	.960	.960	.960	.960
	*****	*****	*****	*****	*****	*****	*****	*****	*****
CUM. EOL FACTOR	4.247	4.247	4.247	4.247	4.247	4.247	4.247	4.247	4.247
PHYSICAL CHARACTERISTICS									
Total Number of Cells	1216512	1290240	1382400	1420800	1574400	1704960	1889280	2064384	2457600
No. of Modules/Panel	8	8	8	8	8	8	8	8	8
No. of Panels/Blanket	48	48	60	60	60	72	72	84	96
Blanket Weight (Kg)	2121.0	2143.0	2456.0	2467.0	2640.0	2941.0	3148.0	3525.0	4143.0
Structure Weight (Kg)	3015.0	3062.0	5659.0	5690.0	6838.0	11165.0	13473.0	22470.0	40953.0
Total Array Weight (Kg)	11499.0	11634.0	15483.0	15558.0	17398.0	22929.0	26065.0	36570.0	57525.0
Solar Cell Area (cm2)	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000
Module Area (M^2)	.980	.980	.900	.900	.980	.900	.980	.940	.980
Concentrator Area (M^2)	8.88	8.88	8.16	8.16	8.88	8.16	8.88	8.52	8.88
Panel Area (M^2)	38.70	38.70	35.60	35.60	38.70	35.60	38.70	37.20	38.70
Blanket Area (M^2)	1897.0	1897.0	2180.0	2180.0	2367.0	2613.0	2837.0	3181.0	3777.0
Total Array Area (M^2)	7588.0	7588.0	8720.0	8720.0	9468.0	10452.0	11348.0	12724.0	15108.0
Power Density (W/M2)	86.56	88.08	75.94	74.61	69.51	63.62	58.09	51.44	43.11
Power/Weight Ratio (W/Kg)	57.12	57.45	42.77	41.82	37.83	29.00	25.29	17.90	11.32
LIFE CYCLE COST (1980$M)									
DDT&E	171.309	173.057	211.401	212.315	218.182	259.059	267.105	314.668	379.026
PRODUCTION	489.455	494.448	604.002	606.615	623.377	740.168	763.157	899.052	1082.930
(Solar Cell - $/Cell)	(29.30)	(29.30)	(29.30)	(29.30)	(29.30)	(29.30)	(29.30)	(29.30)	(29.30)
OPERATIONS & MAINTENANCE	186.276	187.589	222.730	223.392	231.007	265.841	274.979	313.056	361.862
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TOTAL LIFE CYCLE COST	847.040	855.094	1038.133	1042.322	1072.566	1265.068	1305.241	1526.776	1823.818

Exhibit 7b. Cell Degradation

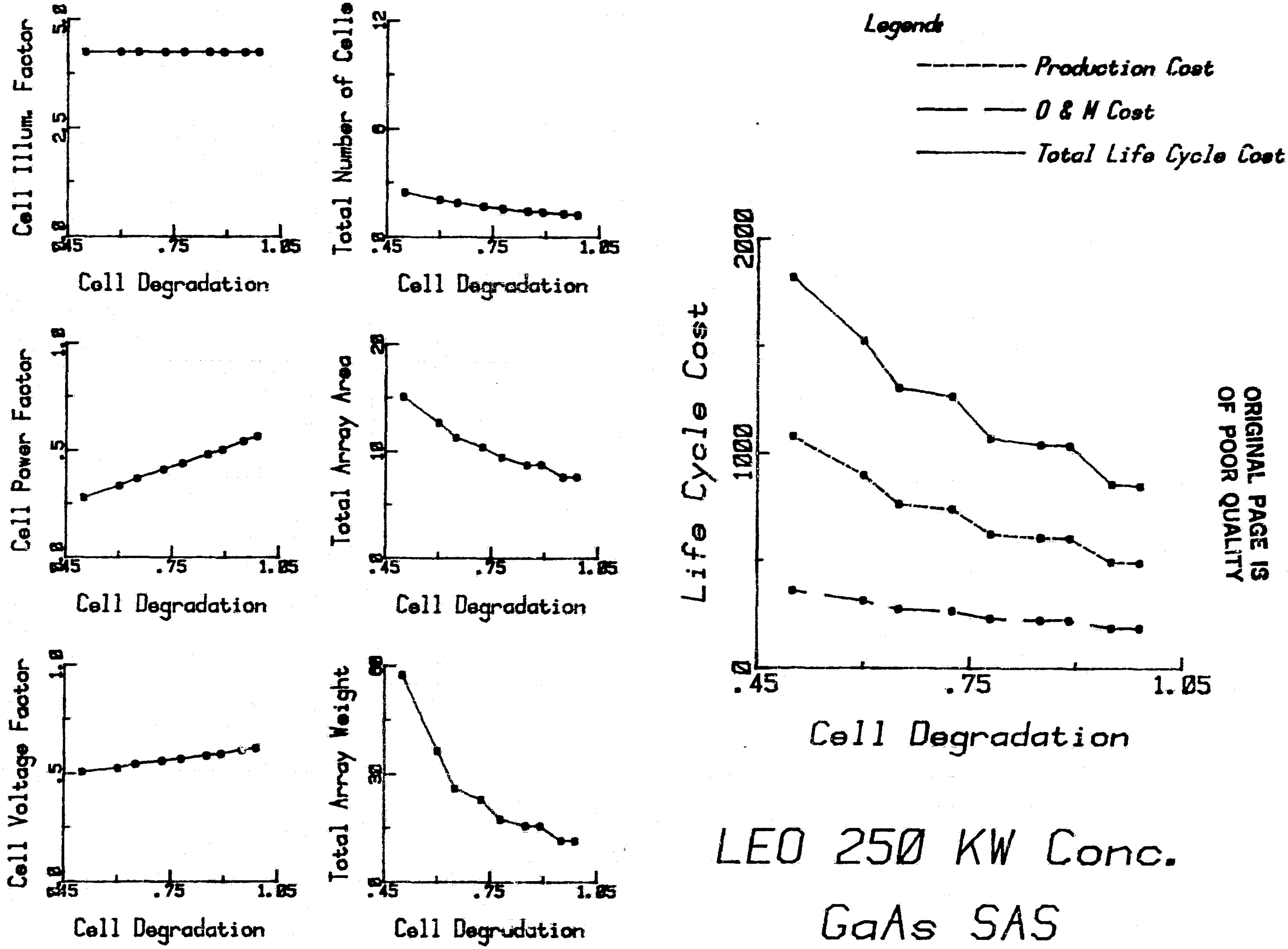

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Exhibit 7b. Cell Degradation Continued

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GEO 50 KW Planar GaAs SAS

ARRAY PERFORMANCE									
No. of Hardware Life Cycles	1	1	1	1	1	1	1	1	1
Total Cell Life Required (Yr)	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0
Total EOL Min. Power (KW)	70.7	71.5	71.6	70.7	70.6	71.5	71.0	70.6	70.6
Total EOL Min. Voltage (V)	182.0	181.0	201.0	200.0	197.0	217.0	213.0	211.0	207.0
BOL Cell Efficiency (%)	18.1	18.1	18.1	18.1	18.1	18.1	18.1	18.1	18.1
BOL Cell Max. Voltage (V)	.810	.810	.810	.810	.810	.810	.810	.810	.810
EOL Cell Power (MW)	139.0	133.0	125.0	119.0	109.0	101.0	91.0	84.0	70.0
EOL Cell Voltage (V)	.759	.754	.746	.741	.731	.721	.710	.702	.689
POWER FACTORS									
Radiation	.990	.950	.891	.850	.779	.725	.650	.600	.500
Temperature	.988	.988	.987	.986	.985	.985	.984	.983	.982
Main Bus	.990	.991	.991	.992	.992	.989	.989	.990	.990
	****	****	****	****	****	****	****	****	****
CUM. EOL FACTOR	.730	.702	.657	.627	.574	.533	.477	.440	.367
VOLTAGE FACTORS									
Radiation	.998	.992	.982	.975	.963	.954	.941	.933	.916
Temperature	.980	.979	.978	.977	.975	.974	.972	.971	.969
Main Bus	.990	.991	.991	.992	.992	.989	.989	.990	.990
	****	****	****	****	****	****	****	****	****
CUM. EOL FACTOR	.937	.931	.921	.915	.902	.890	.876	.867	.851
ILLUMINATION FACTORS									
Cover Degradation (EOL)	.870	.870	.870	.870	.870	.870	.870	.870	.870
Concentration Ratio (BOL)	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Concentrator Degrad. (EOL)	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
	*****	*****	*****	*****	*****	*****	*****	*****	*****
CUM. EOL FACTOR	.885	.885	.885	.985	.885	.885	.885	.885	.885
PHYSICAL CHARACTERISTICS									
Total Number of Cells	508800	537600	572400	594000	648000	708000	780000	840000	1008000
No. of Modules/Panel	15	15	15	15	15	15	15	15	15
No. of Panels/Blanket	5	5	5	5	5	10	10	10	10
Blanket Weight (Kg)	279.0	295.0	312.0	326.0	352.0	356.0	390.0	416.0	497.0
Structure Weight (Kg)	78.0	79.0	78.0	78.0	79.0	94.0	96.0	98.0	103.0
Total Array Weight (Kg)	1194.0	1259.0	1326.0	1382.0	1487.0	1518.0	1656.0	1762.0	2091.0
Solar Cell Area (cm2)	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000
Module Area (M^2)	1.900	1.930	2.110	2.190	2.360	1.360	1.490	1.560	1.860
Concentrator Area (M^2)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Panel Area (M^2)	27.00	28.10	30.00	31.10	33.60	19.[illegible]0	21.00	22.10	26.40
Blanket Area (M^2)	146.0	152.0	162.0	168.0	181.0	199.0	218.0	230.0	275.0
Total Array Area (M^2)	584.0	608.0	648.0	672.0	724.0	796.0	872.0	920.0	1100.0
Power Density (W/M2)	121.10	117.60	110.43	105.18	97.57	89.85	81.42	76.70	64.15
Power/Weight Ratio (W/kg)	59.23	56.79	53.97	51.14	47.51	47.11	42.87	40.05	33.74
LIFE CYCLE COST (1980$M)									
DDT&E	29.861	30.555	31.382	31.910	33.194	50.326	52.038	53.454	57.456
PRODUCTION	85.316	87.299	89.662	91.170	94.841	143.789	148.680	152.725	164.159
(Solar Cell - $/Cell)	(29.30)	(29.30)	(29.30)	(29.30)	(29.30)	(29.30)	(29.30)	(29.30)	(29.30)
OPERATIONS & MAINTENANCE	.900	.900	.900	.900	.900	.900	.900	.900	.900
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TOTAL LIFE CYCLE COST	116.077	118.754	121.944	123.980	128.935	195.015	201.618	207.079	222.515

Exhibit 7c. Cell Degradation

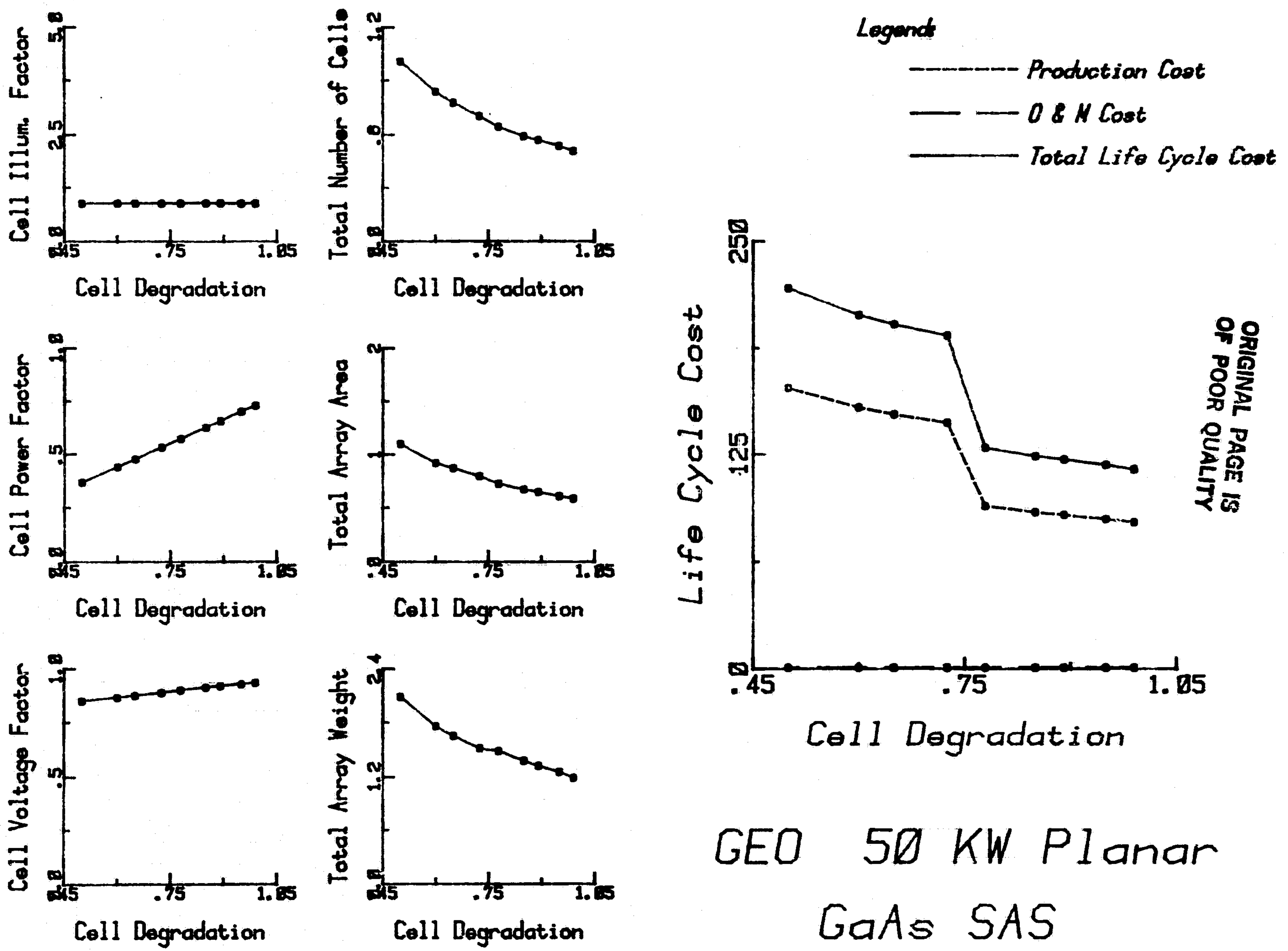

Exhibit 7c. Cell Degradation Continued

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GEO 50 KW Conc. GaAs SAS

ARRAY PERFORMANCE									
No. of Hardware Life Cycles	1	1	1	1	1	1	1	1	1
Total Cell Life Required (Yr)	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0
Total EOL Min. Power (KW)	75.0	71.9	74.1	75.6	75.5	76.0	73.6	72.1	70.7
Total EOL Min. Voltage (V)	184.0	183.0	181.0	192.0	189.0	187.0	184.0	182.0	196.0
BOL Cell Efficiency (%)	18.1	18.1	18.1	18.1	18.1	18.1	18.1	18.1	18.1
BOL Cell Max. Voltage (V)	.810	.810	.810	.810	.810	.810	.810	.810	.810
EOL Cell Power (MW)	558.0	535.0	501.0	477.0	437.0	406.0	365.0	334.0	279.0
EOL Cell Voltage (V)	.548	.544	.538	.534	.526	.519	.511	.504	.494
POWER FACTORS									
Radiation	.990	.950	.891	.850	.779	.725	.650	.600	.500
Temperature	.838	.837	.836	.835	.834	.833	.832	.831	.830
Main Bus	.978	.978	.978	.978	.979	.980	.980	.977	.976
	****	****	****	****	****	****	****	****	****
CUM. EOL FACTOR	.612	.587	.550	.524	.480	.446	.400	.367	.306
VOLTAGE FACTORS									
Radiation	.998	.992	.982	.975	.963	.954	.941	.933	.916
Temperature	.724	.723	.721	.720	.718	.717	.715	.713	.711
Main Bus	.978	.978	.978	.978	.979	.980	.980	.977	.976
	****	****	****	****	****	****	****	****	****
CUM. EOL FACTOR	.676	.671	.664	.659	.649	.641	.631	.622	.610
ILLUMINATION FACTORS									
Cover Degradation (EOL)	.870	.870	.870	.870	.870	.870	.870	.870	.870
Concentration Ratio (BOL)	5.000	5.000	5.000	5.000	5.000	5.000	5.000	5.000	5.000
Concentrator Degrad. (EOL)	.960	.960	.960	.960	.960	.960	.960	.960	.960
	*****	*****	*****	*****	*****	*****	*****	-*****	*****
CUM. EOL FACTOR	4.247	4.247	4.247	4.247	4.247	4.247	4.247	4.247	4.247
PHYSICAL CHARACTERISTICS									
Total Number of Cells	134400	134400	147840	158400	172800	187200	201600	216000	253440
No. of Modules/Panel	6	6	6	6	6	6	6	6	6
No. of Panels/Blanket	10	10	10	10	10	10	10	15	15
Blanket Weight (Kg)	317.0	317.0	336.0	352.0	376.0	388.0	403.0	457.0	523.0
Structure Weight (Kg)	75.0	75.0	76.0	76.0	78.0	80.0	80.0	90.0	97.0
Total Array Weight (Kg)	1343.0	1343.0	1420.0	1484.0	1582.0	1632.0	1692.0	1918.0	2189.0
Solar Cell Area (cm2)	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000
Module Area (M^2)	.710	.710	.770	.830	.900	.940	.980	.740	.900
Concentrator Area (M^2)	6.43	6.43	6.98	7.52	8.16	8.52	8.88	6.71	8.16
Panel Area (M^2)	20.90	20.90	23.00	24.50	26.70	27.90	29.00	21.90	26.70
Blanket Area (M^2)	223.0	223.0	244.0	260.0	283.0	295.0	306.0	344.0	418.0
Total Array Area (M^2)	892.0	892.0	976.0	1040.0	1132.0	1180.0	1224.0	1376.0	1672.0
Power Density (W/M2)	84.08	80.63	75.90	72.65	66.71	64.41	60.13	52.41	42.31
Power/Weight Ratio (W/Kg)	55.35	53.55	52.17	50.92	47.74	46.57	43.50	37.60	32.32
LIFE CYCLE COST (1980$M)									
DDT&E	28.248	28.248	28.667	29.009	29.478	29.874	30.279	41.750	43.031
PRODUCTION	80.708	80.708	81.907	82.882	84.223	85.355	86.512	119.285	122.947
(Solar Cell - $/Cell)	(29.30)	(29.30)	(29.30)	(29.30)	(29.30)	(29.30)	(29.30)	(29.30)	(29.30)
OPERATIONS & MAINTENANCE	.900	.900	.900	.900	.900	.900	.900	.900	.900
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TOTAL LIFE CYCLE COST	109.856	109.856	111.474	112.791	114.601	116.129	117.691	161.935	166.878

Exhibit 7d. Cell Degradation

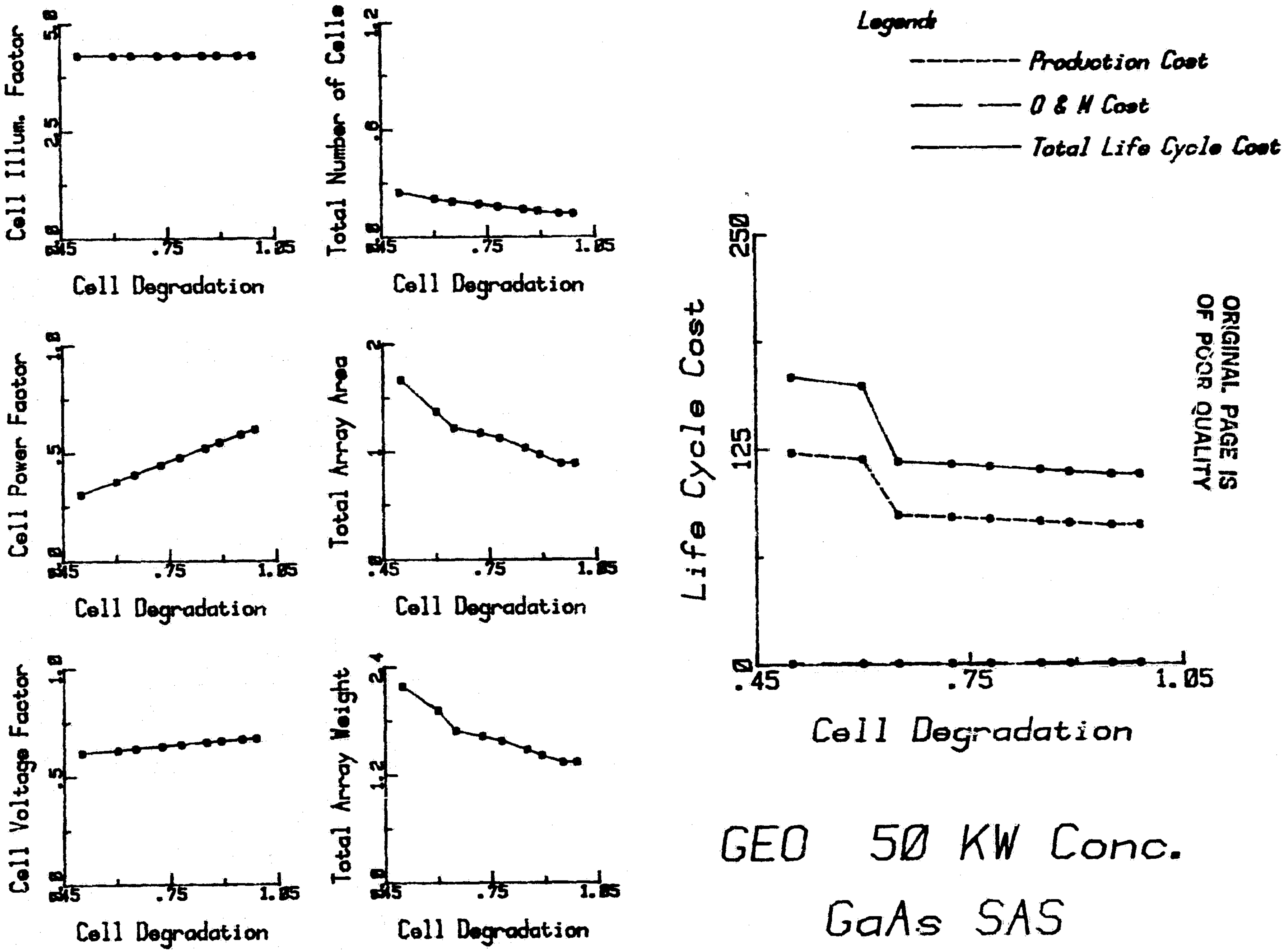

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Exhibit 7d. Cell Degradation Continued

