NASA Contractor Report 185181
ARINC Research Publication 4247-01-01-5032

Space Station Freedom Electric Power System Availability Study

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February 1990

Prepared for
Lewis Research Center
Under Contract NAS3-24564

National Aeronautics and
Space Administration

FOREWORD

ARINC Research Corporation was contracted by ANALEX Corporation to provide continued reliability, availability, and maintainability (RAM) support to National Aeronautics and Space Administration (NASA) Lewis Research Center (LeRC) Systems Engineering and Integration (SE&I) for the Space Station Freedom (SSF) Electric Power System (EPS) under contract number 88-622. This report describes the application of the UNIRAM (unit reliability, availability, and maintainability) methodology to the EPS design as of June 1989, and the results of the various analyses performed. The EPS RAM data and availability model design information were obtained from the January 31, 1989, edition of the *Space Station Freedom Power System Description Document* (DR:SE-02), two working group meetings held at LeRC, and comments resulting from an interim briefing given at LeRC to present the availability models. The working group meetings were held on December 7, 1988, and April 13, 1989, and the interim briefing was given on June 8, 1989.

The author expresses his thanks to the following persons for their support and help in this effort: Bruce Bream of ANALEX Corporation; Dave Hoffman and Edward Zampino of NASA LeRC; and Dr. Susan Richart of Rocketdyne Corporation.

GLOSSARY OF ABBREVIATIONS AND ACRONYMS

A	Availability
ABD	Availability Block Diagram
BCDU	Battery Charge/Discharge Unit
dc RBI	dc Remote Bus Isolator
DCSU	dc Switching Unit
EA	Equivalent Availability
EPRI	Electric Power Research Institute
EPS	Electric Power System
LeRC	Lewis Research Center
MBSU	Main Bus Switching Unit
MDT	Mean Downtime
MLT	Mean Lead Time
MRI	Mean Replacement Interval
MTBF	Mean Time Between Failures
MTTR	Mean Time to Repair
NASA	National Aeronautics and Space Administration
ORU	Orbital Replacement Unit
PMAD	Power Management and Distribution
PMC	Power Management Controller
PSDD	Power System Description Document
PV	Photovoltaic
PVC	Photovoltaic Controller
RAM	Reliability, Availability, and Maintainability
RBI	Remote Bus Isolator
SD	Solar Dynamic
SE&I	Systems Engineering and Integration
SSF	Space Station Freedom
SSU	Sequential Shunt Unit
UNIRAM	Unit Reliability, Availability, and Maintainability

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CHAPTER ONE

INTRODUCTION

ARINC Research Corporation was contracted by ANALEX Corporation, under contract 88-622, to provide continued reliability, availability, and maintainability (RAM) analysis support to National Aeronautics and Space Administration (NASA) Lewis Research Center (LeRC) Systems Engineering and Integration (SE&I) for the Space Station Freedom (SSF) Electric Power System (EPS). This report provides the results of applying the UNIRAM (unit reliability, availability, and maintainability) methodology to the evolving SSF EPS design. The RAM data used in this study represent design goals and, as such, should be construed as being valid when the relative failure rates of EPS components are assessed.

Two basic RAM metrics are availability and equivalent availability. They are used throughout this document and are defined in the following text. In general, in this report these metrics are expressed as percentages (%) rather than as fractional values.

Availability is a binary (on/off) type of RAM metric. It can be considered as the ratio of the time a system is operating at some level to the sum of the times it is either operating or failed. In this study, the UNIRAM defintion of availability is used.

> ***Availability (A):*** A measure of the fraction of time in a given period that a system will perform or has performed its function. In the case of the EPS, it is the fraction of time during an interval that the EPS can be expected to produce power at any level other than zero.

In a system that is made up of discrete components, the failure of one or more of these components may have no effect on the system or may reduce system capability, but not necessarily cause the system to fail completely. For the EPS, this means that the power level can drop to discrete, lower levels—levels that are below full capacity due to component failures, but at which the system may still be operating. Thus, equivalent availability of the EPS is then defined as:

> ***Equivalent Availability (EA):*** The ratio of the power actually produced or delivered by the EPS to the power that would have been produced in the same period had there been no power outages due to component failures or planned subsystem shutdowns.

An initial EPS RAM analysis study* was performed using the UNIRAM methodology to assess the EPS availability. Appendix A provides a description of the UNIRAM methodology and a detailed summary of the results of that previous study.

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*Scott R. Turnquist and Mark A. Twombly, *Space Station Electrical Power System Availability Study*, ARINC Research Publication 5149-11-01-4744, NASA Contractor Report 182198, NASA Lewis Research Center, November 1988.

In this chapter, some of the highlights of the initial study are reviewed to provide a background for this document. The differences between this study and the initial study are then discussed. Finally, the scope of this study and the organization of this report are provided.

1.1 INITIAL STUDY

ARINC Research Corporation was tasked by NASA Lewis Research Center to perform, from June 1987 to July 1988, a preliminary RAM analysis of the Space Station Freedom EPS. The EPS design evaluated corresponded to the design given in the July 1987 Power System Description Document (PSDD). The study used the UNIRAM methodology that was developed by ARINC Research Corporation for the Electric Power Research Institute (EPRI) to evaluate the characteristics of electrical power generation systems.

The UNIRAM methodology was applied as an engineering tool to better understand the ability of EPS to achieve reasonably high-power availability on the basis of the level of on-orbit maintenance, component reliability, redundancy, and logistic sparing alternatives.

1.1.1 Initial Study Approach

The initial EPS RAM assessment was performed in the following five basic steps:

- Model the EPS
- Evaluate the EPS model to determine the baseline system RAM values and component criticality rankings
- Perform assessments of EPS availability sensitivity to sparing orbital replacement units (ORUs) on-orbit
- Perform assessments of EPS availability sensitivity to changes in ORU reliability and analyze expected ORU failure rates
- Integrate the power generation and power distribution system results to obtain overall EPS RAM performance measures

Figure 1–1 is a basic representation of the EPS and shows some of the major factors that contribute to an availability model of the EPS. The initial UNIRAM modeling took into consideration the interconnection of ORUs, in terms of availability; the different operating modes, in terms of sun and eclipse portions of the orbit; the nesting of subsystems to account for functional paths and redundancy; and the development of fault trees for each basic subsystem.

1.1.2 Results of the Initial EPS RAM Assessment

The initial analyses determined system availabilities and equivalent availabilities; system output levels (states) and their associated probabilities; and ORU criticality rankings. Other assessments determined the effects on system sparing of ORUs, either on-ground or on-orbit. The following eight ORUs have a significant impact on system equivalent availability when spared on-orbit:

- Alpha Joint Power and Data Transfer Assembly
- Beta Gimbal Power and Data Transfer Assembly

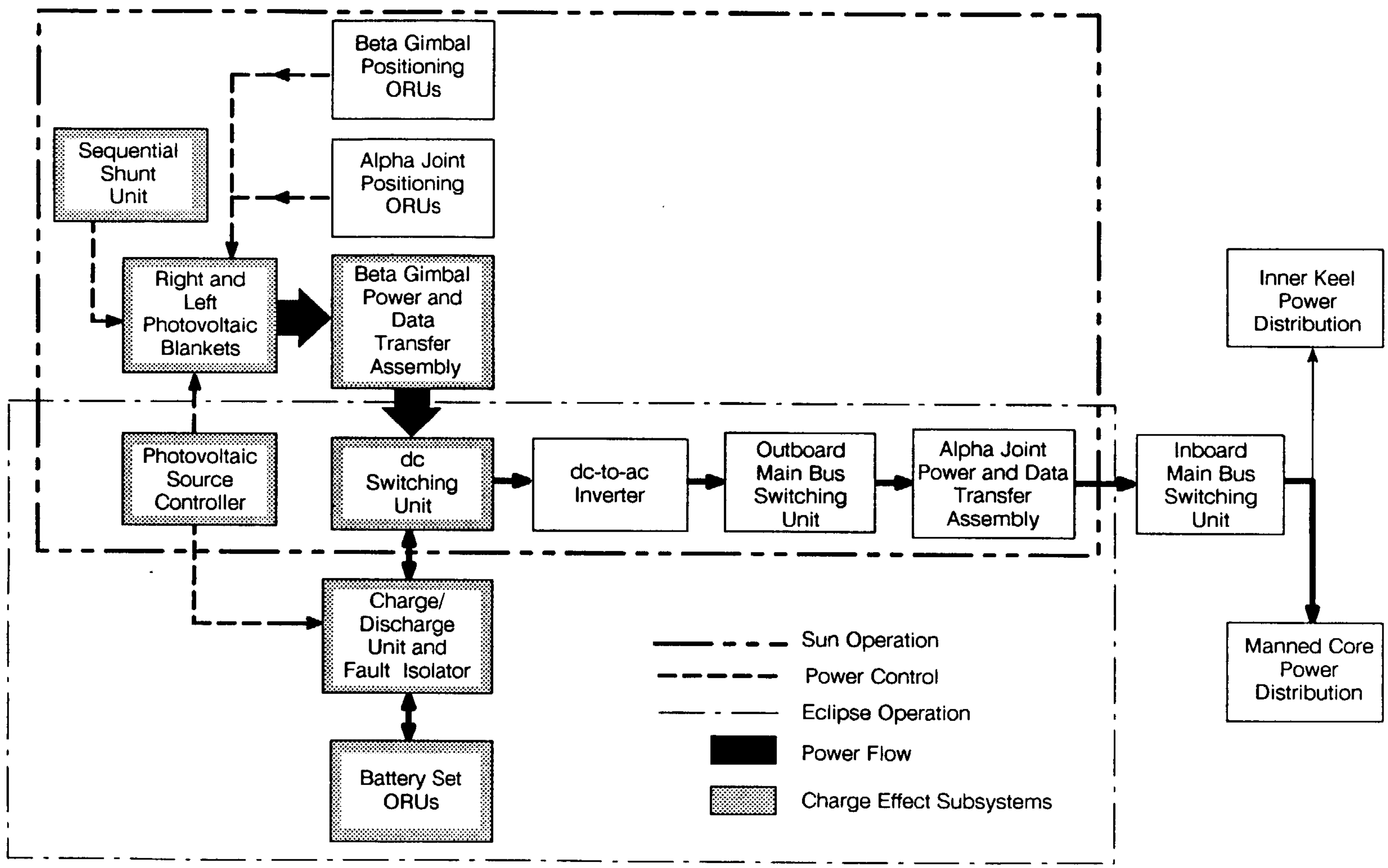

Figure 1-1. Initial Study—EPS Basic Power Generation Block Diagram

- Charge/Discharge Unit
- Power Distribution Control Unit
- Power Management Controller
- Sequential Shunt Unit
- Solar Array Electronics Assembly
- Thermal Control Plate

The reliability sensitivity analyses were performed by scaling the expected ORU mean time between failures (MTBF) values from half to five times the originally established value. This assessment showed that these eight ORUs have the most impact on system equivalent availability, in relation to the increase in EPS equivalent availability, when the availability of the EPS components is increased.

After the individual analyses were completed, an overall combined model assessment was made to determine a range of EPS output power levels and the ability of the EPS to supply a 25-kW load. Appendix A contains a summary of the analysis results of the initial study.

1.1.3 Availability Model Usefulness

As a design analysis and evaluation tool, the UNIRAM methodology proved effective in the EPS design process and validated alternative design considerations in terms of availability. Part of the effectiveness of the UNIRAM methodology is in its ability to determine the various EPS operating power levels and the availabilities associated with these power levels. On the basis of this initial study, areas for further evaluation were defined that could aid in improving and optimizing the EPS availability. These areas included assessing various distributed power load scenarios, using lifetime data to evaluate the effect of ORUs with predictable life cycles on EPS RAM, completing RAM analyses of individual ORUs, refining ORU reliability estimates through a parts-type evaluation, optimizing the on-orbit level of ORU sparing, addressing maintainability in more detail, and performing testability analysis that would enhance the maintainability of individual ORUs.

1.2 CURRENT STUDY

The study documented in this report constitutes follow-on EPS availability analyses performed to keep pace with the evolution of the EPS design. Of the recommendations listed in the initial study report, three were specifically evaluated in the current study:

- Component sparing (in more detail than addressed previously)
- EPS availability at component levels below the ORU in selected ORUs
- Effects of structural and long-life ORUs on EPS availability

1.2.1 Component Sparing

To assess component sparing in greater detail, we focused our attention on the effect that increasing the number of ORU or component on-orbit spares has on the mean downtime (MDT) of a particular ORU or component.

1.2.2 Modeling EPS Availability with Component Levels Below ORU

Several ORUs have no single, well-defined failure mode because of their internal architecture. Examples of this are the dc switching unit (DCSU) and the main bus switching unit (MBSU). The DCSU and MBSU comprise dc and ac remote bus isolators (RBIs), respectively; bus components; cabling; and control circuitry. In the event of a failure of an RBI in either of these types of ORU, the ORU does not fail. In general its output capacity will not even be affected. However, without replacement or repair of the ORU, the next failure of an RBI can cause lower power levels. Because of these considerations, the internal constructions of several ORUs were modeled. ORUs modeled in this way include DCSUs, MBSUs, and battery charge/discharge units (BCDUs).

1.2.3 Structural and Long-Life Component Effects on Availability

Many of the ORUs in the EPS fall into two categories: structual and wearout. For this study, the wearout ORUs were subdivided into ORUs with a very large MTBF (MTBFs that are estimated to be equal to or greater than the 30-year mission of SSF) and those with MTBFs that are less than the 30-year mission of SSF, such as the batteries. In the course of the analyses described in this report, several EPS models were developed. One of these models characterizes the EPS as if all items were subject to random failures; this is the baseline EPS model. Another model removes structural components and components subject to wearout with estimated MTBFs that exceed the 30-year mission of SSF. (In the UNIRAM input files these component MTBFs are set to 99,999,999 hours, and the MDTs are set equal to 0.01 hour.) As a result, the availability of the EPS is bounded between an upper and lower limit. The lower limit is established by the baseline EPS model, and the upper limit is established by removing the probabilistic failure effects of structural components and components subject to wearout with very large MTBFs.

1.3 COMPARISON OF CURRENT STUDY AND INITIAL STUDY

In addition to performing three of the analyses recommended in the initial study report, the models used in this analysis differed significantly from those of the initial study. Figure 1–1 shows ORUs that provide for the availability of a full battery charge at the beginning of the eclipse portion of an orbit. In the initial analysis, the power generation systems for the eclipse and sun portions of the orbits were modeled separately, and the availability of a fully charged battery was included in the eclipse model. In the current analyses, the generation systems for the sun and eclipse portions of an orbit were combined into one model. This is a valid approach because the orbital period for SSF will be short, which means a failure during any portion of an orbit will most probably affect the EPS during the complementary portion of the orbit, and the effects will probably continue for several orbits thereafter. Figure 1–2 is a block diagram showing SSF EPS availability dependency.

1.4 SCOPE OF CURRENT STUDY

In this study, we were able to model components immediately below the ORU level. Also, there were several EPS model variations, including one that was restricted to the ORU level for comparing sparing options in terms of mass, and one that was used to assess only those components for which work-package-4 (the LeRC and Rocketdyne design team) has responsibility. For this study, analyses of EPS sensitivity to component MTBF and MDT variations were performed, and the components critical to EPS equivalent availability were determined. Also, the effects of variations in the EPS design were analyzed, including a model of a predominantly solar-dynamic EPS, as were the effects of increased levels of component redundancy.