LEO 250 KW Planar GaAs SAS

ARRAY PERFORMANCE									
No. of Hardware Life Cycles	1	1	1	1	1	1	1	1	1
Total Cell Life Required (Yr)	2.50	3.00	3.75	5.00	6.00	7.50	10.00	15.00	30.00
Total EOL Min. Power (KW)	652.1	652.3	652.3	651.1	651.2	651.3	650.7	651.5	650.2
Total EOL Min. Voltage (V)	218.0	217.0	218.0	217.0	217.0	216.0	215.0	191.0	246.0
BOL Cell Efficiency (%)	18.1	18.1	18.1	18.1	18.1	18.1	18.1	18.1	18.1
BOL Cell Max. Voltage (V)	.810	.810	.810	.809	.809	.809	.809	.808	.807
EOL Cell Power (MW)	153.0	151.0	149.0	144.0	140.0	135.0	128.0	110.0	71.0
EOL Cell Voltage (V)	.725	.723	.725	.722	.722	.720	.718	.705	.682
POWER FACTORS									
Radiation	.903	.902	.900	.898	.896	.894	.890	.864	.783
Temperature	.984	.983	.984	.984	.983	.983	.983	.981	.979
Main Bus	.976	.976	.976	.976	.976	.976	.976	.971	.973
Temperature Cycling	.946	.935	.920	.894	.875	.846	.800	.715	.511
	****	****	****	****	****	****	****	****	****
CUM. EOL FACTOR	.774	.763	.751	.728	.710	.685	.645	.555	.360
VOLTAGE FACTORS									
Radiation	.974	.973	.973	.972	.971	.970	.968	.957	.930
Temperature	.973	.971	.972	.972	.972	.971	.970	.968	.964
Main Bus	.976	.976	.976	.976	.976	.976	.976	.971	.973
Temperature Cycling	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
	****	****	****	****	****	****	****	****	****
CUM. EOL FACTOR	.895	.892	.895	.893	.892	.890	.887	.872	.845
ILLUMINATION FACTORS									
Cover Degradation (EOL)	.966	.959	.949	.933	.920	.901	.870	.811	.658
Concentration Ratio (BOL)	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Concentrator Degrad. (EOL)	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
	*****	*****	*****	*****	*****	*****	*****	*****	*****
CUM. EOL FACTOR	.982	.975	.965	.949	.936	.916	.885	.825	.669
PHYSICAL CHARACTERISTICS									
Total Number of Cells	4262400	4320000	4377600	4521600	4653200	4824000	5083200	5922720	9158400
No. of Modules/Panel	15	15	15	15	15	15	15	15	15
No. of Panels/Blanket	24	24	24	24	24	24	24	36	48
Blanket Weight (Kg)	1674.0	1691.0	1712.0	1759.0	1802.0	1857.0	1944.0	2295.0	3433.0
Structure Weight (Kg)	1876.0	1893.0	1917.0	1969.0	2019.0	2080.0	2184.0	2627.0	3783.0
Total Array Weight (Kg)	8572.0	8657.0	8765.0	9005.0	9227.0	9508.0	9960.0	11807.0	17515.0
Solar Cell Area (cm2)	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000
Module Area (M^2)	2.880	2.880	2.950	3.030	3.130	3.200	3.420	2.630	3.030
Concentrator Area (M^2)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Panel Area (M^2)	43.00	43.00	44.10	45.20	46.80	47.80	51.00	39.30	45.20
Blanket Area (M^2)	1061.0	1061.0	1086.0	1111.0	1150.0	1175.0	1253.0	1447.0	2206.0
Total Array Area (M^2)	4244.0	4244.0	4344.0	4444.0	4600.0	4700.0	5012.0	5788.0	8824.0
Power Density (W/M2)	153.66	153.70	150.15	146.51	141.56	138.56	129.82	112.56	73.69
Power/Weight Ratio (W/Kg)	76.08	75.35	74.42	72.31	70.57	68.50	65.33	55.18	37.13
LIFE CYCLE COST (1980$M)									
DDT&E	186.843	188.183	189.561	192.954	196.021	200.082	206.229	268.048	386.196
PRODUCTION	533.838	537.665	541.602	551.298	560.060	571.663	589.225	765.850	1103.418
(Solar Cell - $/Cell)	(29.30)	(29.30)	(29.30)	(29.30)	(29.30)	(29.30)	(29.30)	(29.30)	(29.30)
OPERATIONS & MAINTENANCE	37.167	44.905	56.594	76.861	93.789	119.699	164.868	311.902	894.977
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TOTAL LIFE CYCLE COST	757.848	770.753	787.757	821.113	849.870	891.444	960.322	1345.800	2384.591

Exhibit 8a. Hardware Life

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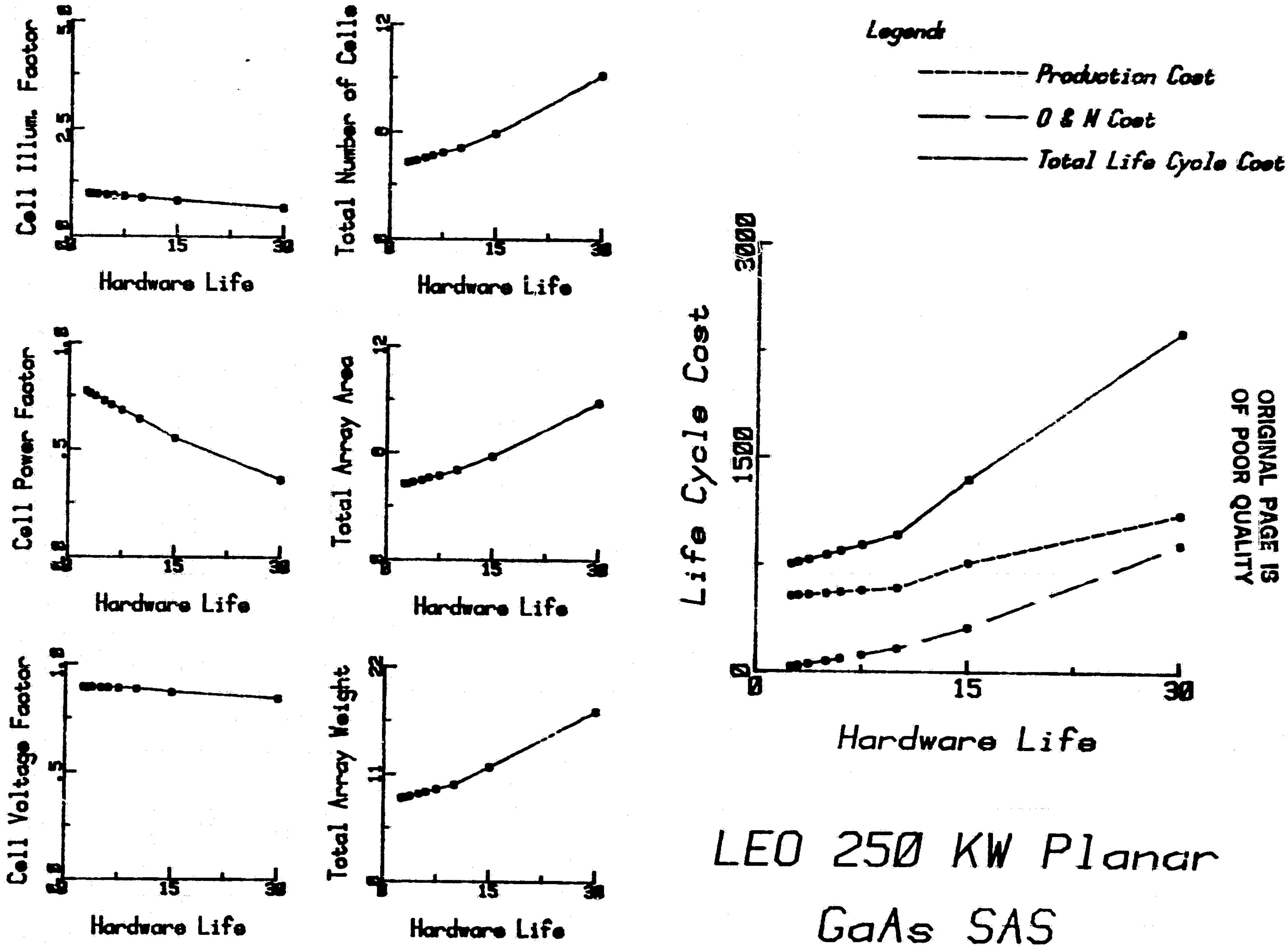

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Exhibit 8a. Hardware Life Continued

LEO 250 KW Conc. GaAs SAS

ARRAY PERFORMANCE									
No. of Hardware Life Cycles	1	1	1	1	1	1	1	1	1
Total Cell Life Required (Yr)	2.50	3.00	3.75	5.00	6.00	7.50	10.00	15.00	30.00
Total EOL Min. Power (KW)	653.6	650.3	657.7	657.3	654.2	655.5	656.6	651.8	650.3
Total EOL Min. Voltage (V)	197.0	197.0	198.0	198.0	196.0	196.0	195.0	201.0	215.0
BOL Cell Efficiency (%)	18.1	18.1	18.1	18.1	18.1	18.1	18.1	18.1	18.1
BOL Cell Max. Voltage (V)	.850	.849	.848	.847	.847	.845	.843	.839	.830
EOL Cell Power (MW)	601.0	598.0	585.0	566.0	546.0	523.0	488.0	414.0	252.0
EOL Cell Voltage (V)	.513	.514	.516	.517	.512	.511	.508	.501	.481
POWER FACTORS									
Radiation	.903	.902	.900	.898	.896	.894	.890	.864	.783
Temperature	.824	.825	.825	.826	.825	.826	.826	.829	.834
Main Bus	.924	.927	.928	.930	.926	.925	.925	.920	.915
Temperature Cycling	.946	.935	.920	.894	.875	.846	.800	.715	.511
	****	****	****	****	****	****	****	****	****
CUM. EOL FACTOR	.613	.611	.600	.583	.565	.545	.513	.445	.288
VOLTAGE FACTORS									
Radiation	.974	.973	.973	.972	.971	.970	.968	.957	.930
Temperature	.701	.702	.703	.704	.703	.703	.704	.708	.718
Main Bus	.924	.927	.928	.930	.926	.925	.925	.920	.915
Temperature Cycling	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
	****	****	****	****	****	****	****	****	****
CUM. EOL FACTOR	.604	.606	.609	.610	.605	.605	.603	.597	.580
ILLUMINATION FACTORS									
Cover Degradation (EOL)	.966	.959	.949	.933	.920	.901	.870	.811	.658
Concentration Ratio (BOL)	5.000	5.000	5.000	5.000	5.000	5.000	5.000	5.000	5.000
Concentrator Degrad. (EOL)	.990	.988	.985	.980	.976	.970	.960	.940	.884
	*****	*****	*****	*****	*****	*****	*****	*****	*****
CUM. EOL FACTOR	4.861	4.817	4.753	4.650	4.568	4.443	4.248	3.878	2.957
PHYSICAL CHARACTERISTICS									
Total Number of Cells	1087488	1087488	1124352	1161216	1198080	1253376	1345536	1574400	2580480
No. of Modules/Panel	8	8	8	8	8	8	8	8	8
No. of Panels/Blanket	48	48	48	48	48	48	48	60	84
Blanket Weight (Kg)	1264.0	1264.0	1275.0	1285.0	1348.0	1403.0	1503.0	1729.0	2749.0
Structure Weight (Kg)	1494.0	1493.0	1509.0	1522.0	1587.0	1646.0	1753.0	2011.0	3153.0
Total Array Weight (Kg)	6550.0	6549.0	6609.0	6662.0	6979.0	7258.0	7765.0	8927.0	14149.0
Solar Cell Area (cm2)	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000
Module Area (M^2)	.720	.720	.720	.720	.770	.810	.880	.810	.960
Concentrator Area (M^2)	6.53	6.53	6.53	6.53	6.98	7.34	7.98	7.34	8.70
Panel Area (M^2)	28.90	28.90	28.90	28.90	31.10	32.60	35.50	32.60	38.60
Blanket Area (M^2)	1422.0	1422.0	1422.0	1422.0	1525.0	1598.0	1743.0	1995.0	3300.0
Total Array Area (M^2)	5688.0	5688.0	5688.0	5688.0	6100.0	6392.0	6972.0	7980.0	13200.0
Power Density (W/M2)	114.90	114.33	115.64	115.55	107.24	102.55	94.18	81.68	49.26
Power/Weight Ratio (W/Kg)	99.78	99.30	99.52	98.66	93.73	90.31	84.56	73.01	45.96
LIFE CYCLE COST (1980$M)									
DDT&E	161.959	161.958	162.821	163.679	165.094	166.813	169.748	208.105	302.072
PRODUCTION	462.739	462.736	465.203	467.655	471.698	476.609	484.994	594.586	863.063
(Solar Cell - $/Cell)	(29.30)	(29.30)	(29.30)	(29.30)	(29.30)	(29.30)	(29.30)	(29.30)	(29.30)
OPERATIONS & MAINTENANCE	42.808	51.369	64.455	86.261	105.365	133.922	183.650	330.795	971.657
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TOTAL LIFE CYCLE COST	667.506	676.063	692.479	717.595	742.157	777.344	838.392	1133.486	2136.792

Exhibit 8b. Hardware Life

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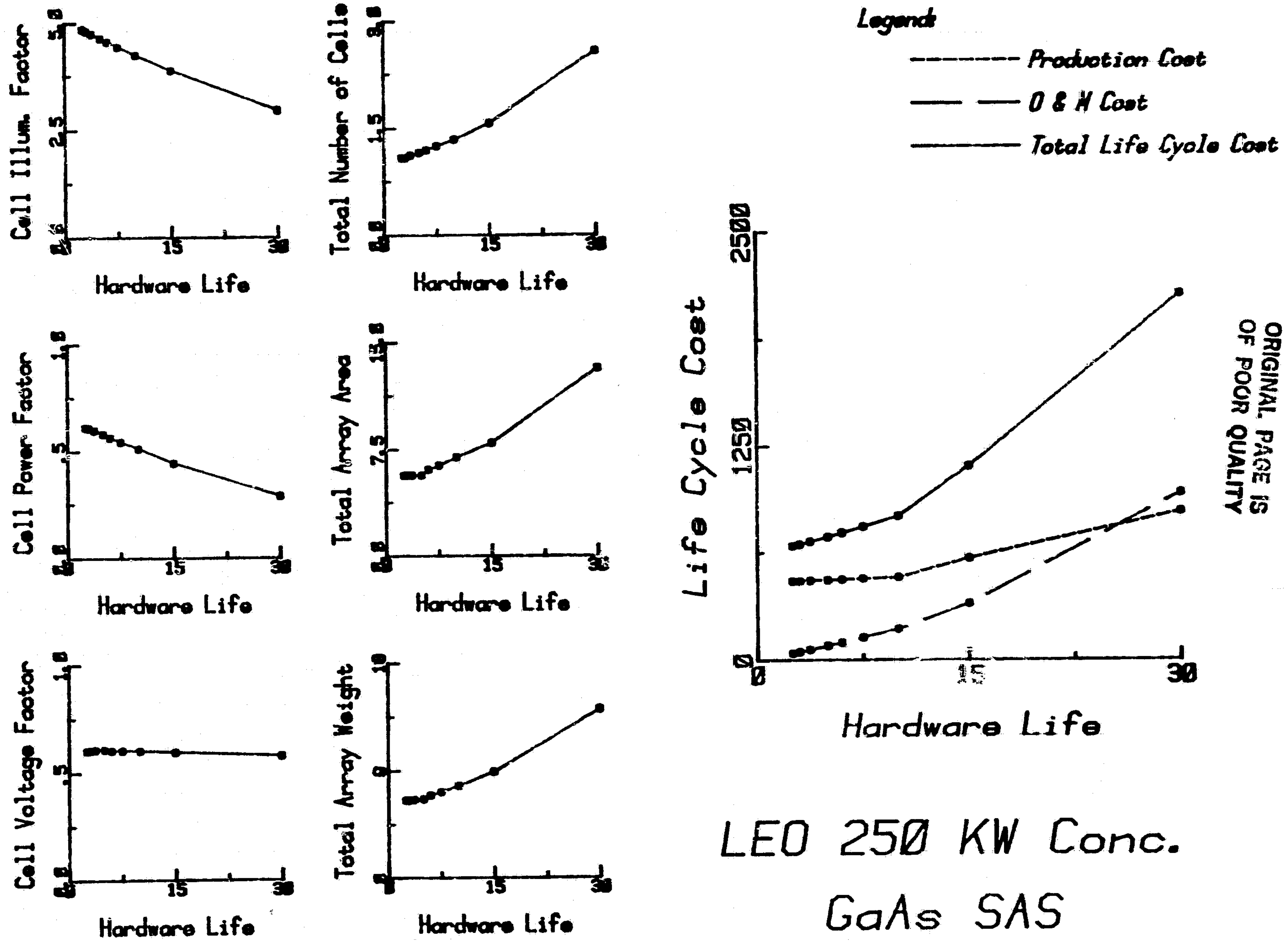

Exhibit 8b. Hardware Life Continued

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GEO 50 KW Planar GaAs SAS

ARRAY PERFORMANCE									
No. of Hardware Life Cycles	1	1	1	1	1	1	1	1	1
Total Cell Life Required (Yr)	2.50	3.00	3.75	5.00	6.00	7.50	10.00	15.00	30.00
Total EOL Min. Power (KW)	71.1	70.8	70.6	70.7	71.0	70.8	70.8	70.8	70.6
Total EOL Min. Voltage (V)	182.0	181.0	180.0	191.0	190.0	195.0	193.0	188.0	187.0
BOL Cell Efficiency (%)	18.1	18.1	18.1	18.1	18.1	18.1	18.1	18.1	18.1
BOL Cell Max. Voltage (V)	.810	.810	.810	.809	.809	.809	.809	.808	.807
EOL Cell Power (MW)	156.0	152.0	147.0	138.0	132.0	123.0	109.0	86.0	42.0
EOL Cell Voltage (V)	.757	.756	.752	.747	.743	.739	.730	.712	.667
POWER FACTORS									
Radiation	.939	.928	.910	.882	.861	.829	.779	.683	.472
Temperature	.991	.991	.990	.990	.989	.988	.987	.985	.983
Main Bus	.989	.989	.989	.989	.989	.990	.989	.989	.986
Temperature Cycling	.946	.935	.920	.894	.875	.846	.800	.715	.511
	****	****	****	****	****	****	****	****	****
CUM. EOL FACTOR	.821	.802	.773	.728	.695	.648	.574	.452	.227
VOLTAGE FACTORS									
Radiation	.991	.989	.986	.981	.977	.972	.963	.944	.842
Temperature	.985	.984	.984	.982	.981	.980	.978	.975	.930
Main Bus	.989	.989	.989	.989	.989	.990	.989	.989	.986
Temperature Cycling	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
	****	****	****	****	****	****	****	****	****
CUM. EOL FACTOR	.934	.933	.929	.923	.919	.913	.902	.881	.826
ILLUMINATION FACTORS									
Cover Degradation (EOL)	.966	.959	.949	.933	.920	.901	.870	.811	.658
Concentration Ratio (BOL)	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Concentrator Degrad. (EOL)	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
	*****	*****	*****	*****	*****	*****	*****	*****	*****
CUM. EOL FACTOR	.982	.975	.965	.949	.936	.916	.865	.825	.659
PHYSICAL CHARACTERISTICS									
Total Number of Cells	456000	465600	480000	512000	537600	575520	649440	823680	1680000
No. of Modules/Panel	4	4	4	4	4	4	4	4	4
No. of Panels/Blanket	10	10	10	10	10	15	15	15	35
Blanket Weight (Kg)	222.0	225.0	230.0	241.0	249.0	275.0	300.0	357.0	695.0
Structure Weight (Kg)	217.0	220.0	225.0	233.0	241.0	263.0	287.0	341.0	663.0
Total Array Weight (Kg)	1105.0	1120.0	1145.0	1197.0	1237.0	1363.0	1487.0	1769.0	3443.0
Solar Cell Area (cm2)	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000
Module Area (M^2)	2.740	2.810	2.900	3.100	3.270	2.310	2.610	3.270	2.900
Concentrator Area (M^2)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Panel Area (M^2)	11.00	11.20	11.60	12.40	13.10	9.20	10.40	13.10	11.60
Blanket Area (M^2)	117.0	120.0	124.0	132.0	139.0	148.0	166.0	205.0	419.0
Total Array Area (M^2)	468.0	480.0	496.0	528.0	556.0	592.0	664.0	820.0	1676.0
Power Density (W/M2)	152.00	147.44	142.26	133.82	127.63	119.58	106.61	86.39	42.10
Power/Weight Ratio (W/Kg)	64.38	63.19	61.62	59.03	57.37	51.94	47.61	40.04	20.49
LIFE CYCLE COST (1980$M)									
DDT&E	32.294	32.520	32.860	33.613	34.214	44.893	46.636	50.732	110.059
PRODUCTION	92.269	92.914	93.887	96.036	97.753	128.265	133.245	144.949	314.454
(Solar Cell - $/Cell)	(29.30)	(29.30)	(29.30)	(29.30)	(29.30)	(29.30)	(29.30)	(29.30)	(29.30)
OPERATIONS & MAINTENANCE	.225	.270	.338	.450	.540	.675	.900	1.350	2.700
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TOTAL LIFE CYCLE COST	124.788	125.704	127.085	130.099	132.507	173.833	180.781	197.031	427.213

Exhibit 8c. Hardware Life

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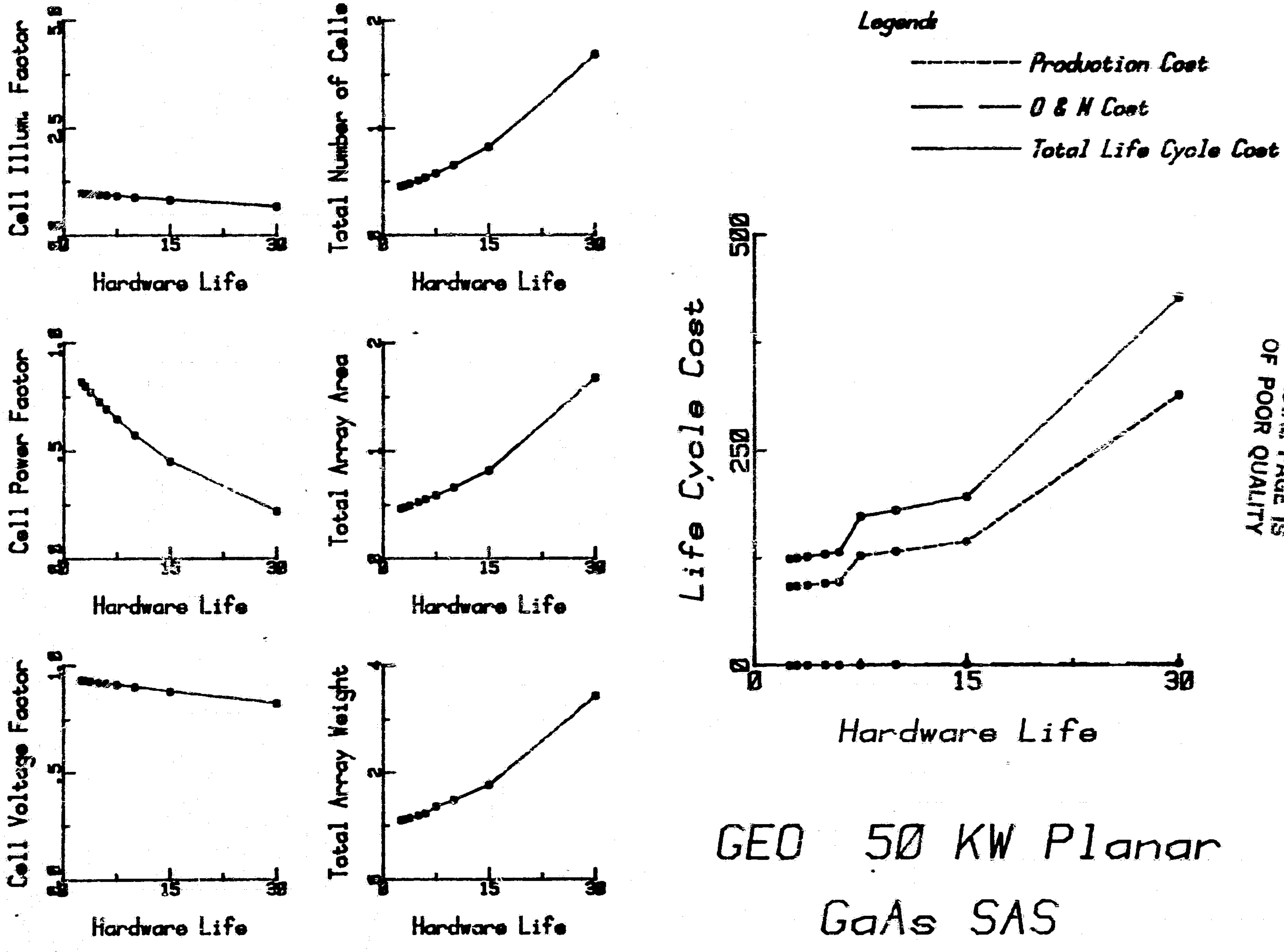

Exhibit 8c. Hardware Life Continued

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GEO 50 KW Conc. GaAs SAS

ARRAY PERFORMANCE									
No. of Hardware Life Cycles	1	1	1	1	1	1	1	1	1
Total Cell Life Required (Yr)	2.50	3.00	3.75	5.00	6.00	7.50	10.00	15.00	30.00
Total EOL Min. Power (KW)	74.4	72.6	73.6	73.0	73.1	71.0	71.6	72.4	71.0
Total EOL Min. Voltage (V)	183.0	182.0	181.0	181.0	190.0	189.0	187.0	192.0	191.0
EOL Cell Efficiency (%)	18.1	18.1	18.1	18.1	18.1	18.1	18.1	18.1	18.1
BOL Cell Max. Voltage (V)	.850	.849	.848	.847	.847	.845	.843	.839	.830
EOL Cell Power (MW)	638.0	622.0	598.0	563.0	534.0	494.0	436.0	335.0	154.0
EOL Cell Voltage (V)	.565	.562	.559	.558	.555	.553	.546	.532	.497
POWER FACTORS									
Radiation	.939	.928	.910	.882	.861	.829	.779	.687	.472
Temperature	.837	.836	.836	.837	.836	.836	.836	.837	.840
Main Bus	.969	.969	.970	.971	.970	.971	.971	.969	.962
Temperature Cycling	.946	.935	.920	.894	.875	.846	.800	.715	.511
	****	****	****	****	****	****	****	****	****
CUM. EOL FACTOR	.679	.663	.640	.605	.576	.537	.478	.376	.184
VOLTAGE FACTORS									
Radiation	.991	.989	.986	.981	.977	.972	.963	.944	.892
Temperature	.723	.721	.721	.722	.720	.721	.721	.722	.729
Main Bus	.969	.969	.970	.971	.970	.971	.971	.969	.962
Temperature Cycling	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
	****	****	****	****	****	****	****	****	****
CUM. EOL FACTOR	.665	.662	.659	.659	.655	.654	.648	.634	.599
ILLUMINATION FACTORS									
Cover Degradation (EOL)	.966	.959	.949	.933	.920	.901	.870	.811	.658
Concentration Ratio (BOL)	5.000	5.000	5.000	5.000	5.000	5.000	5.000	5.000	5.000
Concentrator Degrad. (EOL)	.990	.988	.985	.980	.976	.970	.960	.940	.884
	*****	*****	*****	*****	*****	*****	*****	*****	*****
CUM. EOL FACTOR	4.361	4.817	4.753	4.650	4.568	4.443	4.248	3.878	2.957
PHYSICAL CHARACTERISTICS									
Total Number of Cells	116640	116640	123120	129600	136800	143640	164160	216000	460800
No. of Modules/Panel	3	3	3	3	3	3	3	3	3
No. of Panels/Blanket	15	15	15	15	15	15	15	20	40
Blanket Weight (Kg)	169.0	169.0	171.0	181.0	184.0	199.0	215.0	272.0	534.0
Structure Weight (Kg)	171.0	170.0	172.0	181.0	184.0	195.0	211.0	262.0	509.0
Total Array Weight (Kg)	847.0	846.0	856.0	905.0	920.0	991.0	1071.0	1350.0	2645.0
Solar Cell Area (cm2)	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000
Module Area (M^2)	.660	.660	.660	.720	.720	.810	.830	.880	.960
Concentrator Area (M^2)	5.98	5.98	5.98	6.53	6.53	7.34	7.98	7.98	8.70
Panel Area (M^2)	9.80	9.80	9.80	10.80	10.80	12.20	13.30	13.30	14.50
Blanket Area (M^2)	155.0	155.0	155.0	171.0	171.0	192.0	209.0	276.0	593.0
Total Array Area (M^2)	620.0	620.0	620.0	684.0	684.0	768.0	836.0	1104.0	2372.0
Power Density (W/M2)	120.03	117.02	118.75	106.67	106.80	92.40	85.62	65.54	29.92
Power/Weight Ratio (W/Kg)	87.86	85.76	86.01	80.62	79.40	71.60	66.83	53.60	26.83
LIFE CYCLE COST (1980$M)									
DDT&E	33.081	33.080	33.231	33.460	33.631	33.906	34.475	45.245	89.441
PRODUCTION	94.517	94.515	94.946	95.599	96.089	96.875	98.509	129.270	255.545
(Solar Cell - $/Cell)	(29.30)	(29.30)	(29.30)	(29.30)	(29.30)	(29.30)	(29.30)	(29.30)	(29.30)
OPERATIONS & MAINTENANCE	.225	.270	.338	.450	.540	.675	.900	1.350	2.700
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TOTAL LIFE CYCLE COST	127.823	127.865	128.515	129.509	130.260	131.456	133.887	175.865	347.686

Exhibit 8d. Hardware Life

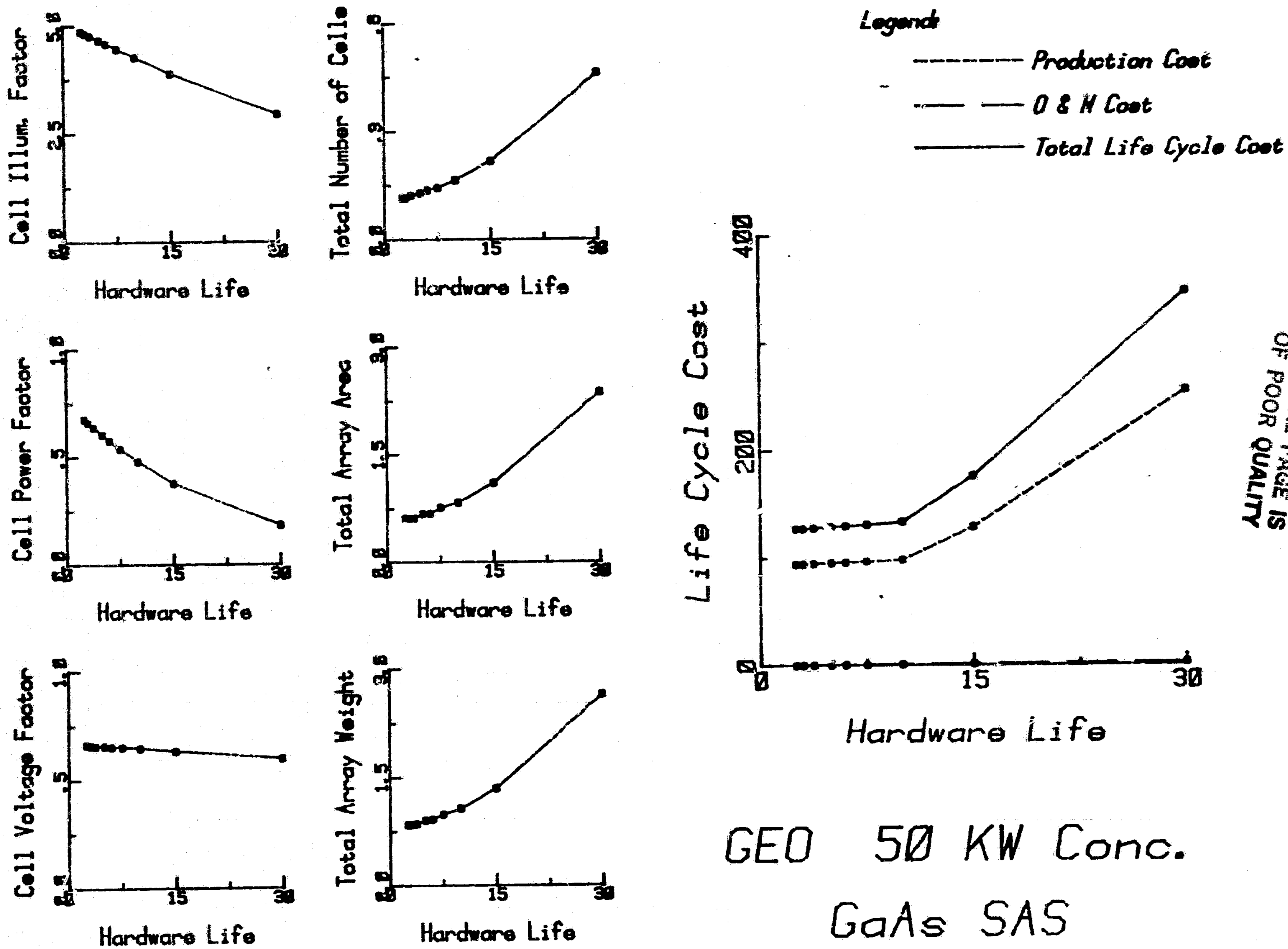

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Exhibit 8d. Hardware Life Continued

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LEO 250 KW Planar GaAs SAS

ARRAY PERFORMANCE									
No. of Hardware Life Cycles	1	1	1	1	1	1	1	1	1
Total Cell Life Required (Yr)	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0
Total EOL Min. Power (KW)	683.7	716.1	748.5	780.9	813.3	845.7	881.3	911.6	946.2
Total EOL Min. Voltage (V)	191.0	191.0	191.0	191.0	191.0	191.0	254.0	254.0	254.0
BOL Cell Efficiency (%)	18.1	18.1	18.1	18.1	18.1	18.1	18.1	18.1	18.1
BOL Cell Max. Voltage (V)	.810	.810	.810	.810	.810	.810	.810	.810	.810
EOL Cell Power (MW)	125.0	125.0	125.0	125.0	125.0	125.0	125.0	125.0	125.0
EOL Cell Voltage (V)	.706	.706	.706	.706	.706	.706	.706	.706	.706
Spares Factor (%)	5.0	10.0	15.0	20.0	25.0	30.0	35.0	40.0	45.0
POWER FACTORS									
Radiation	.891	.891	.891	.891	.891	.891	.891	.891	.891
Temperature	.981	.981	.981	.981	.981	.981	.981	.981	.981
Main Bus	.960	.960	.960	.960	.960	.960	.961	.961	.961
	****	****	****	****	****	****	****	****	****
CUM. EOL FACTOR	.634	.634	.634	.634	.634	.634	.634	.634	.634
VOLTAGE FACTORS									
Radiation	.968	.968	.968	.968	.968	.968	.968	.968	.968
Temperature	.968	.968	.968	.968	.968	.968	.968	.968	.968
Main Bus	.960	.960	.960	.960	.960	.960	.961	.961	.961
	****	****	****	****	****	****	****	****	****
CUM. EOL FACTOR	.871	.871	.871	.871	.871	.871	.872	.872	.872
ILLUMINATION FACTORS									
Cover Degradation (EOL)	.870	.870	.870	.870	.870	.870	.870	.870	.870
Concentration Ratio (BOL)	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Concentrator Degrad. (EOL)	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
	*****	*****	*****	*****	*****	*****	*****	*****	*****
CUM. EOL FACTOR	.885	.885	.885	.885	.885	.885	.885	.885	.885
PHYSICAL CHARACTERISTICS									
Total Number of Cells	5469120	5728320	5987520	6246720	6505920	6765120	7050240	7292160	7568640
No. of Modules/Panel	15	15	15	15	15	15	15	15	15
No. of Panels/Blanket	36	36	36	36	36	36	48	48	48
Blanket Weight (Kg)	2434.0	2544.0	2658.0	2770.0	2878.0	2994.0	3114.0	3219.0	3329.0
Structure Weight (Kg)	3584.0	3741.0	3903.0	4061.0	4216.0	4379.0	9420.0	9733.0	10065.0
Total Array Weight (Kg)	13320.0	13917.0	14535.0	15141.0	15728.0	16355.0	21876.0	22609.0	23381.0
Solar Cell Area (cm2)	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000
Module Area (M^2)	2.780	2.900	3.030	3.160	3.280	3.410	2.690	2.780	2.860
Concentrator Area (M^2)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Panel Area (M^2)	39.70	41.50	43.30	45.20	46.90	48.80	38.50	39.70	40.90
Blanket Area (M^2)	1457.0	1520.0	1589.0	1657.0	1720.0	1788.0	1875.0	1938.0	1994.0
Total Array Area (M^2)	5828.0	6080.0	6356.0	6628.0	6880.0	7152.0	7500.0	7752.0	7976.0
Power Density (W/M2)	117.32	117.78	117.76	117.82	118.21	118.25	117.50	117.60	118.63
Power/Weight Ratio (W/Kg)	51.33	51.46	51.50	51.58	51.71	51.71	40.29	40.32	40.47
LIFE CYCLE COST (1980$M)									
DDT&E	248.775	255.061	261.369	267.665	273.941	280.258	330.335	336.393	343.241
PRODUCTION	710.787	728.745	746.768	764.758	782.688	800.738	943.813	961.122	980.689
(Solar Cell - $/Cell)	(29.30)	(29.30)	(29.30)	(29.30)	(29.30)	(29.30)	(29.30)	(29.30)	(29.30)
OPERATIONS & MAINTENANCE	89.152	89.152	89.152	89.152	89.152	89.152	115.153	115.153	115.153
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TOTAL LIFE CYCLE COST	1048.714	1072.958	1097.289	1121.575	1145.781	1170.148	1389.301	1412.668	1439.083

Exhibit 9a. Reliability (Built-In Spares)

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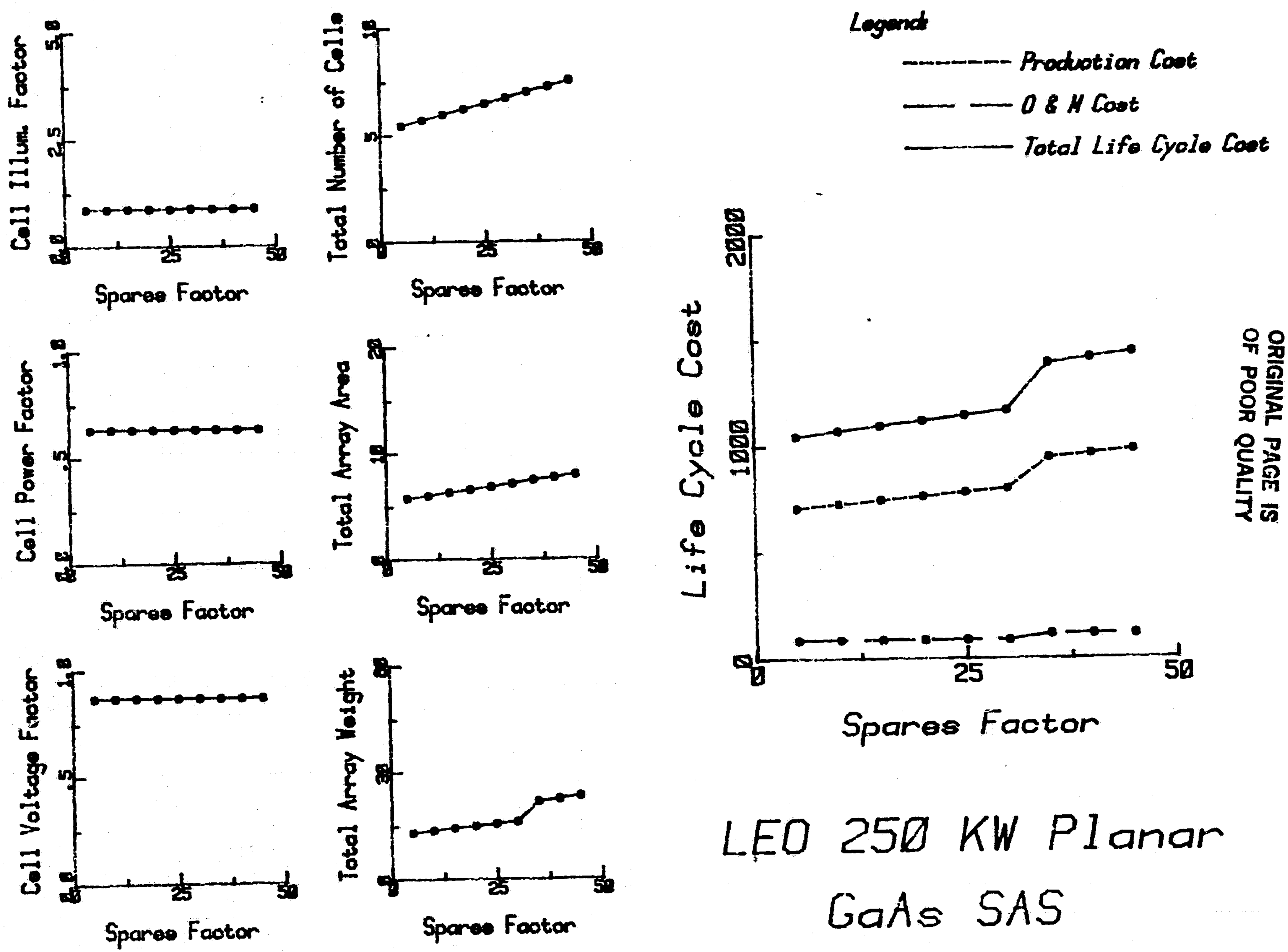

Exhibit 9a. Reliability (Built-In Spares) Continued

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LEO 250 KW Conc. GaAs SAS

ARRAY PERFORMANCE									
No. of Hardware Life Cycles	1	1	1	1	1	1	1	1	1
Total Cell Life Required (Yr)	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0
Total EOL Min. Power (KW)	697.0	725.5	754.0	791.4	813.1	846.4	879.6	914.6	961.2
Total EOL Min. Voltage (V)	181.0	181.0	224.0	224.0	209.0	209.0	209.0	209.0	238.0
BOL Cell Efficiency (%)	18.1	18.1	18.1	18.1	18.1	18.1	18.1	18.1	18.1
BOL Cell Max. Voltage (V)	.819	.810	.810	.810	.810	.810	.810	.810	.810
EOL Cell Power (MW)	411.0	410.0	409.0	409.0	411.0	410.0	409.0	409.0	399.0
EOL Cell Voltage (V)	.472	.471	.467	.467	.467	.465	.464	.464	.465
Spares Factor (%)	5.0	10.0	15.0	20.0	25.0	30.0	35.0	40.0	45.0
POWER FACTORS									
Radiation	.779	.779	.779	.779	.779	.779	.779	.779	.779
Temperature	.825	.825	.825	.825	.825	.825	.825	.825	.825
Main Bus	.891	.888	.886	.886	.892	.890	.888	.888	.878
	****	****	****	****	****	****	****	****	****
CUM. EOL FACTOR	.433	.432	.431	.431	.433	.432	.431	.431	.420
VOLTAGE FACTORS									
Radiation	.963	.963	.963	.963	.963	.963	.963	.963	.963
Temperature	.703	.703	.703	.703	.703	.703	.703	.703	.703
Main Bus	.891	.888	.886	.886	.892	.890	.888	.888	.878
	****	****	****	****	****	****	****	****	****
CUM. EOL FACTOR	.583	.582	.576	.576	.576	.574	.573	.573	.574
ILLUMINATION FACTORS									
Cover Degradation (EOL)	.870	.870	.870	.870	.870	.870	.870	.870	.870
Concentration Ratio (BOL)	5.000	5.000	5.000	5.000	5.000	5.000	5.000	5.000	5.000
Concentrator Degrad. (EOL)	.960	.960	.960	.960	.960	.960	.960	.960	.960
	*****	*****	*****	*****	*****	*****	*****	*****	*****
CUM. EOL FACTOR	4.247	4.247	4.247	4.247	4.247	4.247	4.247	4.247	4.247
PHYSICAL CHARACTERISTICS									
Total Number of Cells	1695744	1769472	1843200	1935360	1978368	2064384	2150400	2236416	2408448
No. of Modules/Panel	8	8	8	8	8	8	8	8	8
No. of Panels/Blanket	72	72	72	72	84	84	84	84	96
Blanket Weight (Kg)	2939.0	3037.0	3134.0	3161.0	3412.0	3525.0	3639.0	3664.0	4128.0
Structure Weight (Kg)	11338.0	12531.0	13418.0	13570.0	20371.0	22540.0	24569.0	24794.0	40920.0
Total Array Weight (Kg)	23094.0	24679.0	25954.0	26214.0	34019.0	36640.0	39125.0	39450.0	57432.0
Solar Cell Area (cm2)	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000
Module Area (M^2)	.900	.940	.980	.980	.900	.940	.980	.980	.980
Concentrator Area (M^2)	8.16	8.52	8.88	8.88	8.16	8.52	8.88	8.88	8.88
Panel Area (M^2)	35.60	37.20	38.70	38.70	35.60	37.20	38.70	38.70	38.70
Blanket Area (M^2)	2613.0	2729.0	2837.0	2837.0	3045.0	3181.0	3307.0	3307.0	3777.0
Total Array Area (M^2)	10452.0	10916.0	11348.0	11348.0	12180.0	12724.0	13228.0	13228.0	15108.0
Power Density (W/M2)	66.68	66.46	66.44	69.74	66.76	66.52	66.50	69.14	63.62
Power/Weight Ratio (W/Kg)	30.18	29.30	29.05	30.19	23.90	23.10	22.48	23.18	16.74
LIFE CYCLE COST (1980$M)									
DDT&E	241.612	245.227	248.464	250.749	289.288	294.346	299.255	301.480	354.509
PRODUCTION	690.321	700.649	709.898	716.427	826.538	840.989	855.014	861.371	1012.882
(Solar Cell - $/Cell)	(29.30)	(29.30)	(29.30)	(29.30)	(29.30)	(29.30)	(29.30)	(29.30)	(29.30)
OPERATIONS & MAINTENANCE	167.154	167.154	167.154	167.154	193.154	193.154	193.154	193.154	219.155
	--------	--------	--------	--------	--------	--------	--------	--------	--------
TOTAL LIFE CYCLE COST	1099.087	1113.030	1125.516	1134.330	1308.980	1328.489	1347.423	1356.005	1586.546

Exhibit 9b. Reliability (Built-In Spares)

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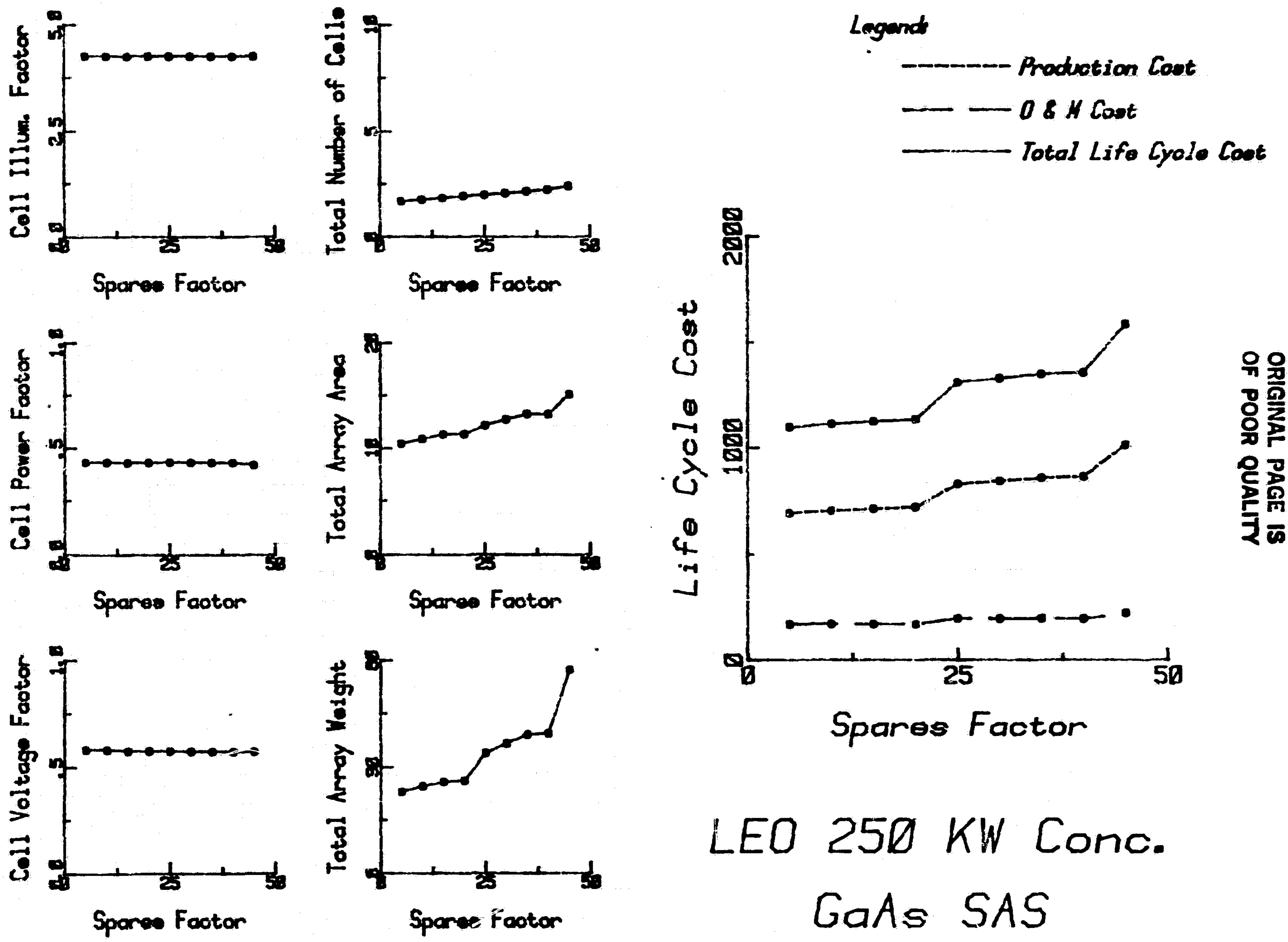