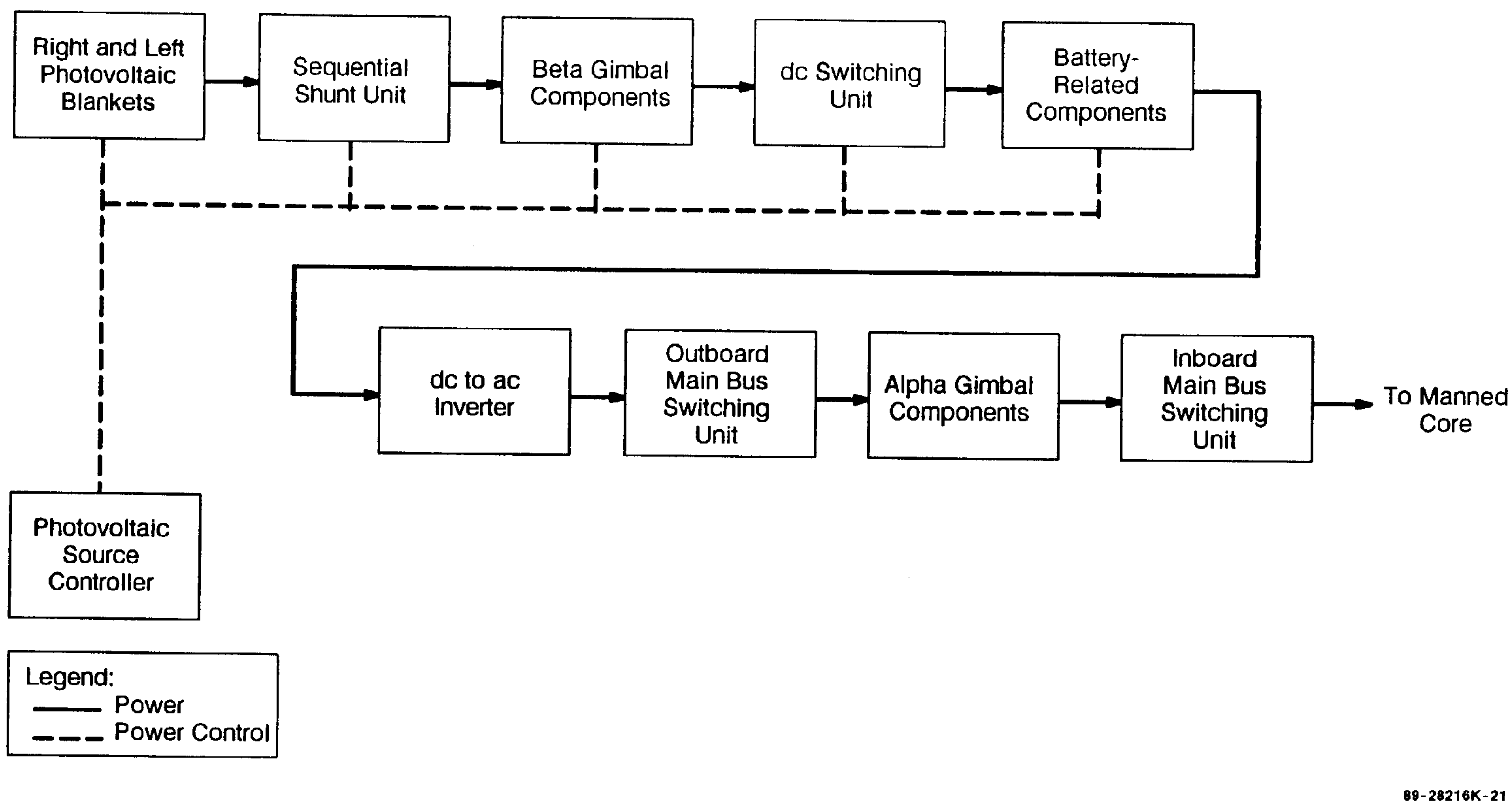

Figure 1-2. Space Station Freedom EPS Availability Dependency Block Diagram

1.5 REPORT ORGANIZATION

The main body of this report, Chapters Two through Four, provides a summary of the analysis results with which the reader can quickly identify important results and conclusions. The appendixes provide the details of the analysis results, modeling, and methodology information.

Chapter Two contains a discussion on how the baseline EPS availability model was created and why. Essentially this discussion focuses on the formulation of the current baseline model and the key assumptions that led to it.

Chapter Three provides key RAM analysis results. It details the results obtained when the RAM characteristic data of the models are varied, including the component criticality rankings. These rankings provide an indication of where EPS design and maintainability changes can best be applied for maximum effect. Other variations for the analyses include the determination of EPS sensitivity to component MTBF and MDT variations. Chapter Three also provides discussion and analysis results for EPS design variations, including (1) the effects of variations on EPS RAM in the level of redundancy of the power management controller, (2) addition of two photovoltaic (PV) modules (for a total of six PV modules), and (3) the RAM characteristics of a three-solar-dynamic-one PV (3SD–1PV) module EPS design.

Chapter Four provides the conclusions arrived at through this extensive series of analyses and provides recommendations for EPS design changes and further analyses.

CHAPTER TWO

BASELINE MODELING APPROACH

To perform the RAM analyses of this study, a building block approach was used. The key element in the analyses was the creation of a baseline EPS power generation model that could be molded for each type of analysis performed for this study. Figures 2–1 and 2–2 provide the availability block diagrams (ABDs) of the baseline EPS model. There is also a set of baseline component data which is varied as required by each type of analysis. The baseline EPS data are listed in Table 2–1.

The ABD shown in Figures 2–1 and 2–2 represent the *flow* of availability for a process of EPS power generation and control. That is, the generation of power requires components in the flow path to be operational. Therefore, with components, such as those of the thermal control system, logically in series with the PV blanket and box assemblies (Figure 2–2), it is required that the power generation and control systems have cooling in order to function.

All EPS components and subsystems that are pertinent to EPS availability are represented in Figure 2–2, including structural and wearout components, such as the PV blanket and box assemblies and utility plates. Another feature of the baseline EPS model is that for nearly all components the component MDTs (which are about 90 days) are based on assumed values for component spares being located on the ground (on-ground).

2.1 KEY MODEL FEATURES

The following list provides the key features that were incorporated into the baseline EPS model:

- The power producing and controlling components for the sun and eclipse portions of each orbit were modeled together.
- The component-level was allowed to extend below the ORU.
- Structural components were modeled.
- Long-life components were modeled.
- Battery power input and output were modeled as fully cross-connected.
- PV radiator panel assemblies were set to perfect availability.
- Power is produced at a lower level if alpha gimbal positioning fails.
- Component MDTs are approximately 90 days except for the batteries and PV blankets.

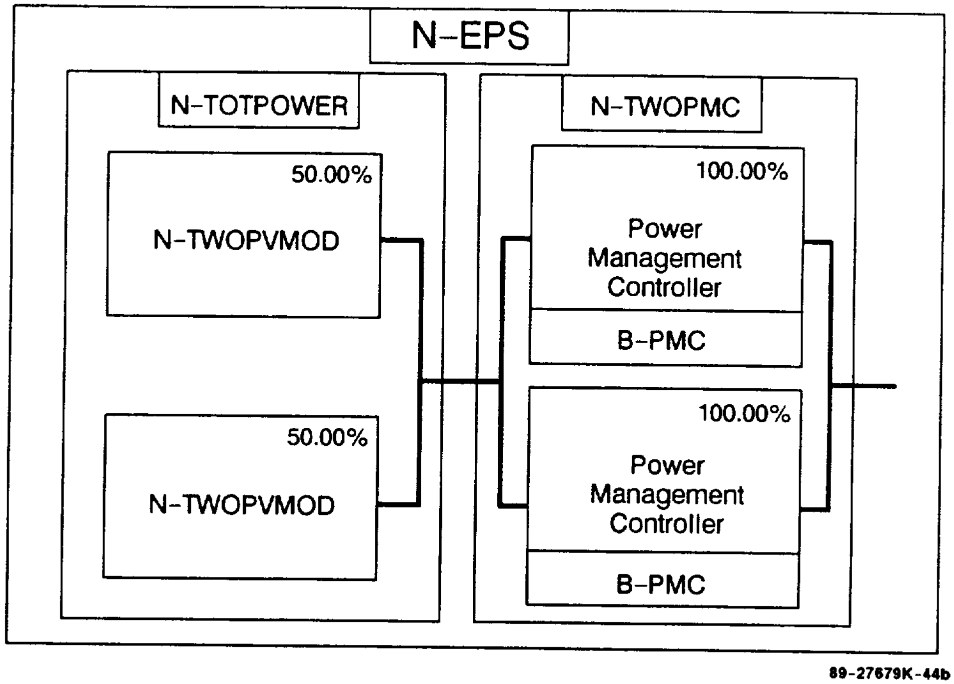

Figure 2-1. Full EPS Power Generation Availability Block Diagram

As shown in Figure 2-1, a boxed area label, such as N-TWOPVMOD, allows use of that label in a single block in future drawings as a shorthand technique to simplify these drawings. An abbreviation in the lower part of the box is a UNIRAM model abbreviation for that subsystem. In Figure 2-2, some basic subsystems are represented with shaded boxes to show that the constituent components are structural or long-life components. (Long-life components are components with life cycles of duration equal to or exceeding that of SSF.)

In addition to the key model features, several important assumptions were used in the creation of the baseline model:

- The outboard PV module power depends on the inboard PV module thermal control system.
- The output of the entire EPS depends on the operation of the power management controllers (PMCs).
- Main bus switching units (MBSUs) are capable of being quickly cross-connected. Therefore, the outboard MBSUs are modeled as cross-connected prior to the alpha gimbal; and the inputs to the inboard MBSUs, from the alpha gimbal, are cross-connected.
- Photovoltaic controllers (PVCs) are dually redundant in each PV module.
- With the exception of the PVCs and PMCs, the EPS control system and buses are not modeled.

Table 2-1. ORU and Component Data Used in the Baseline EPS Availability Model

ORUs and Components	Abbreviation	MTBF (hours)	MDT (hours)	Mass (lbm)
Photovoltaic Blanket and Box	PVBBC	131,400	24.0	506.00
Deployable Mast	DMC	131,400	2,334.0	195.00
Sequential Shunt Unit	SSUC	87,600	2,329.5	37.50
Beta Gimbal Roll Ring	BGRRC	262,800	2,331.0	84.00
Beta Gimbal Transition Structure	BGTS	262,800	2,334.0	44.00
Utility Plate	UPC	350,400	2,331.0	42.00
Thermal Control System Condenser	Condenser	876,000	2,334.0	100.00
Thermal Control System Piping	TCAIP	262,800	2,329.0	-
Thermal Control System Pump	TCAP	280,320	2,329.5	129.00
Condenser Mounting Strut	CMS	262,800	2,331.0	100.00
Photovoltaic Radiator Panel Assembly	PVRADC	99,999,999	0.01	-
Integrated Equipment Assembly Transition Structure	IEATS	262,800	2,334.0	440.00
Integrated Equipment Assembly Support Structure	IEAS	262,800	2,334.0	64.00
Photovoltaic Cable Set	PVCS	262,800	2,340.0	-
Photovoltaic Controller	PVC	43,800	2,329.5	111.00
Photovoltaic Controller Error Signal Generator	PVCE	87,600	2,329.5	0.25
10-kW dc Remote Bus Isolator (DCSU)	DCRBI10KWC	262,800	2,329.5	3.00
25-kW dc Remote Bus Isolator (DCSU)	DCRBI25KWC	262,800	2,329.5	14.00
Battery Monitor	BATMON	262,800	2,329.5	53.33
Charge Power Converter	CPC	262,800	2,329.5	53.33
Discharge Power Converter	DPC	262,800	2,329.5	53.33
Battery	BATTERY	61,320	24.0	242.50
Main Inverter Unit	MIUC	87,600	2,329.5	205.00
Outboard Power Distribution Control Unit	OPDCU	87,600	2,329.5	213.00
Alpha Gimbal Roll Ring	AGRRC	262,800	2,331.0	-
Alpha Gimbal Bearing	AGB	131,400	2,334.0	-
Alpha Gimbal Motor	AGM	87,600	2,331.0	-
Alpha Gimbal Transition Structure	AGTS	262,800	2,334.0	-
Power Management Controller	PMC	43,800	2,328.5	143.00
25-kW ac Remote Bus Isolator	ACRBI25KWC	262,800	2,331.0	14.00

Data Source: *Space Station Freedom Power System Description Document*, DR:SE-02, January 31, 1989.

2.1.1 Combined-Cycle Power Generation Model

As shown in Figure 2–2, power producing components for the sun (i.e., PV components) and eclipse (i.e., battery discharge components) portions of each SSF orbit have been included in the same model. There are two reasons that this is an acceptable modeling approach. First, there are few idle components during either the eclipse or sun portions of an orbit. Second, the cycle period for each cyclic component (such as the PV arrays or sequential shunt unit) is short. Therefore, it is assumed that a component failure will require more than one orbit for repair, and the failure effects would cross the sun/eclipse (photovoltaic/battery) operation boundary.

2.1.2 Modeling Below the ORU Level

The scope of the modeling effort was allowed to extend below the ORU level in cases where it could aid in the modeling effort. Initially, this was used to alleviate cross-connection dependencies in the model. Such dependencies are similar to a two-dimensional drawing of a three-dimensional problem; paths cross but are assumed not to touch. In the case of the DCSU, the cross-connection of the two PV modules providing input to the DCSU raises this problem. Also, it was hoped that RAM and physical characteristic data specific to the dc and ac RBIs would be available at some time during the study. Therefore, the DCSUs and MBSUs were modeled using their RBI constituents. These RBIs were given MTBF values corresponding to three times their associated ORU MTBF. The three-fold increase of the RBI MTBF was used because, in the case of the DCSU, up to three RBIs must fail in order for the output of the DCSU to totally fail. Therefore, the combined failure rate of these three RBIs corresponds to the failure rate of the DCSU at the ORU level. However, this value does not account for the effects that maintenance has on component availability.

2.1.3 Modeling Structural and Long-Life EPS Components

Modeling structural and long-life components is not unique to this study; they were also modeled in the initial study. Structural components include such items as the beta gimbal transition structures and integrated equipment support structures. For this study, long-life components are those that have a predictable life cycle and are not expected to be replaced in the 30-year life of SSF. These components include such items as thermal control system condensers and utility plates. Analyses were performed to better judge the impacts of having these components in the EPS model.

2.1.4 Cross-Connected Battery Power Input and Output

As shown in Figure 2–2, the battery and battery-related components are grouped together. The first grouping assumes that the normal battery charging and discharging lineups will have two batteries supplied by one DCSU and three batteries by the other DCSU. There is a cross-connection of power input to the dc RBIs associated with each DCSU, as shown on the left of Figure 2–2. This cross-connection is valid from the standpoint that the physical cross-connection can be quickly realized in the EPS and that the battery charging load can be assumed to be equally distributed over the five batteries in a PV module.

2.1.5 PV Radiator Panel Assembly Set to Perfect Availability

The PV radiator panel assembly consists of 10 panels mounted to the thermal control system condenser. The expected failure rate of one of these panels is 350,400 hours. There is redundancy built into the assembly. In this study it was assumed that three of these panels can fail before the system is inoperable. The results of a Markov analysis provided an effective radiator panel assembly MTBF and MDT. Using a single-panel MTBF of 350,400 hours and MDT of 2,140 hours provided an effective assembly MTBF of 1.9 billion hours. Therefore, because the limit of MTBF resolution in UNIRAM is 99,999,999 hours, the radiator panel assembly subsystem was set to perfect availability. What this assumes is that as PV radiator panels fail, they can be replaced without degrading the PV radiator assembly performance.