Exhibit 9b. Reliability (Built-In Spares) Continued

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GEO 50 KW Planar GaAs SAS

ARRAY PERFORMANCE									
No. of Hardware Life Cycles	1	1	1	1	1	1	1	1	1
Total Cell Life Required (Yr)	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0
Total EOL Min. Power (KW)	74.3	78.3	81.8	84.8	89.3	92.2	96.7	99.7	102.7
Total EOL Min. Voltage (V)	199.0	199.0	220.0	220.0	220.0	220.0	220.0	220.0	220.0
BOL Cell Efficiency (%)	18.1	18.1	18.1	18.1	18.1	18.1	18.1	18.1	18.1
BOL Cell Max. Voltage (V)	.810	.810	.810	.810	.810	.810	.810	.810	.810
EOL Cell Power (MW)	125.0	125.0	124.0	124.0	124.0	124.0	124.0	124.0	124.0
EOL Cell Voltage (V)	.735	.735	.734	.734	.734	.734	.734	.734	.734
Spares Factor (%)	5.0	10.0	15.0	20.0	25.0	30.0	35.0	40.0	45.0
POWER FACTORS									
Radiation	.891	.891	.891	.891	.891	.891	.891	.891	.891
Temperature	.987	.987	.987	.987	.987	.987	.987	.987	.987
Main Bus	.992	.992	.988	.988	.988	.988	.988	.988	.988
	****	****	****	****	****	****	****	****	****
CUM. EOL FACTOR	.658	.658	.655	.655	.655	.655	.655	.655	.655
VOLTAGE FACTORS									
Radiation	.968	.968	.968	.968	.968	.968	.968	.968	.968
Temperature	.978	.978	.978	.978	.978	.978	.978	.978	.978
Main Bus	.992	.992	.988	.988	.988	.988	.988	.988	.988
	****	****	****	****	****	****	****	****	****
CUM. EOL FACTOR	.908	.908	.906	.906	.906	.906	.906	.906	.906
ILLUMINATION FACTORS									
Cover Degradation (EOL)	.870	.870	.870	.870	.870	.870	.870	.870	.870
Concentration Ratio (BOL)	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Concentrator Degrad. (EOL)	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
	*****	*****	*****	*****	*****	*****	*****	*****	*****
CUM. EOL FACTOR	.885	.885	.885	.885	.885	.885	.885	.885	.885
PHYSICAL CHARACTERISTICS									
Total Number of Cells	594000	626400	660000	684000	720000	744000	780000	804000	828000
No. of Modules/Panel	15	15	15	15	15	15	15	15	15
No. of Panels/Blanket	5	5	10	10	10	10	10	10	10
Blanket Weight (Kg)	326.0	343.0	333.0	344.0	359.0	371.0	390.0	400.0	412.0
Structure Weight (Kg)	78.0	79.0	94.0	95.0	96.0	98.0	99.0	100.0	102.0
Total Array Weight (Kg)	1382.0	1451.0	1426.0	1471.0	1532.0	1582.0	1659.0	1700.0	1750.0
Solar Cell Area (cm2)	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000
Module Area (M^2)	2.190	2.320	1.280	1.320	1.360	1.400	1.490	1.520	1.560
Concentrator Area (M^2)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Panel Area (M^2)	31.10	33.00	17.90	18.50	19.10	19.70	21.00	21.50	22.10
Blanket Area (M^2)	168.0	178.0	187.0	193.0	199.0	205.0	218.0	224.0	230.0
Total Array Area (M^2)	672.0	712.0	748.0	772.0	796.0	820.0	872.0	896.0	920.0
Power Density (W/M2)	110.51	109.97	109.41	109.84	112.16	112.49	110.92	111.25	111.61
Power/Weight Ratio (W/Kg)	53.73	53.96	57.39	57.65	58.28	58.31	58.30	58.64	58.67
LIFE CYCLE COST (1980$M)									
DDT&E	31.910	32.688	49.186	49.755	50.602	51.176	52.043	52.608	53.183
PRODUCTION	91.170	93.393	140.530	142.157	144.578	146.218	148.694	150.309	151.952
(Solar Cell - $/Cell)	(29.30)	(29.30)	(29.30)	(29.30)	(29.30)	(29.30)	(29.30)	(29.30)	(29.30)
OPERATIONS & MAINTENANCE	.900	.900	.900	.900	.900	.900	.900	.900	.900
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TOTAL LIFE CYCLE COST	123.980	126.981	190.616	192.812	196.080	198.294	201.637	203.817	206.035

Exhibit 9c. Reliability (Built-In Spares)

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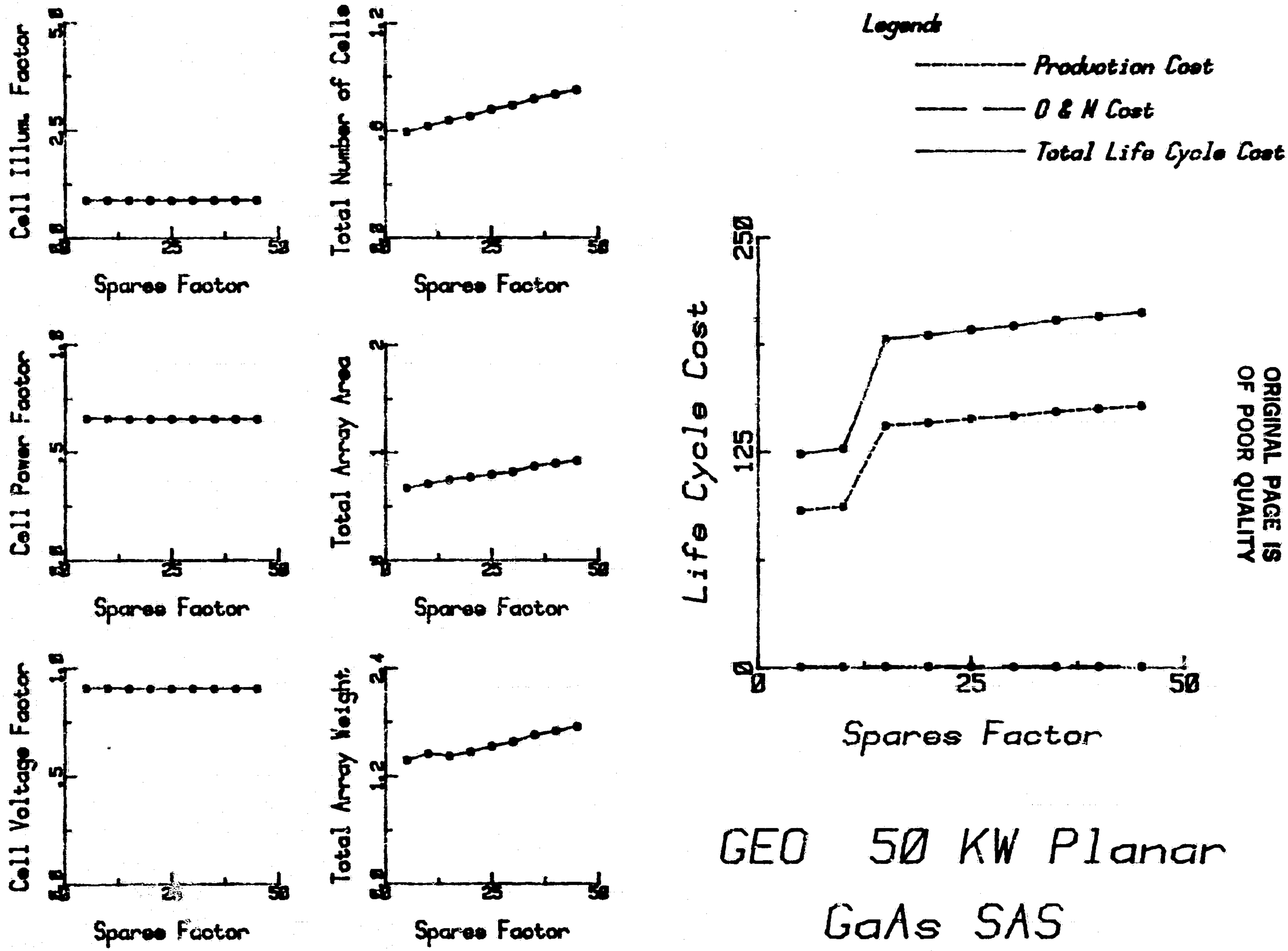

Exhibit 9c. Reliability (Built-In Spares) Continued

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GEO 50 KW Conc. GaAs SAS

ARRAY PERFORMANCE									
No. of Hardware Life Cycles	1	1	1	1	1	1	1	1	1
Total Cell Life Required (Yr)	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0
Total EOL Min. Power (KW)	75.5	81.8	81.8	88.1	94.0	94.0	100.2	100.2	106.5
Total EOL Min. Voltage (V)	189.0	189.0	189.0	189.0	188.0	188.0	188.0	188.0	188.0
BOL Cell Efficiency (%)	18.1	18.1	18.1	18.1	18.1	18.1	18.1	18.1	18.1
BOL Cell Max. Voltage (V)	.810	.810	.810	.810	.810	.810	.810	.810	.810
EOL Cell Power (MW)	437.0	437.0	437.0	437.0	435.0	435.0	435.0	435.0	435.0
EOL Cell Voltage (V)	.526	.526	.526	.526	.522	.522	.522	.522	.522
Spares Factor (%)	5.0	10.0	15.0	20.0	25.0	30.0	35.0	40.0	45.0
POWER FACTORS									
Radiation	.779	.779	.779	.779	.779	.779	.779	.779	.779
Temperature	.834	.834	.834	.834	.834	.834	.834	.834	.834
Main Bus	.979	.979	.979	.979	.974	.974	.973	.973	.973
	****	****	****	****	****	****	****	****	****
CUM. EOL FACTOR	.480	.480	.480	.480	.477	.477	.477	.477	.477
VOLTAGE FACTORS									
Radiation	.963	.963	.963	.963	.963	.963	.963	.963	.963
Temperature	.718	.718	.718	.718	.718	.718	.718	.718	.718
Main Bus	.979	.979	.979	.979	.974	.974	.973	.973	.973
	****	****	****	****	****	****	****	****	****
CUM. EOL FACTOR	.649	.649	.649	.649	.645	.645	.645	.645	.645
ILLUMINATION FACTORS									
Cover Degradation (EOL)	.870	.870	.870	.870	.870	.870	.870	.870	.870
Concentration Ratio (BOL)	5.000	5.000	5.000	5.000	5.000	5.000	5.000	5.000	5.000
Concentrator Degrad. (EOL)	.960	.960	.960	.960	.960	.960	.960	.960	.960
	*****	*****	*****	*****	*****	*****	*****	*****	*****
CUM. EOL FACTOR	4.247	4.247	4.247	4.247	4.247	4.247	4.247	4.247	4.247
PHYSICAL CHARACTERISTICS									
Total Number of Cells	172800	187200	187200	201600	216000	216000	230400	230400	244800
No. of Modules/Panel	6	6	6	6	6	6	6	6	6
No. of Panels/Blanket	10	10	10	10	15	15	15	15	15
Blanket Weight (Kg)	376.0	388.0	388.0	493.0	457.0	457.0	485.0	485.0	494.0
Structure Weight (Kg)	78.0	80.0	80.0	81.0	91.0	91.0	95.0	95.0	97.0
Total Array Weight (Kg)	1582.0	1632.0	1632.0	1693.0	1919.0	1919.0	2035.0	2035.0	2073.0
Solar Cell Area (cm2)	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000
Module Area (M^2)	.900	.940	.940	.980	.740	.740	.810	.810	.830
Concentrator Area (M^2)	8.16	8.52	8.52	8.88	6.71	6.71	7.34	7.34	7.52
Panel Area (M^2)	26.70	27.90	27.90	29.00	21.90	21.90	24.00	24.00	24.50
Blanket Area (M^2)	283.0	295.0	295.0	306.0	344.0	344.0	377.0	377.0	385.0
Total Array Area (M^2)	1132.0	1180.0	1180.0	1224.0	1376.0	1376.0	1508.0	1508.0	1540.0
Power Density (W/M2)	66.71	69.32	69.32	71.96	68.28	68.28	66.45	66.45	69.16
Power/Weight Ratio (W/Kg)	47.74	50.12	50.12	52.03	48.96	48.96	49.24	49.24	51.37
LIFE CYCLE COST (1980$M)									
DDT&E	29.478	29.874	29.874	30.281	41.751	41.751	42.267	42.267	42.642
PRODUCTION	84.223	85.355	85.355	86.517	119.289	119.289	120.763	120.763	121.835
(Solar Cell - $/Cell)	(29.30)	(29.30)	(29.30)	(29.30)	(29.30)	(29.30)	(29.30)	(29.30)	(29.30)
OPERATIONS & MAINTENANCE	.900	.900	.900	.900	.900	.900	.900	.900	.900
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TOTAL LIFE CYCLE COST	114.601	116.129	116.129	117.698	161.940	161.940	163.930	163.930	165.377

Exhibit 9d. Reliability (Built-In Spares)

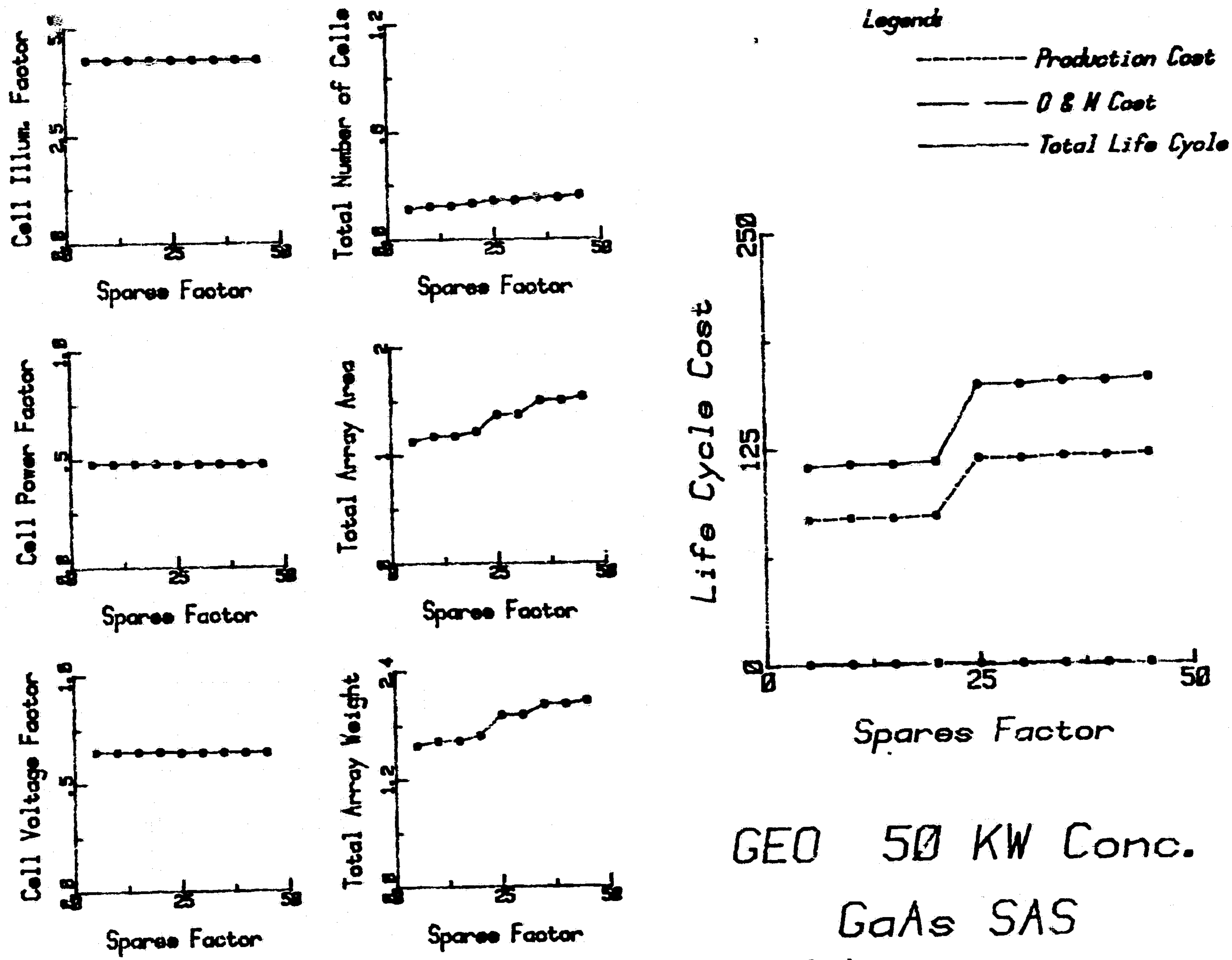

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Exhibit 9d. Reliability (Built-In Spares) Continued

LEO 250 KW Planar GaAs SAS

ARRAY PERFORMANCE									
No. of Hardware Life Cycles	1	1	1	1	1	1	1	1	1
Total Cell Life Required (Yr)	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0
Total EOL Min. Power (KW)	651.3	651.3	651.3	651.3	651.3	651.3	651.3	651.3	651.3
Total EOL Min. Voltage (V)	191.0	191.0	191.0	191.0	191.0	191.0	191.0	191.0	191.0
BOL Cell Efficiency (%)	18.1	18.1	18.1	18.1	18.1	18.1	18.1	18.1	18.1
BOL Cell Max. Voltage (V)	.810	.810	.810	.810	.810	.810	.810	.810	.810
EOL Cell Power (mW)	125.0	125.0	125.0	125.0	125.0	125.0	125.0	125.0	125.0
EOL Cell Voltage (V)	.706	.706	.706	.706	.706	.706	.706	.706	.706
Spares Factor (%)	5.0	10.0	15.0	20.0	25.0	30.0	35.0	40.0	45.0
POWER FACTORS									
Radiation	.891	.891	.891	.891	.891	.891	.891	.891	.891
Temperature	.981	.981	.981	.981	.981	.981	.981	.981	.981
Main Bus	.960	.960	.960	.960	.960	.960	.960	.960	.960
	****	****	****	****	****	****	****	****	****
CUM. EOL FACTOR	.634	.634	.634	.634	.634	.634	.634	.634	.634
VOLTAGE FACTORS									
Radiation	.968	.968	.968	.968	.968	.968	.968	.968	.968
Temperature	.968	.968	.968	.968	.968	.968	.968	.968	.968
Main Bus	.960	.960	.960	.960	.960	.960	.960	.960	.960
	****	****	****	****	****	****	****	****	****
CUM. EOL FACTOR	.871	.871	.871	.871	.871	.871	.871	.871	.871
ILLUMINATION FACTORS									
Cover Degradation (EOL)	.870	.870	.870	.870	.870	.870	.870	.870	.870
Concentration Ratio (BOL)	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Concentrator Degrad. (EOL)	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
	*****	*****	*****	*****	*****	*****	*****	*****	*****
CUM. EOL FACTOR	.885	.885	.885	.885	.885	.885	.885	.885	.885
PHYSICAL CHARACTERISTICS									
Total Number of Cells	5209920	5209920	5209920	5209920	5209920	5209920	5209920	5209920	5209920
No. of Modules/Panel	15	15	15	15	15	15	15	15	15
No. of Panels/Blanket	36	36	36	36	36	36	36	36	36
Blanket Weight (Kg)	2323.0	2323.0	2323.0	2323.0	2323.0	2323.0	2323.0	2323.0	2323.0
Structure Weight (Kg)	3427.0	3427.0	3427.0	3427.0	3427.0	3427.0	3427.0	3427.0	3427.0
Total Array Weight (Kg)	12719.0	12719.0	12719.0	12719.0	12719.0	12719.0	12719.0	12719.0	12719.0
Solar Cell Area (cm2)	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000
Module Area (M^2)	2.650	2.650	2.650	2.650	2.650	2.650	2.650	2.650	2.650
Concentrator Area (M^2)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Panel Area (M^2)	37.90	37.90	37.90	37.90	37.90	37.90	37.90	37.90	37.90
Blanket Area (M^2)	1389.0	1389.0	1389.0	1389.0	1389.0	1389.0	1389.0	1389.0	1389.0
Total Array Area (M^2)	5556.0	5556.0	5556.0	5556.0	5556.0	5556.0	5556.0	5556.0	5556.0
Power Density (W/M2)	117.23	117.23	117.23	117.23	117.23	117.23	117.23	117.23	117.23
Power/Weight Ratio (W/Kg)	51.21	51.21	51.21	51.21	51.21	51.21	51.21	51.21	51.21
LIFE CYCLE COST (1980$M)									
DDT&E	248.018	253.550	259.083	264.615	270.147	275.679	281.211	286.743	292.276
PRODUCTION	708.623	724.429	740.236	756.042	771.848	787.655	803.461	819.267	835.074
(Solar Cell - $/Cell)	(29.30)	(29.30)	(29.30)	(29.30)	(29.30)	(29.30)	(29.30)	(29.30)	(29.30)
OPERATIONS & MAINTENANCE	195.377	195.460	195.543	195.625	195.708	195.791	195.874	195.957	196.040
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TOTAL LIFE CYCLE COST	1152.018	1173.439	1194.862	1216.282	1237.703	1259.125	1280.546	1301.967	1323.390

Exhibit 10a. Spares/Maintenance

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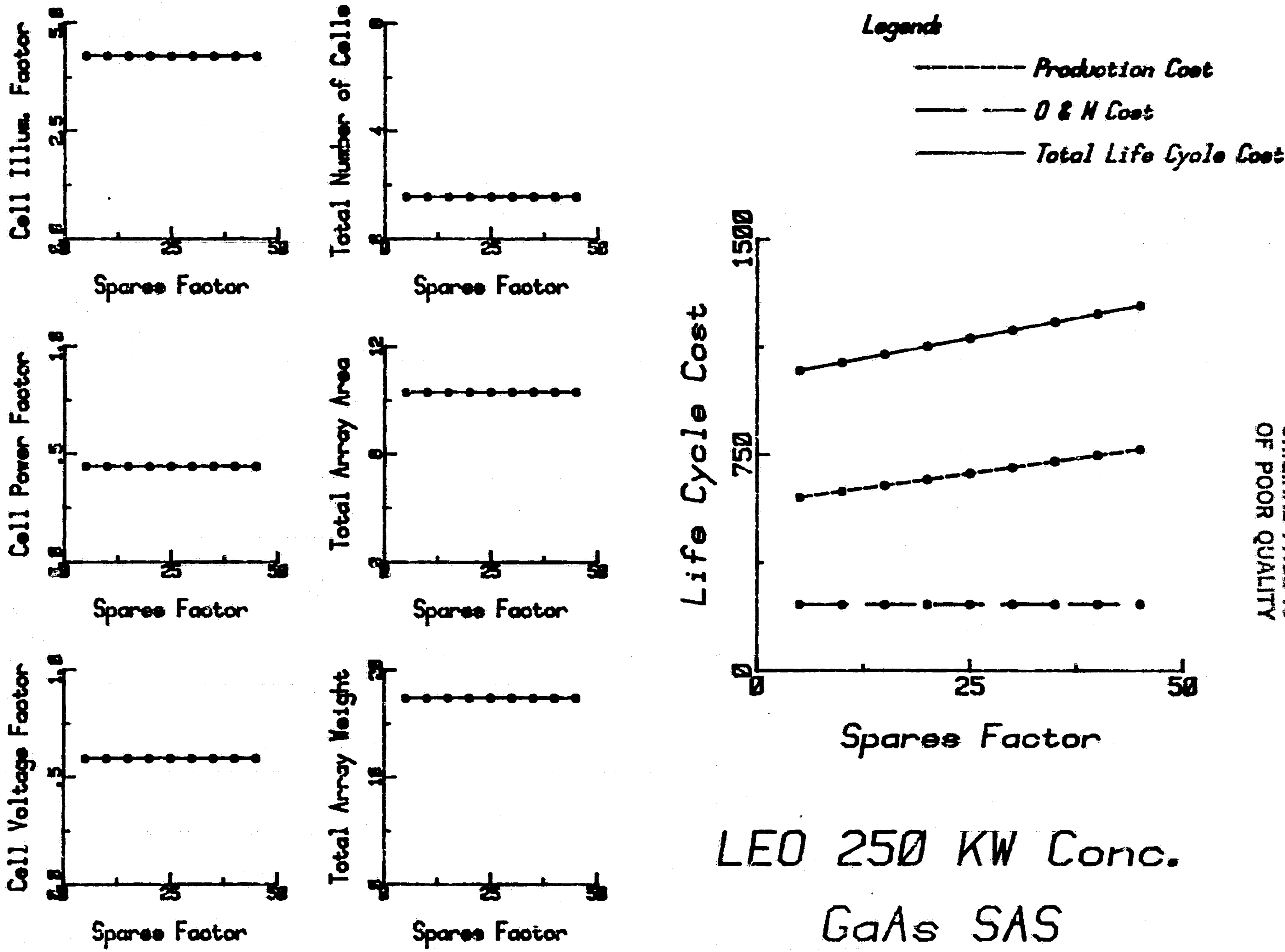

Exhibit 10a. Spares/Maintenance Continued

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LEO 250 KW Conc. GaAs SAS

ARRAY PERFORMANCE									
No. of Hardware Life Cycles	1	1	1	1	1	1	1	1	1
Total Cell Life Required (Yr)	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0
Total EOL Min. Power (KW)	661.2	661.2	661.2	661.2	661.2	661.2	661.2	661.2	661.2
Total EOL Min. Voltage (V)	191.0	191.0	191.0	191.0	191.0	191.0	191.0	191.0	191.0
BOL Cell Efficiency (%)	18.1	18.1	18.1	18.1	18.1	18.1	18.1	18.1	18.1
BOL Cell Max. Voltage (V)	.810	.810	.810	.810	.810	.810	.810	.810	.810
EOL Cell Power (MW)	420.0	420.0	420.0	420.0	420.0	420.0	420.0	420.0	420.0
EOL Cell Voltage (V)	.475	.475	.475	.475	.475	.475	.475	.475	.475
Spares Factor (%)	5.0	10.0	15.0	20.0	25.0	30.0	35.0	40.0	45.0
POWER FACTORS									
Radiation	.779	.779	.779	.779	.779	.779	.779	.779	.779
Temperature	.825	.825	.825	.825	.825	.825	.825	.825	.825
Main Bus	.909	.909	.909	.909	.909	.909	.909	.909	.909
	****	****	****	****	****	****	****	****	****
CUM. EOL FACTOR	.442	.442	.442	.442	.442	.442	.442	.442	.442
VOLTAGE FACTORS									
Radiation	.963	.963	.963	.963	.963	.963	.963	.963	.953
Temperature	.703	.703	.703	.703	.703	.703	.703	.703	.703
Main Bus	.909	.909	.909	.909	.909	.909	.909	.909	.909
	****	****	****	****	****	****	****	****	****
CUM. EOL FACTOR	.587	.587	.587	.587	.587	.587	.587	.587	.587
ILLUMINATION FACTORS									
Cover Degradation (EOL)	.870	.870	.870	.870	.870	.870	.870	.870	.870
Concentration Ratio (BOL)	5.000	5.000	5.000	5.000	5.000	5.000	5.000	5.000	5.000
Concentrator Degrad. (EOL)	.960	.960	.960	.960	.960	.960	.960	.960	.960
	*****	*****	*****	*****	*****	*****	*****	*****	*****
CUM. EOL FACTOR	4.247	4.247	4.247	4.247	4.247	4.247	4.247	4.247	4.247
PHYSICAL CHARACTERISTICS									
Total Number of Cells	1574400	1574400	1574400	1574400	1574400	1574400	1574400	1574400	1574400
No. of Modules/Panel	8	8	8	8	8	8	8	8	8
No. of Panels/Blanket	60	60	60	60	60	60	60	60	60
Blanket Weight (Kg)	2640.0	2640.0	2640.0	2640.0	2640.0	2640.0	2640.0	2640.0	2640.0
Structure Weight (Kg)	6819.0	6819.0	6819.0	6819.0	6819.0	6819.0	6819.0	6819.0	6819.0
Total Array Weight (Kg)	17379.0	17379.0	17379.0	17379.0	17379.0	17379.0	17379.0	17379.0	17379.0
Solar Cell Area (cm2)	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000
Module Area (M^2)	.980	.980	.980	.980	.980	.980	.980	.980	.980
Concentrator Area (M^2)	8.88	8.88	8.88	8.88	8.88	8.88	8.88	8.88	8.88
Panel Area (M^2)	38.70	38.70	38.70	38.70	38.70	38.70	38.70	38.70	38.70
Blanket Area (M^2)	2367.0	2367.0	2367.0	2367.0	2367.0	2367.0	2367.0	2367.0	2367.0
Total Array Area (M^2)	9468.0	9468.0	9468.0	9468.0	9468.0	9468.0	9468.0	9468.0	9468.0
Power Density (W/M2)	69.84	69.84	69.84	69.84	69.84	69.84	69.84	69.84	69.84
Power/Weight Ratio (W/Kg)	38.05	38.05	38.05	38.05	38.05	38.05	38.05	38.05	38.05
LIFE CYCLE COST (1980$M)									
DDT&E	210.856	218.157	225.457	232.758	240.059	247.359	254.659	261.961	269.261
PRODUCTION	602.447	623.305	644.164	665.024	685.882	706.740	727.598	748.459	769.317
(Solar Cell - $/Cell)	(29.30)	(29.30)	(29.30)	(29.30)	(29.30)	(29.30)	(29.30)	(29.30)	(29.30)
OPERATIONS & MAINTENANCE	230.869	231.007	231.146	231.284	231.422	231.560	231.698	231.836	231.974
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TOTAL LIFE CYCLE COST	1044.172	1072.469	1100.767	1129.066	1157.363	1185.659	1213.955	1242.256	1270.552

Exhibit 10b. Spares/Maintenance

C-3

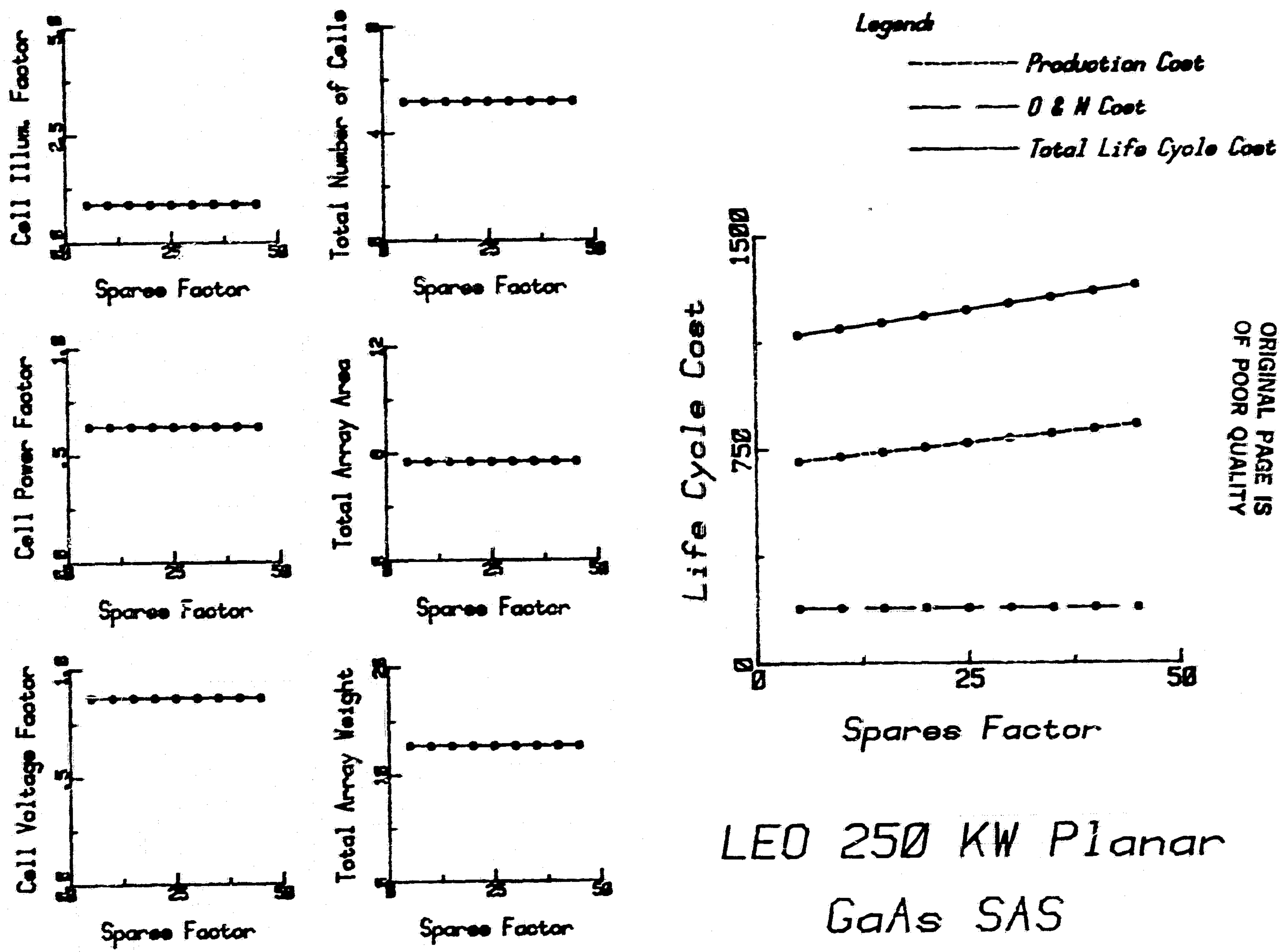

Exhibit 10b. Spares/Maintenance Continued

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LEO 250 KW Planar GaAs SAS

ARRAY PERFORMANCE									
No. of Hardware Life Cycles	1	1	1	1	1	1	1	1	1
Total Cell Life Required (Yr)	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0
Total EOL Min. Power (KW)	651.3	651.3	651.3	651.3	651.3	651.3	651.3	651.3	651.3
Total EOL Min. Voltage (V)	191.0	191.0	191.0	191.0	191.0	191.0	191.0	191.0	191.0
BOL Cell Efficiency (%)	18.1	18.1	18.1	18.1	18.1	18.1	18.1	18.1	18.1
BOL Cell Max. Voltage (V)	.810	.810	.810	.810	.810	.810	.810	.810	.810
EOL Cell Power (MW)	125.0	125.0	125.0	125.0	125.0	125.0	125.0	125.0	125.0
EOL Cell Voltage (V)	.706	.706	.706	.706	.706	.706	.706	.706	.706
POWER FACTORS									
Radiation	.891	.891	.891	.891	.891	.891	.891	.891	.891
Temperature	.981	.981	.981	.981	.981	.981	.981	.981	.981
Main Bus	.960	.960	.960	.960	.960	.960	.960	.960	.960
	****	****	****	****	****	****	****	****	****
CUM. EOL FACTOR	.634	.634	.634	.634	.634	.634	.634	.634	.634
VOLTAGE FACTORS									
Radiation	.968	.968	.968	.968	.968	.968	.968	.968	.968
Temperature	.968	.968	.968	.968	.968	.968	.968	.968	.968
Main Bus	.960	.960	.960	.960	.960	.960	.960	.960	.960
	****	****	****	****	****	****	****	****	****
CUM. EOL FACTOR	.871	.871	.871	.871	.871	.871	.871	.871	.871
ILLUMINATION FACTORS									
Cover Degradation (EOL)	.870	.870	.870	.870	.870	.870	.870	.870	.870
Concentration Ratio (BOL)	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Concentrator Degrad. (EOL)	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
	*****	*****	*****	*****	*****	*****	*****	*****	*****
CUM. EOL FACTOR	.885	.885	.885	.885	.885	.885	.885	.885	.885
PHYSICAL CHARACTERISTICS									
Total Number of Cells	5209920	5209920	5209920	5209920	5209920	5209920	5209920	5209920	5209920
No. of Modules/Panel	15	15	15	15	15	15	15	15	15
No. of Panels/Blanket	36	36	36	36	36	36	36	36	36
Blanket Weight (Kg)	2323.0	2323.0	2323.0	2323.0	2323.0	2323.0	2323.0	2323.0	2323.0
Structure Weight (Kg)	3427.0	3427.0	3427.0	3427.0	3427.0	3427.0	3427.0	3427.0	3427.0
Total Array Weight (Kg)	12719.0	12719.0	12719.0	12719.0	12719.0	12719.0	12719.0	12719.0	12719.0
Solar Cell Area (cm2)	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000
Module Area (M^2)	2.650	2.650	2.650	2.650	2.650	2.650	2.650	2.650	2.650
Concentrator Area (M^2)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Panel Area (M^2)	37.90	37.90	37.90	37.90	37.90	37.90	37.90	37.90	37.90
Blanket Area (M^2)	1389.0	1389.0	1389.0	1389.0	1389.0	1389.0	1389.0	1389.0	1389.0
Total Array Area (M^2)	5556.0	5556.0	5556.0	5556.0	5556.0	5556.0	5556.0	5556.0	5556.0
Power Density (W/M2)	117.23	117.23	117.23	117.23	117.23	117.23	117.23	117.23	117.23
Power/Weight Ratio (W/Kg)	51.21	51.21	51.21	51.21	51.21	51.21	51.21	51.21	51.21
LIFE CYCLE COST (1980$M)									
DDT&E	198.162	220.956	253.550	300.733	414.709	642.634	870.568	1098.502	1326.436
PRODUCTION	566.178	631.302	724.429	859.236	1184.856	1836.096	2487.336	3138.576	3789.816
(Solar Cell - $/Cell)	(5.00)	(15.00)	(29.30)	(50.00)	(100.00)	(200.00)	(300.00)	(400.00)	(500.00)
OPERATIONS & MAINTENANCE	195.460	195.460	195.460	195.460	195.460	195.460	195.460	195.460	195.460
	-------	-------	-------	-------	-------	-------	-------	-------	-------
TOTAL LIFE CYCLE COST	959.800	1047.718	1173.439	1355.429	1795.016	2674.190	3553.364	4432.538	5311.712

Exhibit 11a. Cell Cost

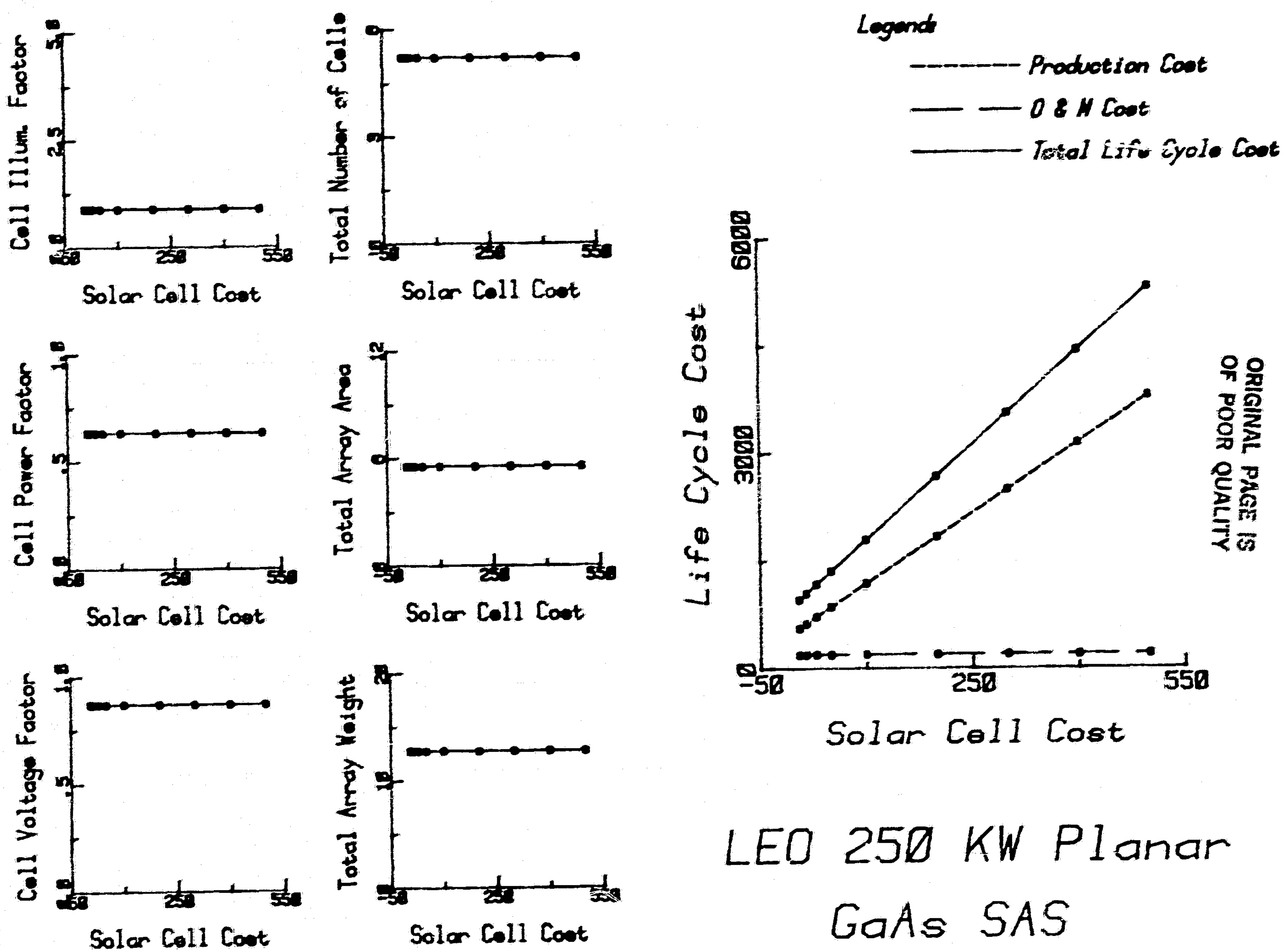

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Exhibit 11a. Cell Cost Continued

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LEO 250 KW Conc. GaAs SAS

ARRAY PERFORMANCE									
No. of Hardware Life Cycles	1	1	1	1	1	1	1	1	1
Total Cell Life Required (Yr)	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0
Total EOL Min. Power (KW)	661.2	661.2	661.2	661.2	661.2	661.2	661.2	661.2	661.2
Total EOL Min. Voltage (V)	191.0	191.0	191.0	191.0	191.0	191.0	191.0	191.0	191.0
BOL Cell Efficiency (%)	18.1	18.1	18.1	18.1	18.1	18.1	18.1	18.1	18.1
BOL Cell Max. Voltage (V)	.810	.810	.810	.810	.810	.810	.810	.810	.810
EOL Cell Power (MW)	420.0	420.0	420.0	420.0	420.0	420.0	420.0	420.0	420.0
EOL Cell Voltage (V)	.475	.475	.475	.475	.475	.475	.475	.475	.475
POWER FACTORS									
Radiation	.779	.779	.779	.779	.779	.779	.779	.779	.779
Temperature	.825	.825	.825	.825	.825	.825	.825	.825	.825
Main Bus	.909	.909	.909	.909	.909	.909	.909	.909	.909
	****	****	****	****	****	****	****	****	****
CUM. EOL FACTOR	.442	.442	.442	.442	.442	.442	.442	.442	.442
VOLTAGE FACTORS									
Radiation	.963	.963	.963	.963	.963	.963	.963	.963	.963
Temperature	.703	.703	.703	.703	.703	.703	.703	.703	.703
Main Bus	.909	.909	.909	.909	.909	.909	.909	.909	.909
	****	****	****	****	****	****	****	****	****
CUM. EOL FACTOR	.587	.587	.587	.587	.587	.587	.587	.587	.587
ILLUMINATION FACTORS									
Cover Degradation (EOL)	.870	.870	.870	.870	.870	.870	.870	.870	.870
Concentration Ratio (EOL)	5.000	5.000	5.000	5.000	5.000	5.000	5.000	5.000	5.000
Concentrator Degrad. (EOL)	.960	.960	.960	.960	.960	.960	.960	.960	.960
	*****	*****	*****	*****	*****	*****	*****	*****	*****
CUM. EOL FACTOR	4.247	4.247	4.247	4.247	4.247	4.247	4.247	4.247	4.247
PHYSICAL CHARACTERISTICS									
Total Number of Cells	1574400	1574400	1574400	1574400	1574400	1574400	1574400	1574400	1574400
No. of Modules/Panel	8	8	8	8	8	8	8	8	8
No. of Panels/Blanket	60	60	60	60	60	60	60	60	60
Blanket Weight (Kg)	2640.0	2640.0	2640.0	2640.0	2640.0	2640.0	2640.0	2640.0	2640.0
Structure Weight (Kg)	6819.0	6819.0	6819.0	6819.0	6819.0	6819.0	6819.0	6819.0	6819.0
Total Array Weight (Kg)	17379.0	17379.0	17379.0	17379.0	17379.0	17379.0	17379.0	17379.0	17379.0
Solar Cell Area (cm2)	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000
Module Area (M^2)	.980	.980	.980	.980	.980	.980	.980	.980	.980
Concentrator Area (M^2)	8.88	8.88	8.88	8.88	8.88	8.88	8.88	8.88	8.88
Panel Area (M^2)	38.70	38.70	38.70	38.70	38.70	38.70	38.70	38.70	38.70
Blanket Area (M^2)	2367.0	2367.0	2367.0	2367.0	2367.0	2367.0	2367.0	2367.0	2367.0
Total Array Area (M^2)	9468.0	9468.0	9468.0	9468.0	9468.0	9468.0	9468.0	9468.0	9468.0
Power Density (W/M2)	69.84	69.84	69.84	69.84	69.84	69.84	69.84	69.84	69.84
Power/Weight Ratio (W/Kg)	38.05	38.05	38.05	38.05	38.05	38.05	38.05	38.05	38.05
LIFE CYCLE COST (1980$M)									
DDT&E	201.419	208.307	218.157	232.415	266.855	335.735	404.615	473.495	542.375
PRODUCTION	575.482	595.162	623.305	664.042	762.442	959.242	1156.042	1352.842	1549.642
(Solar Cell - $/Cell)	(5.00)	(15.00)	(29.30)	(50.00)	(100.00)	(200.00)	(300.00)	(400.00)	(500.00)
OPERATIONS & MAINTENANCE	231.007	231.007	231.007	231.007	231.007	231.007	231.007	231.007	231.007
	-------	-------	-------	-------	-------	-------	-------	-------	-------
TOTAL LIFE CYCLE COST	1007.908	1034.476	1072.469	1127.464	1260.304	1525.984	1791.664	2057.344	2323.024