2.1.6 Alpha Gimbal Positioning Failure Effects

The positioning and power transfer functions of the alpha gimbal have been separated. It is assumed that the alpha gimbal can be manually repositioned to the single optimum sun-period position upon loss of automatic positioning capability. This positioning leads to an average power level, over one-half orbit, of 23.87 kW. This power level is derived as follows:

Power as a function of position *P(pos)* is:

$$P(pos) = P_{max} * \sin(\theta)$$

The average power (P_{ave}) over one-half of the orbit is:

$$P_{ave} = 2/\pi * \int_0^{\pi/2} P_{max} * \sin(\theta)\, d\theta$$

$$P_{ave} = P_{max} * 2/\pi * [-\cos(\theta)] \Big|_0^{\pi/2}$$

$$P_{ave} = P_{max} * 2/\pi * [-\cos(\pi/2) + \cos(0)]$$

$$P_{ave} = P_{max} * 2/\pi$$

$$P_{max} = 75 \text{ kW}/2 = 37.5 \text{ kW}$$

$$P_{ave} = 23.87 \text{ kW} = 31.83\% \text{ of total power}$$

2.1.7 Component MDTs Are Approximately 90 Days

With the exception of the batteries and PV blanket assemblies, baseline model component MDTs have been set to approximately 90 days (2,160 hours). This period corresponds to the expected space shuttle resupply interval. The batteries and PV blankets are assumed to have MDTs of 24 hours. This period was arrived at because these components have well-defined lifetimes, which will allow NASA to plan for supply and replacement of them. Also, it is assumed that the shutdown period for the replacement of these components will not exceed 24 hours.

CHAPTER THREE

ANALYSIS RESULTS

The EPS RAM analyses discussed in sections 3.1 through 3.5 are as follows:

- Availability and equivalent availability of the baseline EPS model and two variation cases
- Baseline case component criticality rankings and MTBF variation analysis
- Sparing strategy analysis
- EPS subsystem and component redundancy analyses
- Additional model analyses
  - An extension of the baseline model, which includes power management and distribution system components
  - An analysis of an earlier proposed EPS design using three solar-dynamic modules and one 10-kW PV module

Some of the data contained in the figures in this chapter are given within the respective section. The rest of the data are too extensive and have been placed in tables in Appendix B.

3.1 AVAILABILITY AND EQUIVALENT AVAILABILITY RESULTS OF BASELINE EPS MODEL AND TWO MODEL VARIATION CASES

Figures 3-1 and 3-2 show the availability and equivalent availability, respectively, of three EPS analyses. The first analysis is that of the baseline EPS model, the second is the baseline EPS with no structural or long-life ORUs, and the third is similar to the second, except that the alpha gimbal ORUs are excluded.

The baseline EPS model (see also Figures 2-1 and 2-2) includes all pertinent structural and wearout EPS ORUs and components required for EPS operation. This case and two other cases assume that all spares are kept on-ground. Also, the MDTs of the PV blanket and box, and the batteries, are 24 hours. These MDTs are set to 24 hours, since the PV blanket and batteries have well-defined life cycles, so that the replacements for them can be assumed to be available on-orbit when

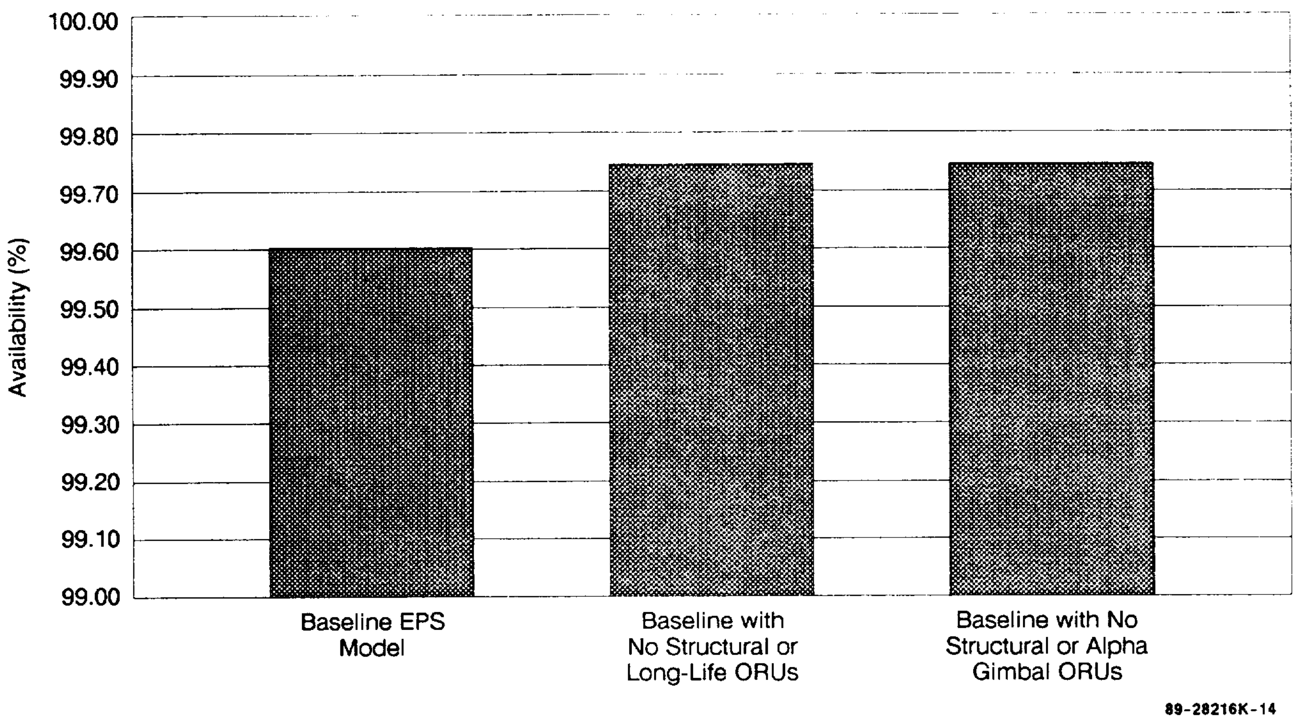

Figure 3-1. EPS Baseline Design Comparison—Availability

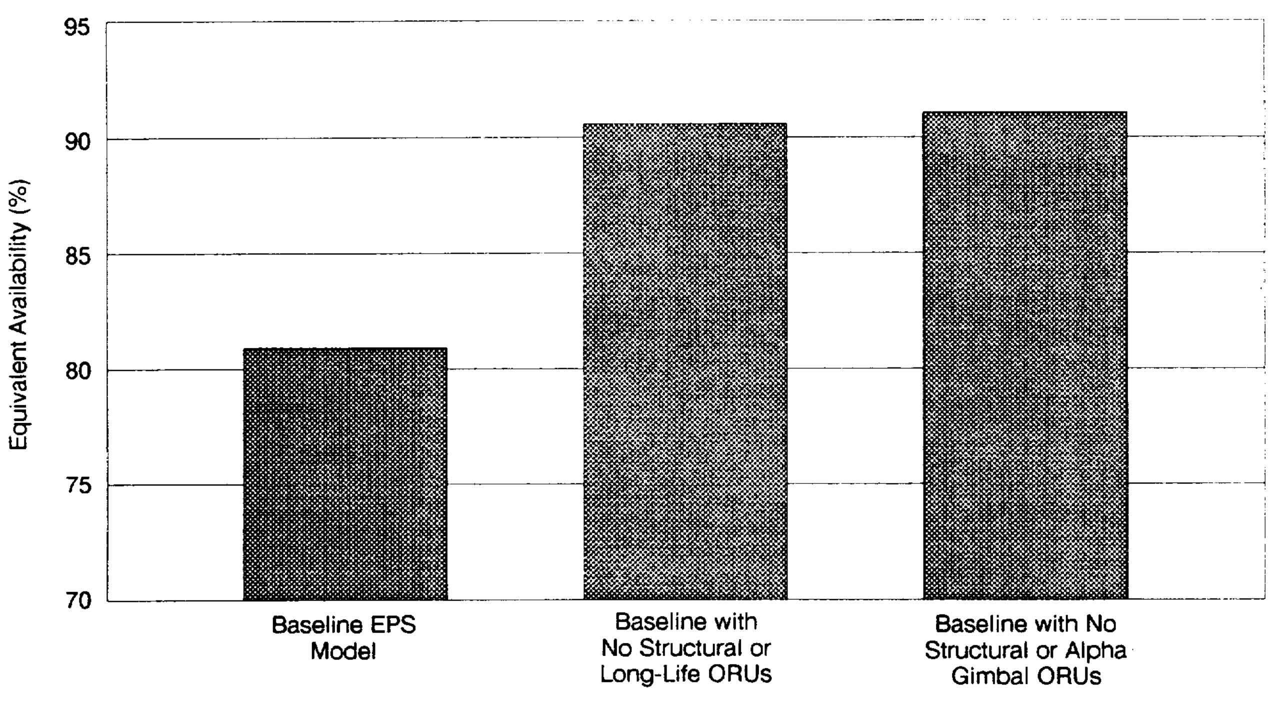

Figure 3-2. EPS Baseline Design Comparison—Equivalent Availability

needed. The actual shutdown period for replacement of these ORUs probably will not exceed 24 hours. The availability and equivalent availability of the baseline case are the following:

- Availability: 99.6032%
- Equivalent Availability: 80.9260%

For the first variation case, the availability effects of structural and long-life ORUs were effectively removed by setting them to the UNIRAM equivalent of "perfect" availability (MTBF = 99,999,999 hours, and MDT = 0.01 hour). This analysis was performed to determine the limits of the effects of structural and long-life ORUs on EPS availability and equivalent availabilities (spares are assumed to be kept on-ground). As shown in Figure 3-1, the availability increase is less than 0.15%, and the equivalent availability, as shown in Figure 3-2, has a marked increase of about 10% over the baseline case. The availability and equivalent availability of the baseline EPS case without structural and long-life ORUs are the following:

- Availability: 99.7451%
- Equivalent Availability: 90.5670%

For the second variation case, the baseline EPS model without structural elements was further reduced by eliminating the alpha gimbal ORUs because they are not the responsibility of Work Package 4. As can be seen in Figures 3–1 and 3–2, removing the alpha gimbal ORUs has only a small effect on availability. The RAM data associated with these ORUs were unavailable, so the alpha gimbal was modeled after a beta gimbal. The availability and equivalent availability of the baseline model without structural and long-life ORUs and without the alpha gimbal ORUs are the following:

- Availability: 99.7451%
- Equivalent Availability: 91.0729%

Figures 3–3 and 3–4 show the discrete power levels caused by EPS component failures and the cumulative availability associated with these power levels. Excluding the availability effects of structural and long-life ORUs from the baseline model (Figure 3–3) has increased the high power level availabilities (Figure 3–4).

3.2 BASELINE CASE COMPONENT CRITICALITY RANKINGS AND MTBF VARIATION ANALYSIS RESULTS

Results from four sets of analyses are presented in this section:

- Criticality rankings of the ORUs and components in the baseline case and the baseline case without structural and long-life ORUs
- EPS sensitivity to component failure rate variations
- Sparing strategy analyses performed on the baseline case, with and without structural and long-life components
- Effect of applying ORU K-factors and replacement ratios to component MTBFs on the baseline EPS model RAM characteristics