Exhibit 11b. Cell Cost

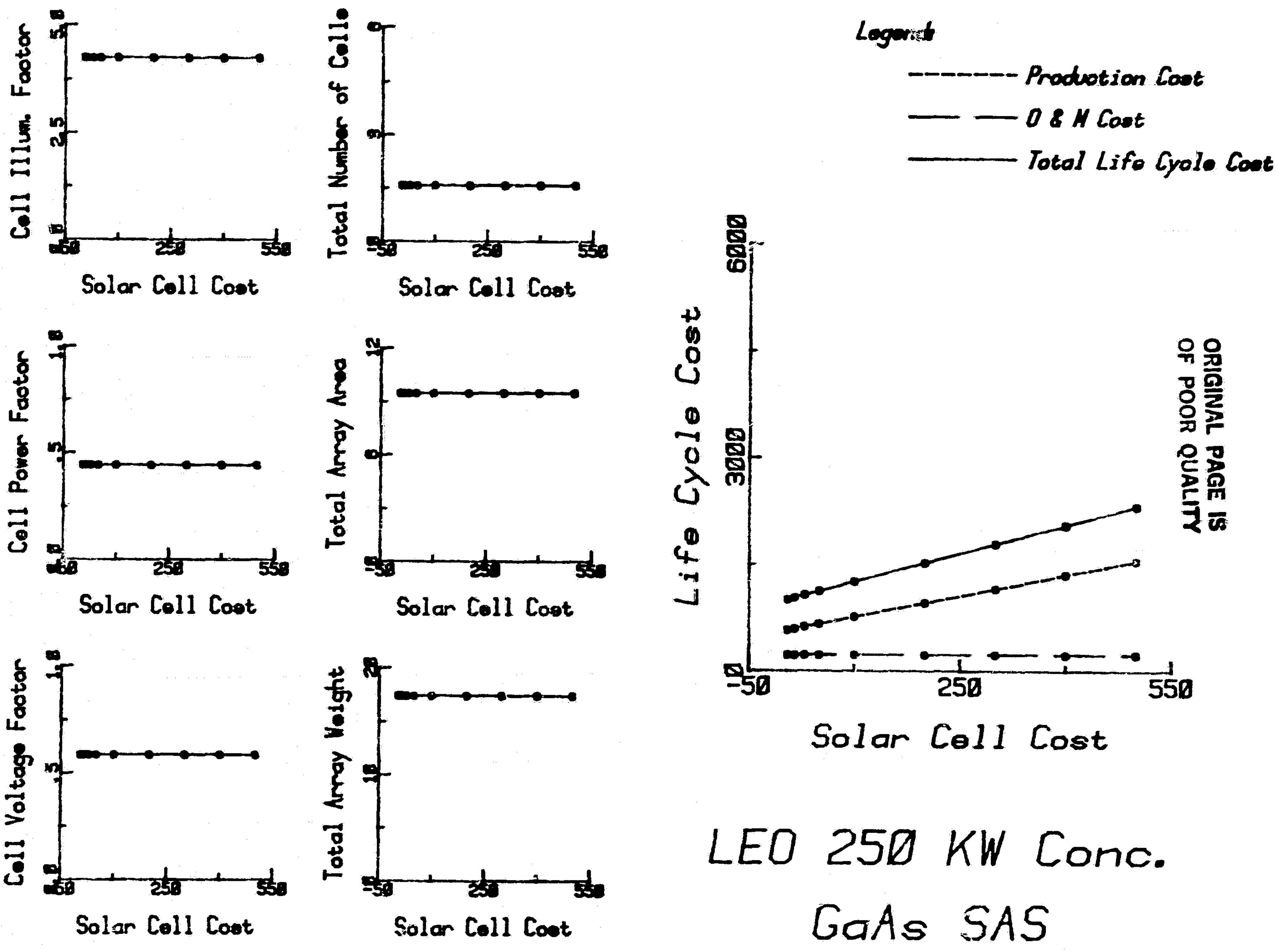

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Exhibit 11b. Cell Cost Continued

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CEO 50 KW Planar GaAs SAS

ARRAY PERFORMANCE									
No. of Hardware Life Cycles	1	1	1	1	1	1	1	1	1
Total Cell Life Required (Yr)	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0
Total EOL Min. Power (KW)	71.6	71.6	71.6	71.6	71.6	71.6	71.6	71.6	71.6
Total EOL Min. Voltage (V)	199.0	199.0	199.0	199.0	199.0	199.0	199.0	199.0	199.0
BOL Cell Efficiency (%)	18.1	18.1	18.1	18.1	18.1	18.1	18.1	18.1	18.1
BOL Cell Max. Voltage (V)	.810	.810	.810	.810	.810	.810	.810	.810	.810
EOL Cell Power (MW)	125.0	125.0	125.0	125.0	125.0	125.0	125.0	125.0	125.0
EOL Cell Voltage (V)	.735	.735	.735	.735	.735	.735	.735	.735	.735
POWER FACTORS									
Radiation	.891	.891	.891	.891	.891	.891	.891	.891	.891
Temperature	.987	.987	.987	.987	.987	.987	.987	.987	.987
Main Bus	.992	.992	.992	.992	.992	.992	.992	.992	.992
	****	****	****	****	****	****	****	****	****
CUM. EOL FACTOR	.658	.658	.658	.658	.658	.658	.658	.658	.658
VOLTAGE FACTORS									
Radiation	.968	.968	.968	.968	.968	.968	.968	.968	.968
Temperature	.978	.978	.978	.978	.978	.978	.978	.978	.978
Main Bus	.992	.992	.992	.992	.992	.992	.992	.992	.992
	****	****	****	****	****	****	****	****	****
CUM. EOL FACTOR	.908	.908	.908	.908	.908	.908	.908	.908	.908
ILLUMINATION FACTORS									
Cover Degradation (EOL)	.870	.870	.870	.870	.870	.870	.870	.870	.870
Concentration Ratio (EOL)	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Concentrator Degrad. (EOL)	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
	*****	*****	*****	*****	*****	*****	*****	*****	*****
CUM. EOL FACTOR	.885	.885	.885	.885	.885	.885	.885	.885	.885
PHYSICAL CHARACTERISTICS									
Total Number of Cells	572400	572400	572400	572400	572400	572400	572400	572400	572400
No. of Modules/Panel	15	15	15	15	15	15	15	15	15
No. of Panels/Blanket	5	5	5	5	5	5	5	5	5
Blanket Weight (Kg)	312.0	312.0	312.0	312.0	312.0	312.0	312.0	312.0	312.0
Structure Weight (Kg)	78.0	78.0	78.0	78.0	78.0	78.0	78.0	78.0	78.0
Total Array Weight (Kg)	1326.0	1326.0	1326.0	1326.0	1326.0	1326.0	1326.0	1326.0	1326.0
Solar Cell Area (cm2)	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000
Module Area (M^2)	2.110	2.110	2.110	2.110	2.110	2.110	2.110	2.110	2.110
Concentrator Area (M^2)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Panel Area (M^2)	30.00	30.00	30.00	30.00	30.00	30.00	30.00	30.00	30.00
Blanket Area (M^2)	162.0	162.0	162.0	162.0	162.0	162.0	162.0	162.0	162.0
Total Array Area (M^2)	648.0	648.0	648.0	648.0	648.0	648.0	648.0	648.0	648.0
Power Density (W/M2)	110.43	110.43	110.43	110.43	110.43	110.43	110.43	110.43	110.43
Power/Weight Ratio (W/Kg)	53.97	53.97	53.97	53.97	53.97	53.97	53.97	53.97	53.97
LIFE CYCLE COST (1980$M)									
DDT&E	25.296	27.801	31.382	36.565	49.086	74.129	99.171	124.214	149.256
PRODUCTION	72.275	79.430	89.662	104.472	140.247	211.797	283.347	354.897	426.447
(Solar Cell - $/Cell)	(5.00)	(15.00)	(29.30)	(50.00)	(100.00)	(200.00)	(300.00)	(400.00)	(500.00)
OPERATIONS & MAINTENANCE	.900	.900	.900	.900	.900	.900	.900	.900	.900
	-------	-------	-------	-------	-------	-------	-------	-------	-------
TOTAL LIFE CYCLE COST	98.471	108.131	121.944	141.937	190.233	286.826	383.418	480.011	576.603

Exhibit 11c. Cell Cost

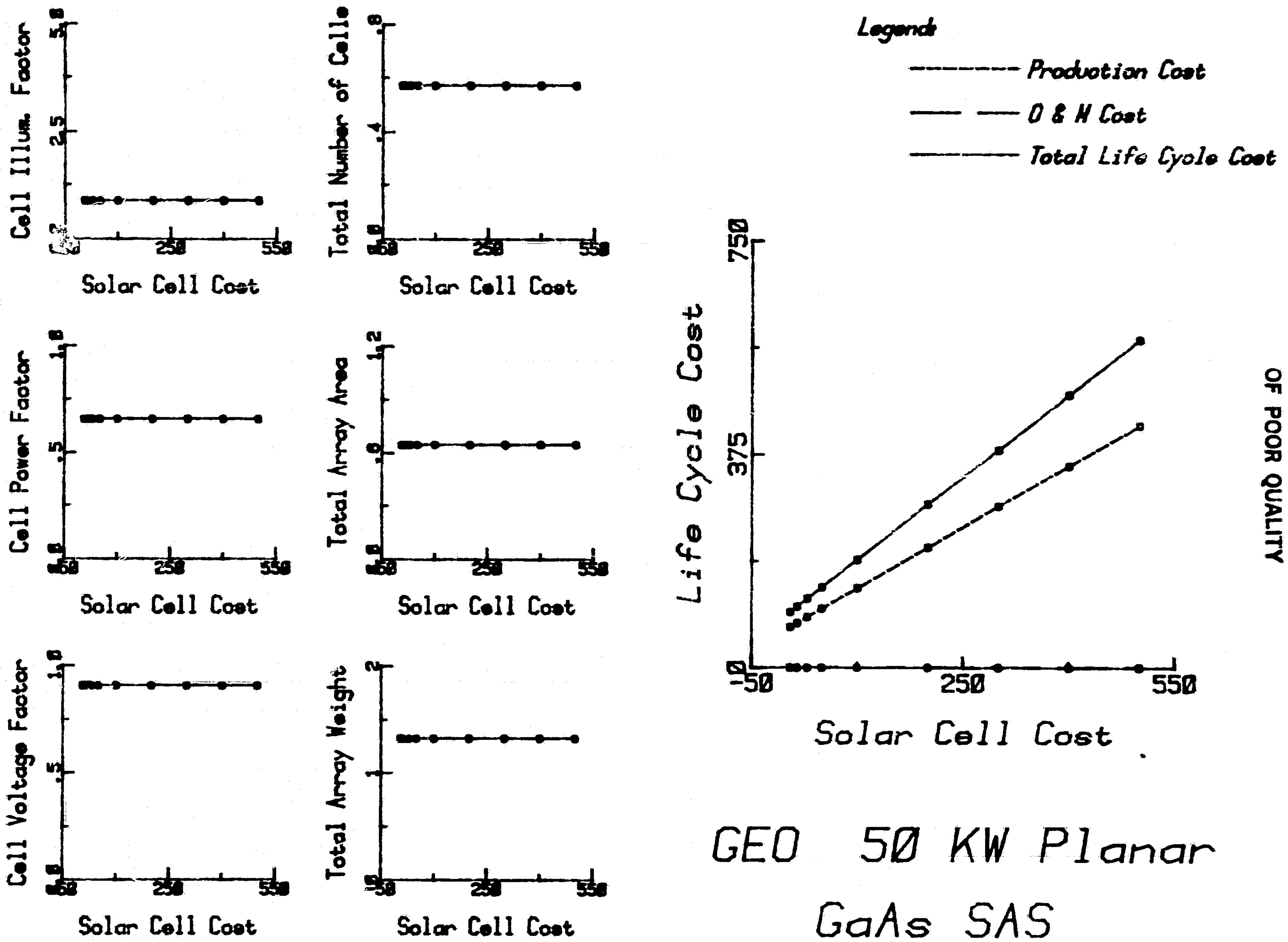

Exhibit 11c. Cell Cost Continued

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GEO 50 KW Conc. GaAs SAS

ARRAY PERFORMANCE									
No. of Hardware Life Cycles	1	1	1	1	1	1	1	1	1
Total Cell Life Required (Yr)	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0
Total EOL Min. Power (KW)	75.5	75.5	75.5	75.5	75.5	75.5	75.5	75.5	75.5
Total EOL Min. Voltage (V)	189.0	189.0	189.0	189.0	189.0	189.0	189.0	189.0	189.0
BOL Cell Efficiency (%)	18.1	18.1	18.1	18.1	18.1	18.1	18.1	18.1	18.1
BOL Cell Max. Voltage (V)	.810	.810	.810	.810	.810	.810	.810	.810	.810
EOL Cell Power (MW)	437.0	437.0	437.0	437.0	437.0	437.0	437.0	437.0	437.0
EOL Cell Voltage (V)	.526	.526	.526	.526	.526	.526	.526	.526	.526
POWER FACTORS									
Radiation	.779	.779	.779	.779	.779	.779	.779	.779	.779
Temperature	.834	.834	.834	.834	.834	.834	.834	.834	.834
Main Bus	.979	.979	.979	.979	.979	.979	.979	.979	.979
	****	****	****	****	****	****	****	****	****
CUM. EOL FACTOR	.480	.480	.480	.480	.480	.480	.480	.480	.480
VOLTAGE FACTORS									
Radiation	.963	.963	.963	.963	.963	.963	.963	.963	.963
Temperature	.718	.718	.718	.718	.718	.718	.718	.718	.718
Main Bus	.979	.979	.979	.979	.979	.979	.979	.979	.979
	****	****	****	****	****	****	****	****	****
CUM. EOL FACTOR	.649	.649	.649	.649	.649	.649	.649	.649	.649
ILLUMINATION FACTORS									
Cover Degradation (EOL)	.870	.870	.870	.870	.870	.870	.870	.870	.870
Concentration Ratio (BOL)	5.000	5.000	5.000	5.000	5.000	5.000	5.000	5.000	5.000
Concentrator Degrad. (EOL)	.960	.960	.960	.960	.960	.960	.960	.960	.960
	*****	*****	*****	*****	*****	*****	*****	*****	*****
CUM. EOL FACTOR	4.247	4.247	4.247	4.247	4.247	4.247	4.247	4.247	4.247
PHYSICAL CHARACTERISTICS									
Total Number of Cells	172800	172800	172800	172800	172800	172800	172800	172800	172800
No. of Modules/Panel	6	6	6	6	6	6	6	6	6
No. of Panels/Blanket	10	10	10	10	10	10	10	10	10
Blanket Weight (Kg)	376.0	376.0	376.0	376.0	376.0	376.0	376.0	376.0	376.0
Structure Weight (Kg)	78.0	78.0	78.0	78.0	78.0	78.0	78.0	78.0	78.0
Total Array Weight (Kg)	1582.0	1582.0	1582.0	1582.0	1582.0	1582.0	1582.0	1582.0	1582.0
Solar Cell Area (cm2)	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000
Module Area (M^2)	.900	.900	.900	.900	.900	.900	.900	.900	.900
Concentrator Area (M^2)	8.16	8.16	8.16	8.16	8.16	8.16	8.16	8.16	8.16
Panel Area (M^2)	26.70	26.70	26.70	26.70	26.70	26.70	26.70	26.70	26.70
Blanket Area (M^2)	283.0	283.0	283.0	283.0	283.0	283.0	283.0	283.0	283.0
Total Array Area (M^2)	1132.0	1132.0	1132.0	1132.0	1132.0	1132.0	1132.0	1132.0	1132.0
Power Density (W/M2)	66.71	66.71	66.71	66.71	66.71	66.71	66.71	66.71	66.71
Power/Weight Ratio (W/Kg)	47.74	47.74	47.74	47.74	47.74	47.74	47.74	47.74	47.74
LIFE CYCLE COST (1980$M)									
DDT&E	27.641	28.397	29.478	31.043	34.823	42.383	49.943	57.503	65.063
PRODUCTION	78.975	81.135	84.223	88.695	99.495	121.095	142.695	164.295	185.895
(Solar Cell - $/Cell)	(5.00)	(15.00)	(29.30)	(50.00)	(100.00)	(200.00)	(300.00)	(400.00)	(500.00)
OPERATIONS & MAINTENANCE	.900	.900	.900	.900	.900	.900	.900	.900	.900
	-------	-------	-------	-------	-------	-------	-------	-------	-------
TOTAL LIFE CYCLE COST	107.516	110.432	114.601	120.638	135.218	164.378	193.538	222.698	251.858

Exhibit 11d. Cell Cost

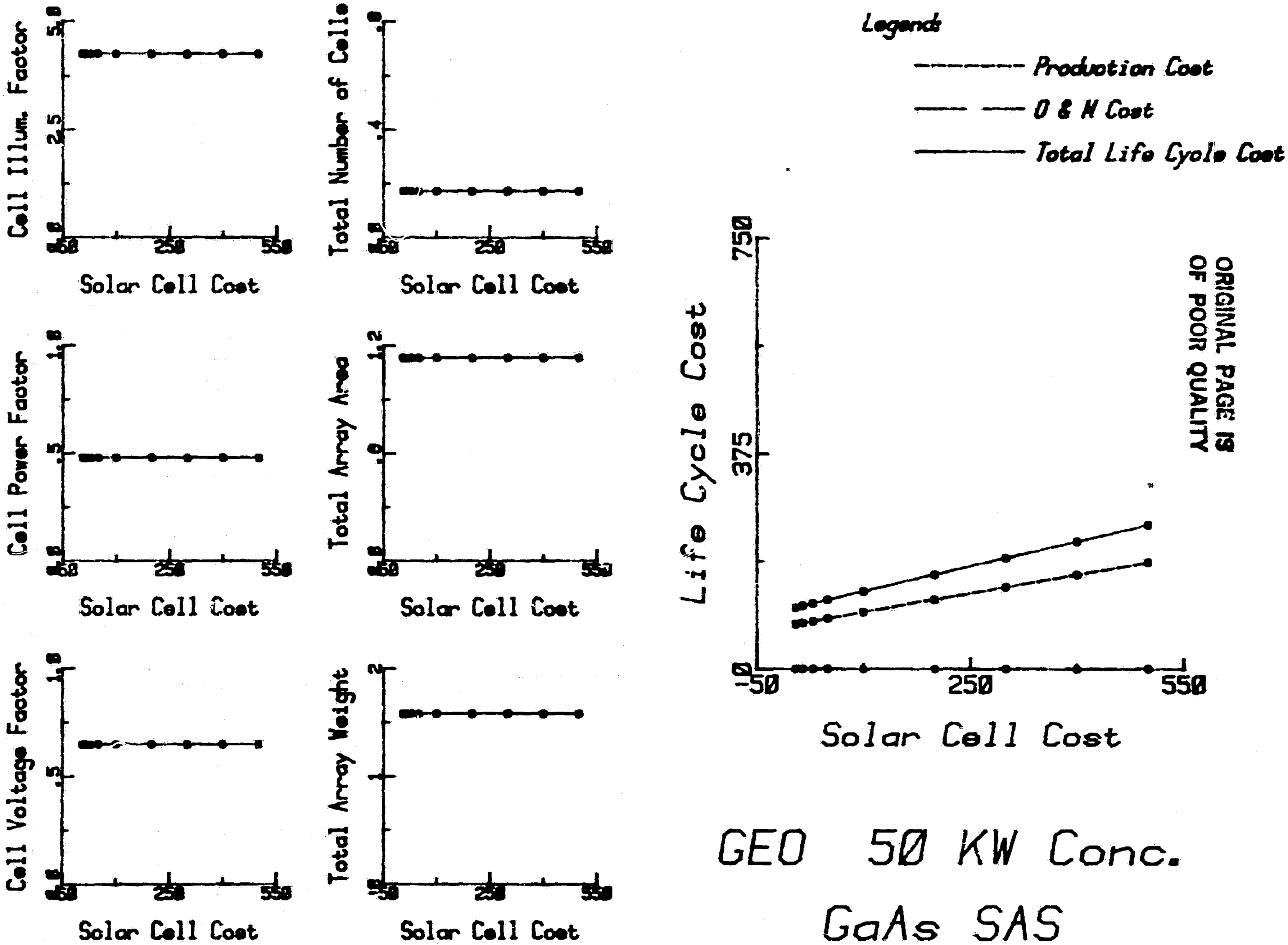

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Exhibit 11d, Cell Cost Continued

GaAs Solar Array Subsystems Study Final Report

Appendix D

COMPUTER PROGRAM LISTING

This appendix contains a "PLIST" of the HP-85 Computer program for the GaAs Solar Array Performance and Cost Model (SACPM), which is discussed in Section 6.0 of this report. The SACPM models the cost/technology relationships for four GaAs Solar Array configurations: (1) 250 kW planar array in LEO, (2) 250 kW concentrator array in LEO, (3) 50 kW planar array in GEO, and (4) 50 kW concentrator array in GEO. The modelling approach, generally, is to

- define the solar cell, cover, substrate and cell interconnect circuitry (module cross section)
- determine the value of the solar array factors which affect performance, and apply to the BOL cell/cover assembly in order to determine the EOL per cell array performance
- determine number of cell/cover assemblies required for baseline orbit and load power/energy requirements
- determine total array area, dimensions and structural requirements (array configuration)
- determine array weights and performance totals
- determine life cycle cost for DDT&E, Production and O&M.

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```
1 ! "GaAs#1"
5 OPTION BASE 1
10 COM G9,X1$[6],X2$[6],X3$[6],X4$[6],X9,X9(4)
20 DIM A(1),A0(2),A3(1),B(1),C0(11),C1(9,11),D0(2),D1(2),D3(10)
30 DIM E8(1),E9(2),G(9),H0(2),H4(6),L0(5),M0(2),M1(9),M2(9)
40 DIM P0(9,13),Q(2),Q0(3,4),Q1(5,4),Q2(5,4),Q3(10)
50 DIM R(2),R0(10,3),R1(10),S(4),S0(2),S1(2),S3(2),S8(3),S9(3)
60 DIM T(3),T0(2),T1(9),T2(2),T3(6),T4(4),T5(9),T6(3),T7(3),T8(3),T9(3)
70 DIM U8(3),V(4),V0(2,11),V1(2,11),V2(2,3),V9(3)
80 DIM W0(2),W1(9),X(75)
90 X1$="GaAs-1" @ X2$="GaAs-2" @ X3$="GaAs-3" @ X4$="GaAs-4"
95 BEEP 100,500 @ CLEAR @ DISP USING "7/,10X,11A" ; "INSERT TAPE" @ PAUSE
100 CLEAR @ DISP USING "/,13X,6A" ; "GaAs#1"
105 DISP USING "/,X,30A,2/" ; "DON'T BOTHER ME, I'M THINKING!"
110 C9=9 @ G=1 @ X9=4
111 FOR I=1 TO X9
112 READ X9(I)
113 DATA 1,2,3,4
114 NEXT I
115 FOR X0=1 TO X9
116 C=X9(X0)
120 DISP USING "14X,4A,D" ; "C =",C
125 IF C#1 THEN 135
130 ASSIGN# 9 TO X1$ @ GOTO 175
135 IF C#2 THEN 145
140 ASSIGN# 9 TO X2$ @ GOTO 175
145 IF C#3 THEN 155
150 ASSIGN# 9 TO X3$ @ GOTO 175
155 IF C#4 THEN 175
160 ASSIGN# 9 TO X4$
175 IF C<3 THEN G8=1 ELSE G8=2 ! 1=LEO; 2=GEO
200 IF C=1 OR C=3 THEN G7=1 ELSE G7=2 ! 1=PLANAR; 2=CONC.
210 E8(1)=1 @ E9(1)=1 @ E9(2)=1
310 IF G8=1 THEN H0=444 ELSE H0=35786 ! ORBIT ALTITUDE
315 H7=1
330 L0=10
500 FOR I=1 TO 9
510 FOR J=1 TO 11
520 READ P0(I,J)
530 NEXT J
540 NEXT I
550 DATA .04,.02,.00225,.00225,.181,.81,.5,.805,.865,.3,.7
560 DATA 0,2200,475,510,575,625,675,720,765,800,850
570 DATA 2,1080,660,725,795,865,910,945,985,1000,1015
580 DATA 8,5325,500,560,615,650,700,720,725,735,750
590 DATA .5,1400,725,800,875,950,1000,1040,1085,1100,1115
600 DATA .5,1420,725,800,875,950,1000,1040,1085,1100,1115
610 DATA 1,2963.3,315,320,330,335,350,380,415,440,495
620 DATA .5,1420,725,800,875,950,1000,1040,1085,1100,1115
630 DATA .5,1400,725,800,875,950,1000,1040,1085,1100,1115
700 A0(1)=INT(P0(1,1)*P0(1,2)*10000000+.5)/10000000
710 A0(2)=INT((P0(1,1)+P0(1,3))*(P0(1,2)+P0(1,4))*10000000+.5)/10000000
720 K0=INT(A0(1)/A0(2)*1000+.5)/1000
730 FOR I=2 TO 9
740 H1(I)=INT(.254*P0(I,1)*P0(I,2)+.5)/10000
750 IF I<=4 THEN U=A0(1) ELSE U=A0(2)
770 IF I=4 THEN V=.375 ELSE V=1
780 W1(I)=INT(U*H1(I)*10000000+.5)/10000000
790 T1(I)=INT(V*P0(I,1)*P0(I,2)/2200*100+.5)/100
800 IF I<=4 THEN H2(I)=INT(K0*H1(I)*1000+.5)/1000 ELSE H2(I)=H1(I)
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810 FOR J=3 TO 11
820 C1(I,J)=INT(M2(I)*P0(I,J)+.5)
830 NEXT J
840 NEXT I
850 ! CELL COVER ASSY.
860 T0(1),H0(1),W0(1)=0
870 FOR I=2 TO 4
880 T0(1)=T0(1)+P0(I,1)
890 H0(1)=H0(1)+H1(I)
900 W0(1)=W0(1)+W1(I)
910 NEXT I
920 D0(1)=INT(H0(1)/T0(1)/.0000254+.5)
930 ! SUBSTRATE ASSY.
940 T0(2),H0(2),W0(2)=0
950 FOR I=5 TO 9
960 T0(2)=T0(2)+P0(I,1)
970 H0(2)=H0(2)+H1(I)
980 W0(2)=W0(2)+W1(I)
990 NEXT I
1000 D0(2)=INT(H0(2)/T0(2)/.0000254+.5)
1010 ! MODULE ASSY.
1020 T0=T0(1)+T0(2)
1030 H0=INT(H0(1)*K0*10000+.5)/10000+H0(2)
1040 W0=W0(1)+W0(2)
1050 D0=INT(H0/T0/.0000254+.5)
1060 A0=A0(2)
1070 IF E8(1)=0 OR G8=2 THEN 1760
1100 ! FRNT SHIELDING
1110 S0(1),S1(1)=0
1120 FOR I=2 TO 3
1130 S0(1)=S0(1)+P0(I,1)
1140 S1(1)=S1(1)+T1(I)
1150 NEXT I
1160 D1(1)=INT(2200*S1(1)/S0(1)+.5)
1170 ! BACK SHIELDING
1180 S0(2),S1(2)=0
1190 FOR I=4 TO 9
1200 S0(2)=S0(2)+P0(I,1)
1210 S1(2)=S1(2)+T1(I)
1220 NEXT I
1230 D1(2)=INT(2200*S1(2)/S0(2)+.5)
1240 S(1)=3 @ S(2)=6 @ S(3)=12 @ S(4)=15.7 ! SHIELDING THICKNESS(mil)
1250 H0(1)=370 @ H0(2)=556 ! ORBIT ALTITUDE (km)
1260 L0(1)=2.5 @ L0(2)=5 @ L0(3)=10 @ L0(4)=20 @ L0(5)=30 ! LIFE (yr)
1270 ! FLUENCE DATA BASE
1280 FOR I=1 TO 5
1290 FOR J=1 TO 4
1300 READ Q1(I,J)
1310 READ Q2(I,J)
1320 NEXT J
1330 NEXT I
1335 DATA 25,32,13,16,5.5,7.1,3.9,5.1
1340 DATA 28,41,14,21,6.1,9.3,4.3,6.7
1345 DATA 33,59,17,29.6,7.3,13.7,5.2,10
1350 DATA 48,133,24,67,10.6,33,7.6,24.5
1355 DATA 69,297,35,149,15.5,78,11.2,59
1360 S=S1(1) @ GOSUB 6000
1370 Q1=Q ! FRONT FLUENCE
1380 S=S1(2) @ GOSUB 6000
1390 Q2=Q ! BACK FLUENCE
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1400 Q0=Q1+Q2 ! TOTAL FLUENCE
1410 T(1)=.3 @ T(2)=.5 @ T(3)=1
1420 FOR I=1 TO 10
1430 READ Q3(I)
1440 READ K1(I)
1450 FOR J=1 TO 3
1460 READ K0(I,J)
1463 NEXT J
1466 NEXT I
1470 DATA 1,.995,.968,.968,.876
1480 DATA 2,.994,.954,.954,.847
1490 DATA 4,.993,.941,.941,.789
1500 DATA 10,.991,.922,.922,.718
1510 DATA 20,.982,.903,.903,.651
1520 DATA 40,.969,.876,.876,.565
1530 DATA 100,.946,.825,.807,.425
1540 DATA 200,.923,.779,.736,.295
1550 DATA 400,.898,.713,.632,.1
1560 DATA 1000,.863,.624,.452,0
1570 D=5 @ D2=Q0 @ D9=40
1580 FOR I=1 TO 10
1590 D3(I)=Q3(I)
1600 NEXT I
1610 GOSUB 6500
1620 L=D
1630 IF P0(1,7)<.5 THEN M=1 ELSE M=2
1640 A1=T(M) @ A2=T(M+1)
1650 B1=K0(L,M) @ B2=K0(L,M+1)
1660 GOSUB 5000
1670 R(1)=A+B*P0(1,7)
1680 B1=K0(L+1,M) @ B2=K0(L+1,M+1)
1690 GOSUB 5000
1700 R(2)=A+B*P0(1,7)
1710 A1=LOG(Q3(L)) @ A2=LOG(Q3(L+1))
1720 B1=R(1) @ B2=R(2)
1725 GOSUB 5000
1730 V0(1,2),V0(2,2)=INT((A+B*LOG(Q0))*1000+.5)/1000 ! RAD POWER FACTOR
1735 B1=K1(L) @ B2=K1(L+1)
1740 GOSUB 5000
1745 V1(1,2),V1(2,2)=INT((A+B*LOG(Q0))*991.8+.5)/1000 ! RAD VOLTAGE FACTOR
1750 GOTO 1780
1760 IF C8=1 THEN V0(1,2),V0(2,2)=.89 ELSE V0(1,2),V0(2,2)=.779
1770 IF C8=1 THEN V1(1,2),V1(2,2)=.968 ELSE V1(1,2),V1(2,2)=.963
1780 FOR J=3 TO 11
1790 C0(J-2)=0
1800 FOR I=2 TO 9
1810 C0(J-2)=C0(J-2)+C1(I,J)
1820 NEXT I
1830 NEXT J
1840 RESTORE 1845
1841 FOR J=1 TO 9
1842 READ T5(J)
1843 NEXT J
1845 DATA 173,198,223,248,273,298,323,348,373
1850 X1,X2,Y1,Y2,Z=0
1851 FOR I=1 TO 9
1852 X1=X1+T5(I) @ X2=X2+T5(I)^2
1853 Y1=Y1+C0(I) @ Y2=Y2+C0(I)^2
1854 Z=Z+T5(I)*C0(I)
1855 NEXT I
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1856 E(1)=(9*Z-X1*Y1)/(9*X2-X1^2)
1857 A(1)=(Y1-E(1)*X1)/9
1870 A3(1)=INT((P0(1,8)*K0+P0(1,10)*(1-K0))*1000+.5)/1000 ! FRONT ABSORPTIVITY
1880 Q3=INT(.45*K0*P0(1,5)*1000+.5)/1000 ! ELECTRICAL ENERGY
1890 A3=A3(1)-Q3 ! EFFECTIVE FRONT ABSORPTIVITO
1900 A4=P0(1,10) ! BACK ABSORPTIVITY
1910 E3=INT((P0(1,9)*K0+P0(1,11)*(1-K0))*1000+.5)/1000 ! FRONT EMISSIVITY
1920 E4=P0(1,11) ! BACK EMISSIVITY
130 Q7=INT(15.4*E4*10+.5)/10 ! HEAT FROM SPACE PLATFORM
1940 E5=INT((E3+E4)*.0000000581*10000000000+.5)/10000000000
1950 H1=6375 @ H2=H0+H1
1960 T2=INT(.016587*H2^1.5+.5)/100 ! ORBIT PERIOD
1970 DEG @ C0=ACS(H1/H2)
1980 T2(1)=INT(T2/180*(90-C0)*100+.5)/100 ! ECLIPSE PERIOD
1990 T2(2)=T2-T2(1) ! SUN PERIOD
2000 K1=360/T2 ! TIME VS POSITION FACTOR
2010 V(1)=1.017 @ V(2)=INT(.98617^L0*1000+.5)/1000
2015 IF G7=1 THEN V(3),V(4)=1 ELSE V(3)=5 @ V(4)=INT(.9959^L0*1000+.5)/1000
2025 V0=1
2030 FOR I=1 TO 4
2040 V0=V0*V(I)
2045 V0=INT(V0*1000+.5)/1000
2050 NEXT I
2060 S3(1)=INT(1309*V(3)*V(4)+.5) @ S3(2)=INT(1399*V(3)*V(4)+.5) ! ILLUMINATION
2070 ! ORBIT TIME MILESTONES
2080 T3(1)=INT(C0/K1*100+.5)/100
2090 T3(2)=INT((90+C0)/K1*100+.5)/100
2100 T3(3)=INT((180+C0)/K1*100+.5)/100
2110 T3(4)=T2(2)
2120 T3(5)=INT((270+C0)/K1*100+.5)/100
2130 T3(6)=T2
2140 IF E9(1)=0 THEN 2200
2150 K=1 @ GOSUB 9000
2160 K=2 @ GOSUB 9000
2170 GOTO 2500
2200 IF C=1 THEN S9(1)=1366 @ T9(1)=320.2 @ S9(2)=1460 @ T9(2)=325.4
2210 IF C=2 THEN S9(1)=6557 @ T9(1)=473.3 @ S9(2)=7008 @ T9(2)=481.2
2220 IF C=3 THEN S9(1)=1311 @ T9(1)=314.5 @ S9(2)=1401 @ T9(2)=319.7
2230 IF C=4 THEN S9(1)=6293 @ T9(1)=464.4 @ S9(2)=6725 @ T9(2)=472.2
2500 ! COMMON PARAMETERS
2501 X(1)=P0(1,1)
2502 X(2)=P0(1,2)
2503 X(3)=P0(1,3)
2504 X(4)=P0(1,4)
2505 X(5)=P0(1,5)
2506 X(6)=P0(1,6)
2507 X(7)=P0(2,1)
2508 X(8)=P0(4,1)
2509 X(9)=A0(1)
2510 X(10)=A0(2)
2511 X(11)=K0
2512 X(12)=T0
2513 X(13)=W0(1)
2514 X(14)=W0(2)
2515 X(15)=W0
2516 X(16)=W1(4)
2517 X(17)=Q3
2518 X(18)=E5
2519 X(19)=H7
2520 X(20)=L0
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2521 X(21)=V0(1,2)
2522 X(22)=V1(1,2)
2523 X(23)=T2(1)
2524 X(24)=T2(2)
2525 X(25)=V(1)
2526 X(26)=V(2)
2527 X(27)=V(3)
2528 X(28)=V(4)
2529 X(29)=V0
2530 X(30)=S9(1)
2531 X(31)=S9(2)
2532 X(32)=T9(1)
2533 X(33)=T9(2)
2590 PRINT# 9,G ; X()
3000 RESTORE 550 @ NEXT X0
3100 ! DISP USING "/,10X,12A" ; "CHAIN GaAs#2" @ CHAIN "GaAs#2"
3500 END
5000 ! EXTRAPOLATION SUBROUTINE
5010 X1=A1+A2 @ X2=A1^2+A2^2
5020 Y1=B1+B2 @ Y2=B1^2+B2^2
5030 Z=A1*B1+A2*B2
5040 B=(2*Z-X1*Y1)/(2*X2-X1^2)
5050 A=(Y1-B*X1)/2
5060 RETURN
6000 ! FLUENCE SUBROUTINE
6005 A1=LOG(370) @ A2=LOG(556)
6010 D=3 @ D2=L0 @ D9=10
6015 FOR I=1 TO 5
6020 D3(I)=L0(I)
6025 NEXT I
6030 GOSUB 6500
6040 IF S<6 THEN E=1
6045 IF S>=6 AND S<=12 THEN E=2
6050 IF S>12 THEN E=3
6060 B1=Q1(D,E) @ B2=Q2(D,E)
6070 GOSUB 5000
6080 Q0(1,1)=A+B*LOG(H0)
6090 B1=Q1(D,E+1) @ B2=Q2(D,E+1)
6100 GOSUB 5000
6110 Q0(1,2)=A+B*LOG(H0)
6120 B1=Q1(D+1,E) @ B2=Q2(D+1,E)
6130 GOSUB 5000
6140 Q0(2,1)=A+B*LOG(H0)
6150 B1=Q1(D+1,E+1) @ B2=Q2(D+1,E+1)
6160 GOSUB 5000
6170 Q0(2,2)=A+B*LOG(H0)
6180 A1=LOG(S(E)) @ A2=LOG(S(E+1))
6190 B1=LOG(Q0(1,1)) @ B2=LOG(Q0(1,2))
6200 GOSUB 5000
6210 A=EXP(A)
6220 Q(1)=A*S^B
6230 B1=LOG(Q02,1)) @ B2=LOG(Q0(2,2))
6240 GOSUB 5000
6250 A=EXP(A)
6260 Q(2)=A*S^B
6270 A1=LOG(L0(D)) @ A2=LOG(L0(D+1))
6280 B1=LOG(Q(1)) @ B2=LOG(Q(2))
6290 GOSUB 5000
6300 A=EXP(A)
6310 Q=INT(A*L0^B*100+.5)/100
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```
6320 RETURN
6500 ! 2-D SUBROUTINE
6505 IF D2>D9 THEN GOTO 6530
6510 D=D-1
6520 IF D3(D)>D2 THEN GOTO 6510 ELSE RETURN
6530 D=D+1
6540 IF D3(D)<D2 THEN GOTO 6530
6550 D=D-1
6560 RETURN
7000 ! TEMPERATURE SUBROUTINE
7010 C0=A(1)+B(1)*T6
7020 IF G8=1 THEN H4(3)=188 ELSE H4(3)=5 ! EARTH EMISSION
7140 ON E GOTO 7150,7220,7270,7320,7390,7440
7150 ! CASE I
7160 G1=K1*T4-G0
7170 H3=SQR(H1^2+H2^2-2*H1*H2*COS(G1))
7180 G2=ACS((H1^2+H3^2-H2^2)/2/H1/H3)-90
7190 G3=90-G1
7200 S5=INT(S3(K)*(1+H4(2)*COS(G2))+.5)
7210 Q8=A3*S5+H4(3)*A3*COS(G3)+Q7-E5*T6^4
7215 RETURN
7220 ! CASE II
7230 G1=K1*T4-G0
7240 G2,G3=90-G1
7250 S5=S3(K)
7260 Q8=S5*(A3+H4(2)*A4*COS(G2))+H4(3)*A4*COS(G3)-E5*T6^4
7265 RETURN
7270 ! CASE III
7280 G1=K1*T4-G0
7290 G2,G3=G1-90
7300 S5=S3(K)
7310 Q8=S5*(A3+H4(2)*A4*COS(G2))+H4(3)*A4*COS(G3)+Q7-E5*T6^4
7315 RETURN
7320 ! CASE IV
7330 G1=K1*T4-G0-180
7340 H3=SQR(H1^2+H2^2-2*H1*H2*COS(G1))
7350 G2=ACS((H1^2+H3^2-H2^2)/2/H1/H3)-90
7360 G3=90-G1
7370 S5=INT(S3(K)*(1+H4(2)*COS(G2))+.5)
7380 Q8=A3*S5+H4(3)*A3*COS(G3)+Q7-E5*T6^4
7385 RETURN
7390 ! CASE V
7400 G1=K1*T4-G0-180
7410 G3=90-G1 @ S5=0
7420 Q8=A3*H4(3)*A3*COS(G3)+Q7-E5*T6^4
7430 RETURN
7440 ! CASE VI
7450 G1=K1*T4-G0-180
7460 G3=G1-90 @ S5=0
7470 Q8=A3*H4(3)*COS(G3)+Q7-E5*T6^4
7480 RETURN
8000 ! 8000 SUBROUTINE
8010 IF T6(2)-T6(1)>0 THEN T6(2)=T6(1)+H4(6) ELSE T6(2)=T6(1)-H4(6)
8020 T6=(T6(1)+T6(2))/2
8025 E8=0
8030 T4=(T4(1)+T4(2))/2
8040 GOSUB 7000
8050 T4(3)=INT((T4(1)+(T6(2)-T6(1))/Q8*C0/60)*1000+.5)/1000
8055 IF T4(3)>T4(4) THEN T4(3)=T4(4)
8060 IF T4(3)>T3(E) THEN T4(3)=T3(E)
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8065 IF T4(3)<T4(1) THEN T4(3)=T4(2)
8070 IF E8<5 AND T4(2)#T4(3) THEN E8=E8+1 @ T4(2)=T4(3) @ GOTO 8030
8075 T4(2)=INT((T4(2)+T4(3))*500+.5)/1000
8080 T5=T4(2)-T4(1)
8090 RETURN
9000 ! 9000 SUBROUTINE
9005 E=1
9010 T4(1)=0
9015 IF G8=1 THEN H4(2)=.27 ELSE H4(2)=.005 ! ALBEDO FACTOR
9020 IF C=1 THEN H4(4)=176.8
9022 IF C=2 THEN H4(4)=176.9
9024 IF C=3 THEN H4(4)=113.1
9026 IF C=4 THEN H4(4)=113
9030 T6(1),T6(2),T8=H4(4)
9035 H4(6)=25 @ E7=0
9040 IF E9(2)=0 THEN 9050
9042 PRINT @ PRINT @ PRINT
9044 PRINT "t=";T4(1)
9046 IF E=1 THEN PRINT "S=";INT(S3(K)*(1+H4(2))+.5)
9048 PRINT "T=";T6(1)
9050 S9,T9=0
9052 IF G8=1 THEN H4(5)=2 ELSE H4(5)=30
9054 T4(4)=H4(5)
9060 T4(2)=T4(1)+H4(5)
9065 IF T4(2)>T4(4) THEN T4(2)=T4(4)
9070 IF T4(2)>T3(E) THEN T4(2)=T3(E)
9075 T4=(T4(1)+T4(2))/2
9080 T5=T4(2)-T4(1)
9085 E9=0
9090 T6=(T6(1)+T6(2))/2
9100 GOSUB 7000
9110 IF ABS(Q8)>10000 THEN Q8=Q8/ABS(Q8)*10000
9120 T6(3)=INT((T6(1)+T5*Q8/C0*60)*10+.5)/10
9125 IF ABS(T6(3)-T6(1))>H4(6) THEN T6(3)=T6(1)+(T6(3)-T6(1))/ABS(T6(3)-T6(1))*H4(6)
9130 IF E9<5 AND T6(2)#T6(3) THEN E9=E9+1 @ T6(2)=T6(3) @ GOTO 9090
9140 T6(2)=INT((T6(2)+T6(3))*5+.5)/10
9150 F ABS(T6(2)-T6(1))>=H4(6) THEN GOSUB 8000
9160 IF C>2 AND T4(2)=30 AND E7=0 THEN H4(6)=1 @ E7=1 @ T6(2)=T6(1) @ GOTO 9085
9170 T6=INT((T6(1)+T6(2))/2*10+.5)/10
9180 IF E<5 THEN S9=S9+S5*T5 @ T9=T9+T5*T6
9200 IF T4(2)=T3(E) THEN E=E+1
9205 IF E>4 THEN H4(6)=25
9210 IF T4(2)#T2(2) THEN 9230
9212 S9(K)=INT(S9/T2(2)+.5)
9214 T9(K)=INT(T9/T2(2)*10+.5)/10
9215 IF E9(2)=0 THEN 9230
9216 PRINT @ PRINT "t=";T2(2)
9218 PRINT "S=";INT(S3(K)*(1+H4(2))+.5)
9220 PRINT "T=";T6(2)
9222 PRINT @ PRINT @ PRINT
9224 PRINT S9(K)
9226 PRINT T9(K)
9228 PRINT @ PRINT
9230 IF E9(2)=0 THEN 9240
9232 PRINT @ PRINT "t=";T4(2)
9234 IF T4(2)<T2(2) THEN T4=T4(2) @ GOSUB 7140 @ PRINT "S=";S5
9236 PRINT "T=";T6(2)
9240 T4(1)=T4(2)
9245 IF T4(2)=T4(4) THEN T4(4)=T4(4)+H4(5)
9250 T6(1)=T6(2)
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```
9260 IF E<7 THEN 9060
9270 ! IF T8#T6(1) OR S9=0 THEN E=1 @ T4(1),T4(4)=0 @ T8=T6(1) @ GOTO 9040
9280 RETURN
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1 ! "GaAs#2"
5 OPTION BASE 1
10 COM C9,X1$[6],X2$[6],X3$[6],X4$[6],X9,X9(4)
20 DIM F0(14),F2(4),X(75),Y(33)
30 DIM A3(1),E1(2),E6(5),G(9),H8(2),L1(2,3),L2(8),L3(2),L4(2),L6(4)
40 DIM N0(3),N1(1),N2(2),N3(2),N4(2),N5(1),N7(5),N8(11),N9(5)
50 DIM P2(3),P8(4),P9(3),S5(1),S8(2),S9(2)
60 DIM T4(4),T5(9),T6(3),T7(3),T8(3),T9(3)