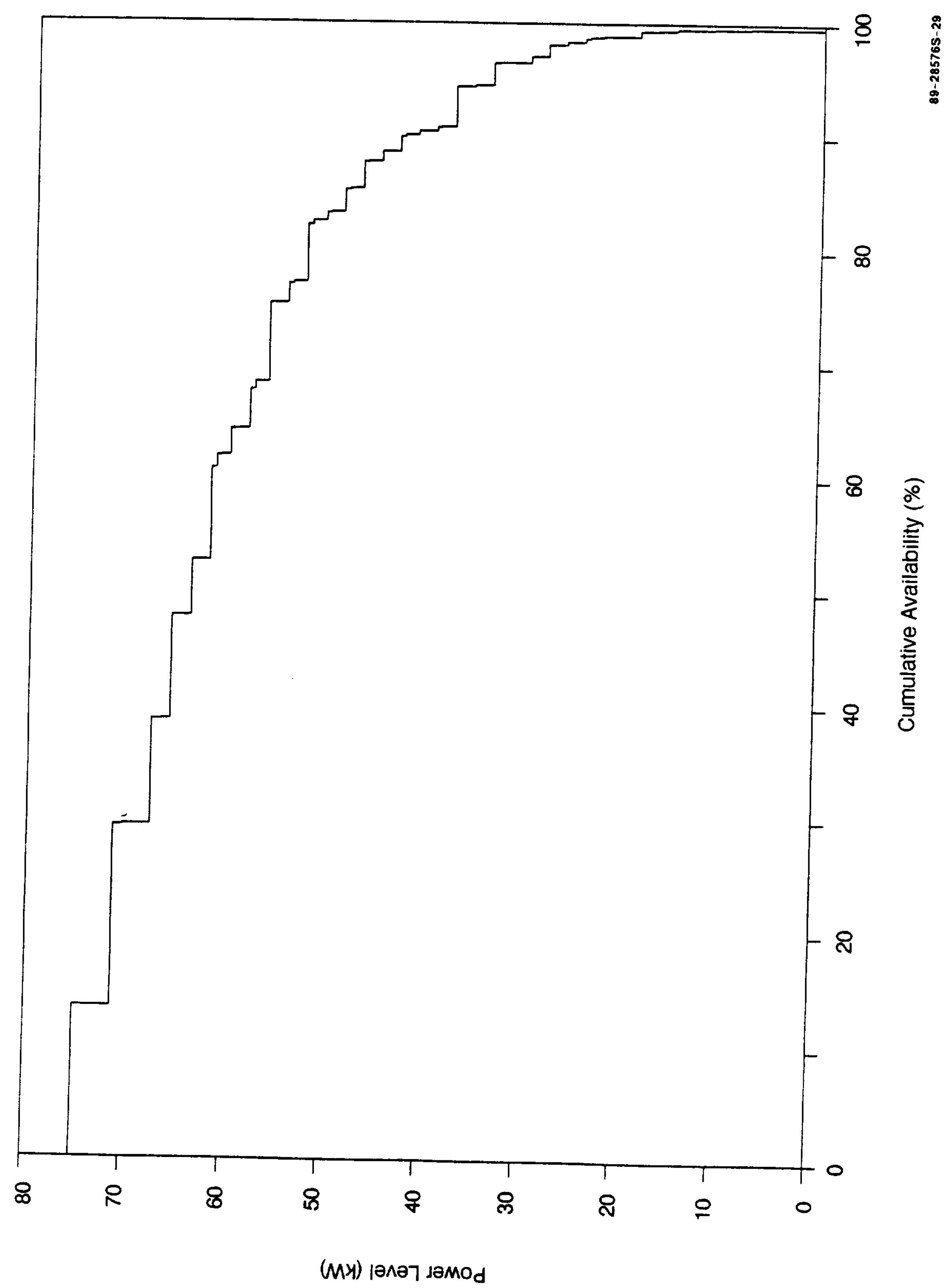

Figure 3–3. Baseline EPS Power Level Versus Cumulative Availability

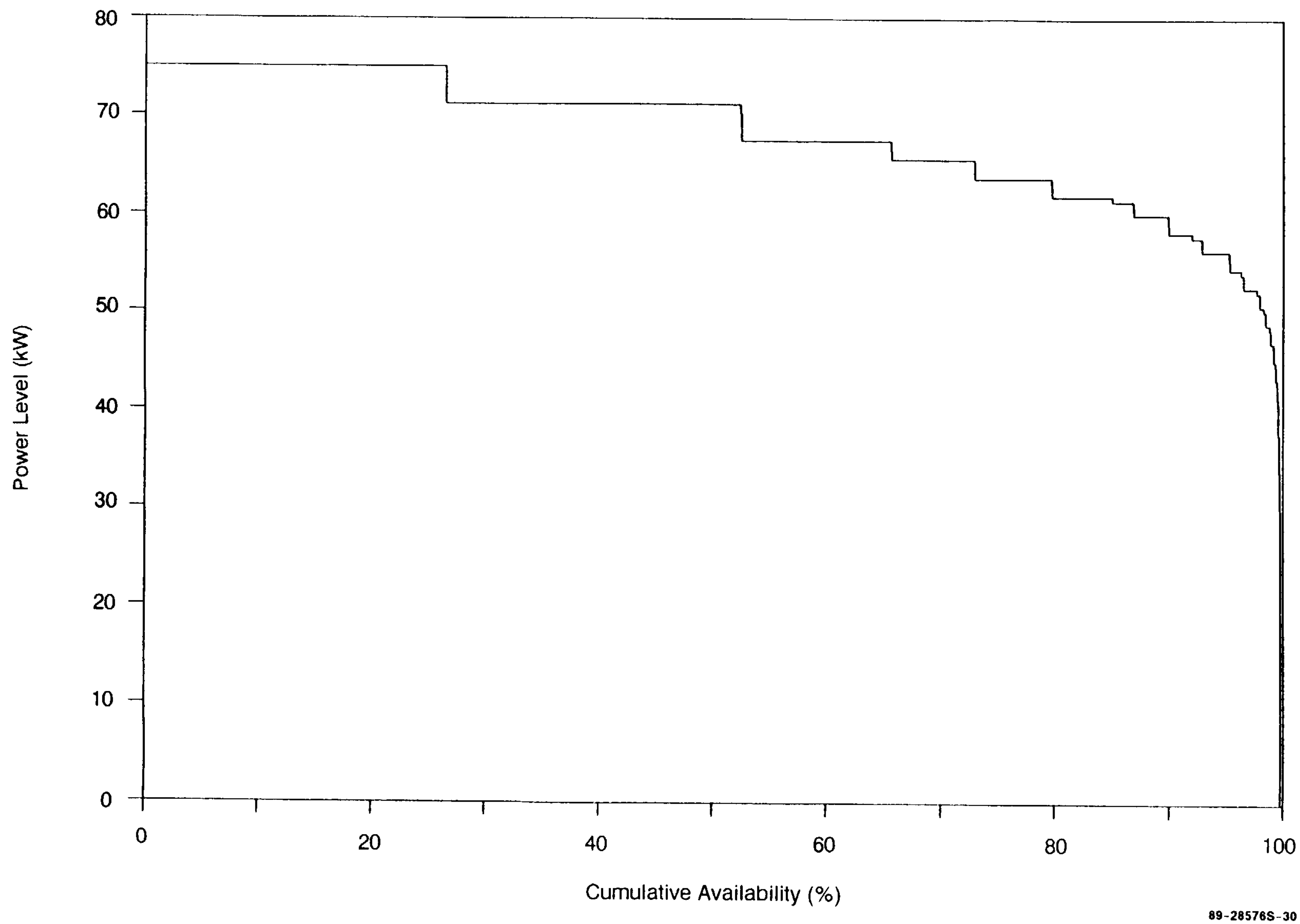

Figure 3–4. Baseline EPS with No Structural or Long-Life ORUs Power Level Versus Cumulative Availability

3.2.1 ORU and Component Criticality Rankings

In UNIRAM, a component criticality ranking analysis determines the effect that a component has on equivalent availability when it is made "perfectly" available. All model components are analyzed, and are rank ordered by the resulting changes in equivalent availability (criticality ranking factors). Figure 3–5 provides the results of the criticality ranking for the baseline model (structural and long-life ORUs included—all on-ground sparing), and Figure 3–6 provides the criticality rankings of the components in the baseline model without structural and long-life ORUs. As can be seen by comparing Figure 3–5 with Figure 3–6, structural and long-life ORUs have a significant impact on EPS equivalent availability when it is assumed that they may fail within the life of SSF.

The criticality rankings associated with the baseline EPS model without structural and long-life ORUs are considered the significant analysis of the two because long-life and structural ORUs are not prone to random failures. This case then points out which ORUs and components will provide the greatest benefit to overall EPS capability if their availability is improved in some manner, whether this be through sparing or design changes to increase reliability or reduce maintenance time. As with the initial study, the "critical" components have been listed. These critical components, when analyzed as a group, provide most of any increase in EPS capability when compared with an analysis of the effects of varying all EPS component availabilities. Analyses of this type are provided in the following sections.

The first eight components in Figure 3–6 account for most of the equivalent availability change effects in the EPS. Of the eight components, seven are considered critical to EPS equivalent availability; the alpha gimbal bearing is not considered critical because, as stated before, no RAM data were available to model the bearing, so it was modeled after a beta gimbal. Also, one additional EPS component considered critical is the PMC, since it has the most effect on EPS availability (section 3.2.2).

Using the previous criteria, the following components are considered the critical EPS components:

- Sequential Shunt Unit (SSU)
- dc Remote Bus Isolator—25 kW
- Main Inverter Unit
- dc Remote Bus Isolator—10 kW
- Battery Charge Monitor
- Charge Power Converter
- Discharge Power Converter
- Power Management Controller

These eight components correspond well with the ORUs determined to be critical in the initial study (Appendix A).

3.2.2 EPS Sensitivity to Component MTBF

Sensitivity to component MTBF was analyzed for the baseline EPS model with and without structural and long-life ORUs. The significance of the effects of varying EPS component MTBFs