70 DIM U(2),U8(3),V(4),V0(2,11),V1(2,11),V2(2,3),V9(3)
80 DIM W(6),W3(3),W4(3),W5(4),W6(3),W8(4)
85 BEEP 100,500 @ CLEAR @ DISP USING "7/,10X,11A" ; "INSERT TAPE" @ PAUSE
86 CLEAR @ DISP USING "/,13X,6A" ; "GaAs#2" @ DISP
87 IF C9#0 THEN Y0=0 @ GOTO 100 ELSE DISP "    (Ignore NULL DATA Warning)"
90 DISP @ DISP "INPUT DATA:  [0=Tape(9);        1=Tape(B/L); 2=Program(B/L)]" @ INPUT Y0
91 IF Y0=0 THEN C9=9 @ GOTO 100 ELSE G,C9=1 @ X9=4
92 X1$="GaAs-1" @ X9(1)=1
93 X2$="GaAs-2" @ X9(2)=2
94 X3$="GaAs-3" @ X9(3)=3
95 X4$="GaAs-4" @ X9(4)=4
96 GOTO 125
100 X9=4
101 X1$="g1-A2" @ X9(1)=1
102 X2$="g2-A2" @ X9(2)=2
103 X3$="g3-A2" @ X9(3)=3
104 X4$="g4-A2" @ X9(4)=4
125 FOR X0=1 TO X9
130 C=X9(X0)
135 CLEAR @ DISP USING "/,13X,6A" ; "GaAs#2"
140 DISP USING "/,X,30A," ; "DON'T BOTHER ME, I'M THINKING!"
151 IF X0#1 THEN 152 ELSE X$=X1$ @ GOTO 175
152 IF X0#2 THEN 153 ELSE X$=X2$ @ GOTO 175
153 IF X0#3 THEN 154 ELSE X$=X3$ @ GOTO 175
154 IF X0#4 THEN 175 ELSE X$=X4$ @ GOTO 175
175 ASSIGN# 9 TO X$
180 DISP USING "/,13X,6A" ; X$
185 DISP USING "13X,4A,2D" ; "X9 =",X9
190 P=0
200 IF C<3 THEN C8=1 ELSE C8=2 ! 1=LEO; 2=GEO
250 IF C=1 OR C=3 THEN G7=1 ELSE G7=2 ! 1=PLANAR; 2=CONCENTRATED
300 E1(1)=5753 @ E1(2)=.00000002603
320 IF C=1 THEN H9=49623
322 IF C=2 THEN H9=99930
324 IF C=3 THEN H9=3775
326 IF C=4 THEN H9=7454
330 L2(1)=.005 @ L2(2)=.05 @ L2(3)=.025 @ L2(4)=6 @ L2(5)=.5
331 IF C8=1 THEN L2(6)=3 @ L2(7)=18 @ L2(8)=1
332 IF C8=2 THEN L2(6)=2 @ L2(7)=6.75 @ L2(8)=1
340 IF C=1 THEN N4(1)=5 @ N4(2)=3
341 IF G7=2 THEN N4(2)=1
342 IF C=3 THEN N4(1)=2 @ N4(2)=2
365 IF C=1 THEN N8(4)=2
366 IF C=2 THEN N8(4)=4
367 IF C=3 THEN N8(4)=3
368 IF C=4 THEN N8(4)=4
375 IF C8=1 THEN N8(5)=12 ELSE N8(5)=5
380 N8(6),N8(7)=2
390 N8(8)=N8(7)*N8(6)*N8(5)
410 N7(1)=.932 @ N7(2)=.844 @ N7(3)=.833 @ N7(4)=.63 @ N7(5)=.935
420 IF C8=1 THEN P0=250000 ELSE P0=50000
430 P8(1)=.75*P0 @ P8(2)=.25*P0 @ P8(3)=.1*P0
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440 P8(4)=P8(1)/H7(1)+P8(2)/H7(2)+P8(3)/H7(3)
450 IF G8=1 THEN S5(1)=.1 ELSE S5(1)=0
460 V9=180
490 IF YO#2 THEN 980
500 ! BASELINE PARAMETERS
510 PO(1,1)=.04
515 PO(1,2)=.02
520 PO(1,3)=.00225
525 PO(1,4)=.00225
530 PO(1,5)=.181
535 PO(1,6)=.81
540 PO(2,1)=6
545 PO(4,1)=8
550 AO(1)=.0008
555 AO(2)=.0009401
560 KO=.851
565 TO=19
570 WO(1)=.0011761
575 WO(2)=.000138
580 WO=.0013141
585 W1(4)=.000864
590 Q3=.069
595 E5=.0000000895
600 H7=1
605 LO=10
610 IF G8=1 THEN VO(1,2),VO(2,2)=.891 ELSE VO(1,2),VO(2,2)=.779
615 IF G8=1 THEN V1(1,2),V1(2,2)=.968 ELSE V1(1,2),V1(2,2)=.963
620 IF G8=1 THEN T2(1)=35.91 ELSE T2(1)=69.38
625 IF G8=1 THEN T2)=57.49 ELSE T2(2)=1366.55
630 V(1)=1.017
635 V(2)=.87
640 IF G7=1 THEN V(3),V(4)=1 ELSE V(3)=5 @ V(4)=1-.004*LO
645 VO=INT(V(1)*V(2)*V(3)*V(4)*1000+.5)/1000
650 IF C=1 THEN S9(1)=1366 @ T9(1)=320.2 @ S9(2)=1460 @ T9(2)=325.4
655 IF C=2 THEN S9(1)=6557 @ T9(1)=473.3 @ S9(2)=7008 @ T9(2)=481.2
660 IF C=3 THEN S9(1)=1311 @ T9(1)=314.5 @ S9(2)=1401 @ T9(2)=319.7
665 IF C=4 THEN S9(1)=6293 @ T9(1)=464.4 @ S9(2)=6725 @ T9(2)=472.2
970 GOTO 2000
980 FOR G=1 TO G9
990 DISP USING "11X,3A,2D,4A,D" ; "XO=",XO,"; G=",G
1000 ! COMMON PARAMETERS
1002 READ# 9,G ; Y()
1003 PO(1,1)=Y(1)
1004 PO(1,2)=Y(2)
1005 PO(1,3)=Y(3)
1006 PO(1,4)=Y(4)
1007 PO(1,5)=Y(5)
1008 PO(1,6)=Y(6)
1009 PO(2,1)=Y(7)
1010 PO(4,1)=Y(8)
1011 AO(1)=Y(9)
1012 AO(2)=Y(10)
1013 KO=Y(11)
1014 TO=Y(12)
1015 WO(1)=Y(13)
1016 WO(2)=Y(14)
1017 WO=Y(15)
1018 W1(4)=Y(16)
1019 Q3=Y(17)
1020 E5=Y(18)
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1021 N7=Y(19)
1022 LO=Y(20)
1023 V0(1,2),V0(2,2)=Y(21)
1024 V1(1,2),V1(2,2)=Y(22)
1025 T2(1)=Y(23)
1026 T2(2)=Y(24)
1027 V(1)=Y(25)
1028 V(2)=Y(26)
1029 V(3)=Y(27)
1030 V(4)=Y(28)
1031 V0=Y(29)
1032 S9(1)=Y(30)
1033 S9(2)=Y(31)
1034 T9(1)=Y(32)
1035 T9(2)=Y(33)
2000 P0(1,6)=INT((P0(1,6)+.041*(V0-1)/4)*1000+.5)/1000
2010 P9=INT(P8(4)*(1+T2(1)/T2(2)/N7(4))/N7(5)+.5)
2020 S8(1)=INT(S9(1)/V(1)*V(2)+.5) @ S8(2)=INT(S9(2)/V(1)*V(2)+.5) ! ILLUMINATION
2300 FOR K=1 TO 2
2310 V0(K,1)=.965 @ V1(K,1)=1
2320 RESTORE 2370
2330 FOR I=4 TO 10
2340 READ V0(K,I)
2350 READ V1(K,I)
2360 NEXT I
2370 DATA .993,.993,.999,.999,.999,.999,.999,.999,.961,.957,.988,.988,1,1
2380 V0(K,11)=INT(.9779^L0*1000+.5)/1000 @ V1(K,11)=1
2390 T8(K)=T9(K)
2400 NEXT K
2410 IF G7=2 THEN 2430
2420 N2(2)=FLOOR(((L2(6)-2*L2(2)+(N4(2)-1)*L2(1))/N4(2)-2*L2(1)+P0(1,4))/2/(P0(1,2)+P0(1,4)))
2421 N2(1)=FLOOR(((L2(7)-2*L2(2)+(N4(1)-1)*L2(1))/N4(1)-2*L2(1)+P0(1,3))/(P0(1,1)+P0(1,3)))
2422 GOTO 2440
2430 N4(1)=FLOOR(L2(7)/(INT(10.06/4.5*SQR(V(3)/5)*L2(8)*100+.5)/100))
2431 N2(2)=FLOOR((L2(8)-2*L2(2)+P0(1,4))/2/(P0(1,2)+P0(1,4)))
2432 N2(1)=FLOOR((L2(8)-2*L2(2)+P0(1,3))/(P0(2,1)+P0(1,3)))
2440 N2=N2(1)*N2(2)
2450 N8(3)=N4(1)*N4(2)
2460 N8(2)=2*N8(3)
2500 E6(3),E6(4),E6(5)=0
2510 FOR K=1 TO 2
2520 E6(1)=0
2530 A=1.298 @ B=-.001
2540 V0(K,3)=INT((A+B*T8(K))*1000+.5)/1000 ! TEMP POWER FACTOR
2560 A=1.5066 @ B=-.0017
2570 V1(K,3)=INT((A+B*T8(K))*1000+.5)/1000 ! TEMP VOLTAGE FACTOR
2780 E6(2)=0
2790 V2(1,K)=1
2800 FOR I=1 TO 11
2810 V2(1,K)=V2(1,K)*V0(K,I)
2820 NEXT I
2822 V2(1,K)=INT(V2(1,K)*1000+.5)/1000
2830 N0(K)=V2(1,K)*P0(1,5)
2840 P2(K)=S9(K)*N0(K)*K0
2850 T8=INT((T9(K)^4-(P2(K)-S8(K)*Q3)/E5)^.25*10+.5)/10
2860 T8(K)=INT((T8(K)+T8)*5+.5)/10
2870 IF T8(K)#T8 AND E6(1)<3 THEN E6(1)=E6(1)+1 @ GOTO 2530
2940 V2(2,K)=1
2950 FOR I=1 TO 11
2960 V2(2,K)=V2(2,K)*V1(K,I)
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2970 NEXT I
2975 V2(2,K)=INT(V2(2,K)*1000+.5)/1000
2990 P9(K)=INT(P2(K)*A0(2)*100+.5)/1000
3000 V9(K)=INT(P0(1,6)*V2(2,K)*1000+.5)/1000
3010 N1(1)=IP(V9/N8(4)/N8(2)/V9(K)+1)
3020 N5(1)=N1(1)*N8(2)*N8(4)
3030 U8(K)=1-INT(SQR(P9(K)/W0*E1(1)*N9*E1(2)/N8(5)/2)/V9(K)/N5(1)*1000+.5)/1000
3035 V0(K,8),V1(K,8)=INT((V0(K,8)+U8(K))*500+.5)/1000
3040 IF V0(K,8)#U8(K) AND E6(2)<3 THEN E6(2)=E6(2)+1 @ GOTO 2790
3050 NEXT K
3060 P1=P9(1)
3070 X=CEIL(P9/P1/N8(8)/N8(2))
3071 Y=CEIL(X/N2)
3072 IF N8(4)#Y AND E6(5)=0 THEN N8(4)=MIN(N8(4),Y)
3080 N2=CEIL(X/N8(4)/N1(1))*N1(1)
3085 N3=2*N2
3090 IF G7=1 THEN N3(1)=N2(1) @ N3(2)=CEIL(N3/N3(1)) @ GOTO 3120
3100 Z=SQR(N3*(P0(1,2)+P0(1,4))/(P0(1,1)+P0(1,3)))
3101 X1=FLOOR(Z) @ X2=CEIL(Z)
3102 Y1=CEIL(N3/X1) @ Y2=CEIL(N3/X2)
3103 Z1=ABS(X1*(P0(1,1)+P0(1,3))-Y1*(P0(1,2)+P0(1,4)))
3104 Z2=ABS(X2*(P0(1,1)+P0(1,3))-Y2*(P0(1,2)+P0(1,4)))
3105 IF Z1<Z2 THEN N3(1)=X1 @ N3(2)=Y1 ELSE N3(1)=X2 @ N3(2)=Y2
3120 N8(10)=N8(4)*N8(8)
3125 N8(9)=N8(3)*N8(10)
3130 L3(1)=INT((N3(1)*(P0(1,1)+P0(1,3))-P0(1,3)+2*L2(1))*100+.5)/100
3135 L3(2)=INT((N3(2)*(P0(1,2)+P0(1,4))-P0(1,4)+2*L2(1))*100+.5)/100
3140 IF G7=2 THEN L3(1),L3(2)=MAX(L3(1),L3(2)) ELSE 3150
3145 IF L3(1)>1 THEN N8(4)=N8(4)+1 @ E6(5)=1 @ GOTO 2510
3150 IF G7=1 THEN L4(1)=INT(((L3(1)-L2(1))*N4(1)+L2(1))*100+.5)/100 ELSE 3175
3155 L4(2)=INT(((L3(2)-L2(1))*N4(2)+L2(1))*100+.5)/100
3160 IF C=1 AND L4(2)>3 THEN N8(4)=N8(4)+1 @ E6(5)=1 @ GOTO 2510
3165 IF C=3 AND L4(2)>2 THEN N8(4)=N8(4)+1 @ E6(5)=1 @ GOTO 2510
3170 GOTO 3190
3175 L4(1),L4(2)=INT(10.06/4.5*SQR(V(3)/5)*100+.5)/100
3180 L4(1)=INT(N4(1)*L3(1)*L4(1)*100+.5)/100
3185 L4(2)=INT(N4(2)*L3(2)*L4(2)*100+.5)/100
3190 L6(3)=L4(2)+L2(3)
3200 U=L2(4)
3210 V=U^2
3220 FOR I=1 TO N8(5)
3230 U=U+N8(4)*L6(3)
3240 IF I=N8(5) THEN V=V+U^2 ELSE V=V+2*U^2
3250 NEXT I
3260 V=INT(V+.5)
3262 IF E6(4)=0 AND E6(5)=1 THEN N9=V @ E6(4)=1 @ GOTO 2510
3264 IF N9#V AND E6(3)<3 THEN N9=V @ E6(3)=E6(3)+1 @ GOTO 2510
3266 N9=INT((N9+V)/2+.5)
3270 S8(1)=INT(S8(1)+.5)
3272 S8(2)=INT(S8(2)+.5)
3274 T8(1)=INT(T8(1)*10+.5)/10
3276 T8(2)=INT(T8(2)*10+.5)/10
3280 V1=V9(2)
3290 P2=INT(P1*N2*100+.5)/100
3295 V2=INT(V1*N1(1)*100+.5)/100
3300 ! WEIGHTS & VOLUMES
3310 A3=INT(L3(1)*L3(2)*100+.5)/100
3315 IF G7=1 THEN A3(1)=0 ELSE A3(1)=INT(A3*906.3*V(3)/5+.5)/100
3316 IF G7=2 AND V(3)=1 THEN A3(1)=0
3320 L1(1,1),L1(2,1)=P0(1,1)*100
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3325 L1(1,2),L1(2,2)=P0(1,2)*100
3330 L1(1,3)=INT(P0(4,1)*2.54+.5)/100
3335 L1(2,3)=INT(P0(2,1)*2.54+.5)/100
3350 P4=P2*N8(2)
3360 V4=V2*N8(2)
3370 P5=P4*N8(4)
3380 V5,V6,V7,V8=INT(V4*N8(4)+.5)
3390 P6=P5*N8(5)
3400 P7=P6*N8(6)
3410 P8=INT(P7*N8(7)+.5)
3420 A4=INT(L4(1)*L4(2)*10+.5)/10
3430 L6(1)=INT((L4(2)*N8(4)*N8(5)+(N8(4)*N8(5)-1)*L2(3)+2*L2(5))*10+.5)/10
3440 L6(2)=L4(1)
3450 A6=INT(L6(1)*L6(2)+.5)
3460 A8=INT(A3*N8(9)+.5)
3470 N8=N3*N8(9)
3475 L6(4)=INT(3.175*T0*N8(5)+.5)/100
3480 W(1)=.026 @ W(2)=0 @ W(3)=7.5 @ W(4)=.86 @ W(5)=154 @ W(6)=.22
3485 U1=U1(4)
3490 U3(1)=INT(N3*W0(1)*1000+.5)/1000
3500 U3(2)=INT(A3/A0(2)*W0(2)*1000+.5)/1000
3510 W3=W3(1)+W3(2)
3520 W4(1)=W3*N8(3)
3530W4(2)=INT((N8(2)-1)*W(1)*N8(3)*2/N8(2)*100+.5)/100
3540 W4(3)=N8(3)*A3(1)*W(6)
3550 W4=W4(1)+W4(2)+W4(3)
3560 W5(1)=INT(W4*N8(4)*N8(5)+.5)
3570 W5(2)=INT((N8(4)*N8(5)-1)*(L2(3)+2*L2(1))*L4(1)*W(3)+.5)
3580 W5(3)=INT(L2(5)*L4(1)*W(3)+.5)*2
3590 W5(4)=INT((N8(4)-1)*N8(5)*W(4)+.5)
3600 W5=W5(1)+W5(2)+W5(3)+W5(4)
3605 L8=INT(1.05*L6(1)+.5)
3610 W8(1)=W5*N8(6)*N8(7)
3620 W8(2)=INT(SQR(N8(5)*2*(P5/V5)^2*E1(2)*E1(1)*N9/P1*W0)*4.1+.5)
3630 W8(3)=INT((W8(1)+W8(2))/5+.0003208*P5*N8(8)+.5)
3635 W8(4)=N8(10)*S5(1)*W4
3640 W8=W8(1)+W8(2)+W8(3)
3650 H8(1)=INT(P8/A6/4*100+.5)/100
3660 H8(2)=INT(P8/W8*100+.5)/100
3800 N9(1)=(1.15+S5(1))*N8
3810 N9(2)=(1.15+S5(1))*A6
3820 N9(3)=(1.05+S5(1))*N8(9)
3830 N9(4)=(1.02+S5(1))*N8(9)*A3(1)
3840 N9(5)=(1.01+S5(1))*N8(10)
4000 ! LIFE CYCLE COSTS
4005 F0(1)=INT(1489.3*A0(1)^.5509*100+.5)/100
4010 F0(2)=INT(627.7*A0(1)^.7078*P0(2,1)^.1616*100+.5)/100
4015 F0(3)=900
4020 F0(4)=INT(N8*(.0000015831+(F0(1)+F0(2)+.11)*.00000125)*1000+.5)/1000
4025 F0(5)=INT(.1157*A8+.2034*N9(2)+.0011795*N8+.5)/1000
4030 F0(6)=INT(3.716*N9(3)+.007374*N8+.5)/1000
4035 IF G7=1 THEN F0(7)=0 ELSE F0(7)=INT(.00115*N9(4)*F0(3)+.5)/1000
4036 IF G7=2 AND V(3)=1 THEN F0(7)=0
4040 F0(8)=INT(71.16*N9(3)+.004128*N8+.5)/1000
4045 F0(9)=INT(1064.1*N9(5)+.004128*N8+.5)/1000
4050 F0(10)=INT(1.385*W8(2)+.5)/1000
4055 F0(11)=INT(.3174*W8(3)+.5)/1000
4060 F0(12)=INT(.01333*W8(1)+.008433*(W8(2)+W8(3)+W8(4))+.0002949*N8+.002828*W3+600+.5)/1000
4065 F0(13)=INT(2.75*W3+4228+.5)/1000
4070 F0(14)=INT(.02744*W8+193+.5)/1000
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4075 F0=0
4076 FOR I=4 TO 14
4077 F0=F0+F0(I)
4078 NEXT I
4080 F1=INT(350*F0+.5)/1000
4085 F2(1)=INT(90*H7*L0+.5)/1000
4090 IF C8=1 THEN F2(2)=INT(250*H7*L0+.5)/1000 ELSE F2(2)=0
4095 IF C8=1 THEN F2(3)=INT(1.3542*(40+.85*S5(1))*H7*L0*N8(10)+.5)/1000 ELSE F2(3)=0
4100 IF C8=1 THEN F2(4)=INT((775+15*N8(4))*H7*L0+.5)/1000 ELSE F2(4)=0
4105 F2=F2(1)+F2(2)+F2(3)+F2(4)
4110 F=F0+F1+F2
4115 GOSUB 4500
4120 IF C9=1 THEN 4130
4125 NEXT G
4130 NEXT X0
4135 DISP USING "/,14X,4A" ; "DONE"
4140 BEEP 80,999
4150 END
4500 ! DATA STORE SUBROUTINE
4501 IF C9=1 THEN X(1)=P0 @ GOTO 4512
4502 IF G=1 THEN X(1)=2
4504 IF G=2 THEN X(1)=P0/1000
4506 IF G=3 THEN X(1)=C8
4508 IF G=4 THEN X(1)=C7
4510 IF G>4 THEN X(1)=0
4512 X(2)=H7
4514 X(3)=L0
4516 X(4)=P9/1000
4518 X(5)=V9
4520 X(6)=P8/1000
4522 X(7)=V5
4524 X(8)=P0(1,5)*100
4526 X(9)=P0(1,6)
4528 X(10)=P1*1000
4530 X(11)=V1
4532 X(12)=S8(2)
4534 X(13)=S8(1)
4536 X(14)=T8(2)
4538 X(15)=T8(1)
4540 X(16)=V0(1,1)*1000+V1(1,1)/10
4542 X(17)=V0(1,2)*1000+V1(1,2)/10
4544 X(18)=V0(1,3)*1000+V1(1,3)/10
4546 X(19)=V0(1,4)*1000+V1(1,4)/10
4548 X(20)=V0(1,5)*1000+V1(1,5)/10
4550 X(21)=V0(1,6)*1000+V1(1,6)/10
4552 X(22)=V0(1,7)*1000+V1(1,7)/10
4554 X(23)=V0(1,8)*1000+V1(1,8)/10
4556 X(24)=V0(1,9)*1000+V1(1,9)/10
4558 X(25)=V0(1,10)*1000+V1(1,10)/10
4560 X(26)=V0(1,11)*1000+V1(1,11/10
4562 X(27)=V2(1,1)*1000+V2(2,2)/10
4564 X(28)=V(1)
4566 X(29)=V(2)
4568 X(30)=V(3)
4570 X(31)=V(4)
4572 X(32)=V0
4574 X(33)=N8
4576 X(34)=N8(3)
4578 X(35)=N8(4)*N8(5)
4580 X(36)=W5
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4582 X(37)=W8(2)+W8(3)
4584 X(38)=W8
4586 X(39)=A0(1)*10000
4588 X(40)=A3
4590 X(41)=A3(1)
4592 X(42)=A4
4594 X(43)=A6
4596 X(44)=A6*4
4598 X(45)=H8(1)
4600 X(46)=H8(2)
4602 X(47)=F1
4604 X(48)=F0
4606 X(49)=F0(1)
4608 X(50)=F0(2)
4610 X(51)=F0(3)
4612 X(52)=F0(4)
4614 X(53)=F0(5)
4616 X(54)=F0(6)
4618 X(55)=F0(7)
4620 X(56)=F0(8)
4622 X(57)=F0(9)
4624 X(58)=F0(10)
4626 X(59)=F0(11)
4628 X(60)=F0(12)
4630 X(61)=F0(13)
4632 X(62)=F0(14)
4634 X(63)=F2
4636 X(64)=F2(1)
4638 X(65)=F2(2)
4640 X(66)=F2(3)
4642 X(67)=F2(4)
4644 X(68)=F
4700 IF P=0 THEN 4720
4701 PRINT @ PRINT X$
4702 PRINT "N4(1)=";N4(1) @ PRINT "N4(2)=";N4(2) @ PRINT "N8(3)=";N8(3) @ PRINT "N8(4)=";N8(4)
4703 PRINT "N2=";N2 @ PRINT "N2(1)=";N2(1) @ PRINT "N2(2)=";N2(2)
4704 PRINT "N3=";N3 @ PRINT "N3(1)=";N3(1) @ PRINT "N3(2)=";N3(2)
4705 PRINT "A3=";A3 @ PRINT "L3(1)=";L3(1) @ PRINT "L3(2)=";L3(2)
4706 PRINT "A4=";A4 @ PRINT "L4(1)=";L4(1) @ PRINT "L4(2)=";L4(2)
4707 PRINT "A6=";A6 @ PRINT "L6(1)=";L6(1) @ PRINT "L6(2)=";L6(2)
4708 PRINT "H9=";H9 @ PRINT "W5=";W5 @ PRINT "W8(1)=";W8(1)
4709 PRINT "W8(2)=";W8(2) @ PRINT "W8(3)=";W8(3) @ PRINT "W8=";W8 @ PRINT "E6(1)=";E6(1)
4710 PRINT "E6(2)=";E6(2) @ PRINT "E6(3)=";E6(3) @ PRINT "E6(4)=";E6(4) @ PRINT "E6(5)=";E6(5)
4711 PRINT "P0(1,6)=";P0(1,6) @ PRINT "V1=";V1 @ PRINT "N1(1)=";N1(1) @ PRINT "V5=";V5
4712 PRINT "P9=";P9 @ PRINT "P8=";P8 @ PRINT "P1=";P1 @ PRINT "N8=";N8 @ PRINT "F=";F
4720 PRINT# 9,C ; X()
4730 RETURN
```