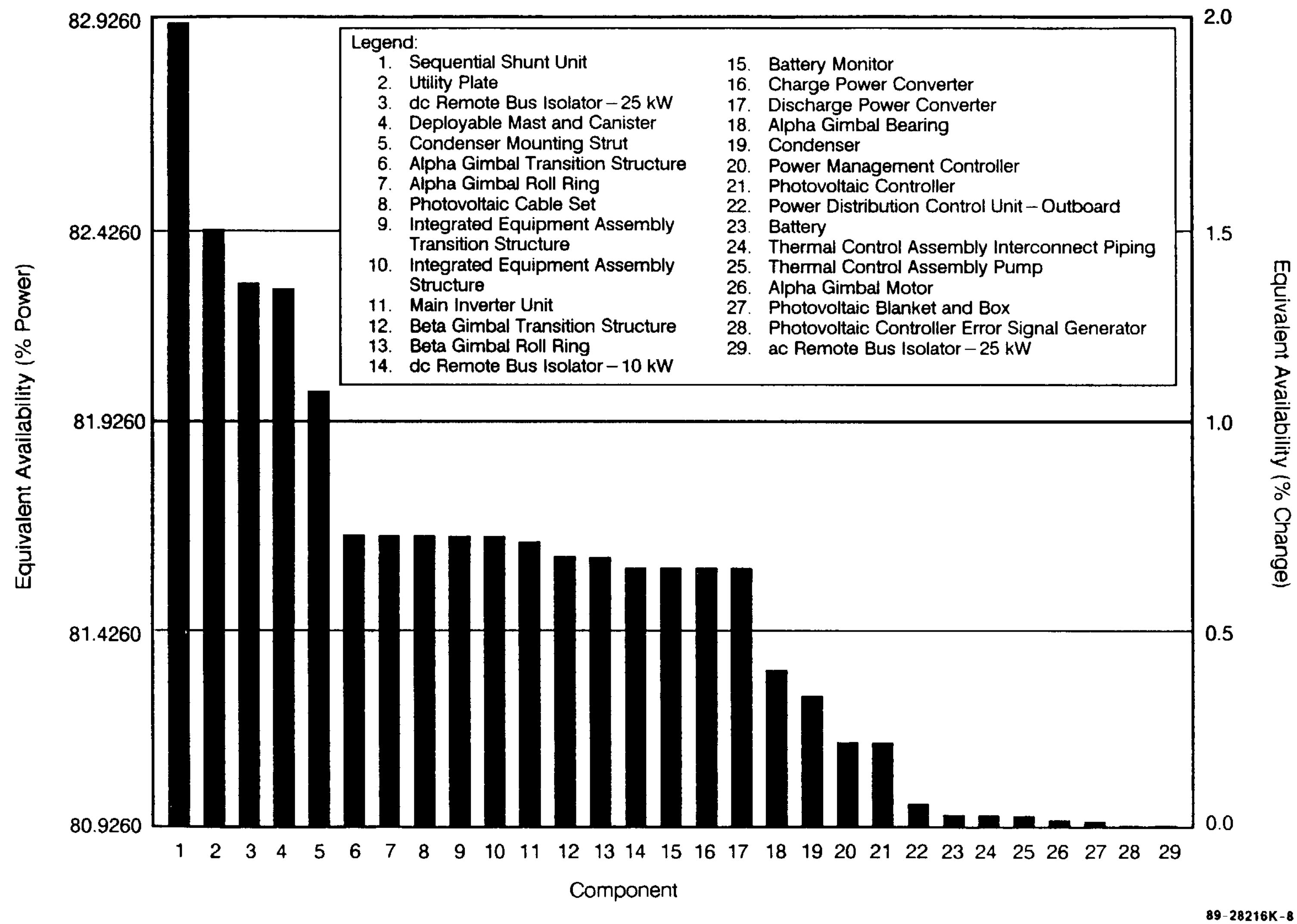

Figure 3–5. Criticality Rankings for Baseline EPS Model

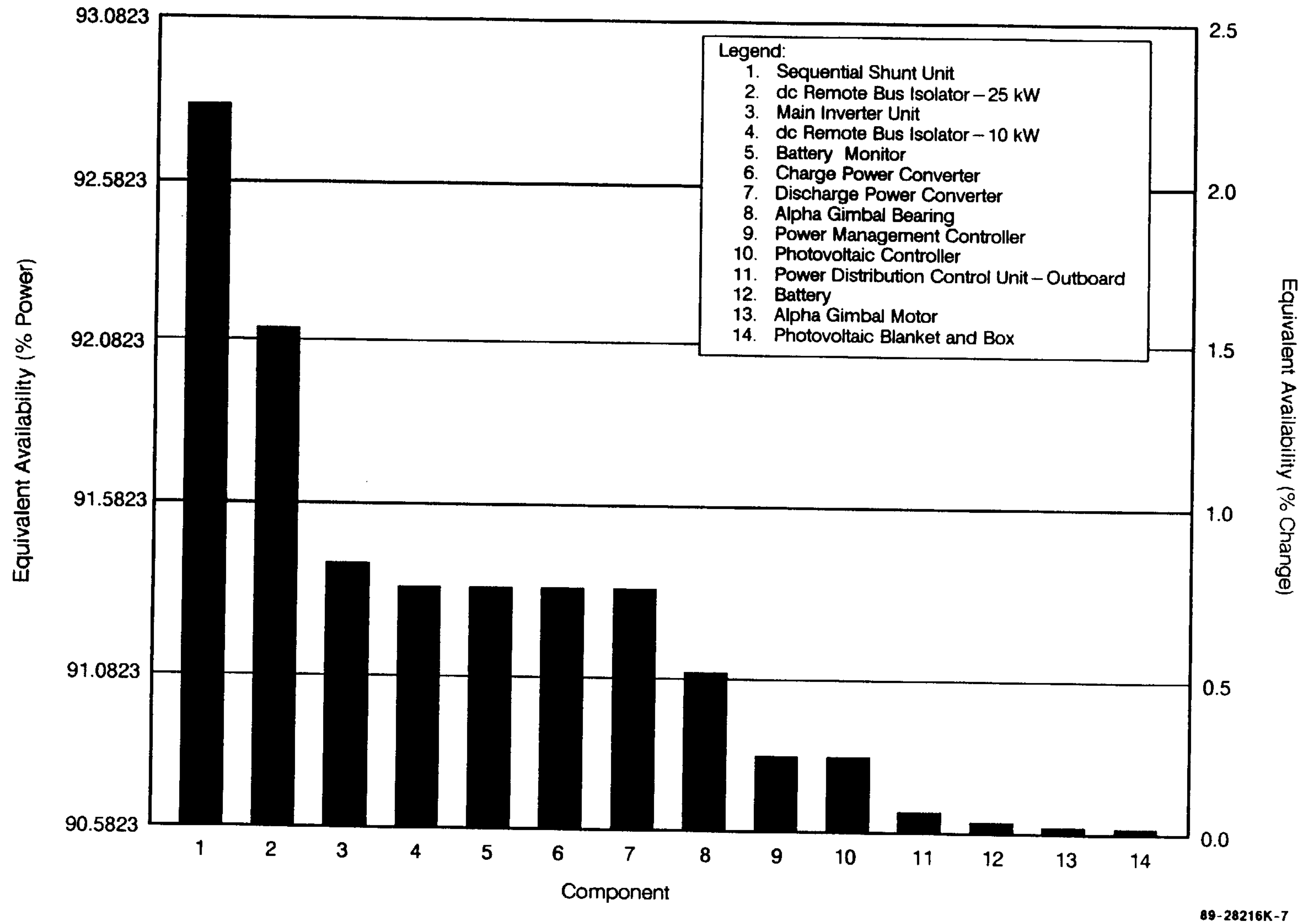

Figure 3–6. Criticality Rankings for Baseline EPS Model with No Structural or Long-Life ORUs

follows the results of the criticality rankings discussed in section 3.2.1. (Appendix B contains the detailed results of these analyses.) This follows since increasing component MTBFs brings them towards perfect availability and the resulting changes in availability follow the magnitude of the component-criticality ranking factor. Component MTBFs were scaled between 0.6 and 3.0, and the effects of these variations on EPS availability were tabulated. The sensitivity of availability and equivalent availability to scaling component MTBFs was analyzed in three ways:

- Initially, each component MTBF was scaled, and the effects of this on EPS availability were tabulated.

- The MTBFs of the eight components identified as critical were scaled as a group, and the effect that this group MTBF variation had on EPS availability was tabulated.

- Similarly, all EPS component MTBFs were varied as a group, and the effects on EPS availability were tabulated.

Figures 3–7 through 3–10 provide examples of the effects that varying the MTBF of one component, all components, and eight critical components has on EPS availability and equivalent-availability. As expected, the rise in EPS availability is exponential, which indicates to the designer that most of the availability gain comes in the first doubling of a component's reliability. Figures 3–7 and 3–8 show the availability and equivalent availability of the baseline EPS model, and Figures 3–9 and 3–10 show the availability and equivalent availability of the baseline model without structural or long-life components. In all four figures, the single-component variation shown is that of the component which gives the greatest EPS availability or equivalent availability change during the sensitivity analysis. In the case of availability (Figures 3–7 and 3–9), the component with the greatest effect was the power management controller (PMC). In the case of equivalent availability (Figures 3–8 and 3–10), the sequential shunt unit had the greatest effect. Comparing Figures 3–7 and 3–9 and the tabular data in Appendix B, it is apparent that the PMC has the single greatest effect on EPS availability. For this reason it was included in the critical component list (section 3.2.1).

In Figure 3–8, it is seen that the relative impact of eight critical components in comparison to that of all components is substantially less than that shown in Figure 3–10. This is because the EPS equivalent availability of the baseline EPS model is spread over the structural components as shown in the criticality ranking of Figure 3–5. Again, if it is assumed that the baseline EPS model without structural and long-life components comes closer to representing the true capability of the EPS, the eight critical components should be evaluated for design changes to increase overall EPS capability.

If there is any variation of the EPS component RAM data from that provided in the PSDD, performing this sensitivity analysis has provided availability bounds for these variations. For example, in Figure 3–8, scaling all EPS component MTBFs to 0.6 of the original values give an equivalent availability of 70.4%; for the scale factor of 3.0 the equivalent availability is 85.7. This corresponds to about a -10.5% to +4.8% variation from the baseline value of 80.9%.

If the RAM data are assumed to vary randomly between these scale factors so that some component MTBFs are less than the baseline value and some are above, the EPS equivalent availability resulting from these variations will probably still be close to the baseline value.

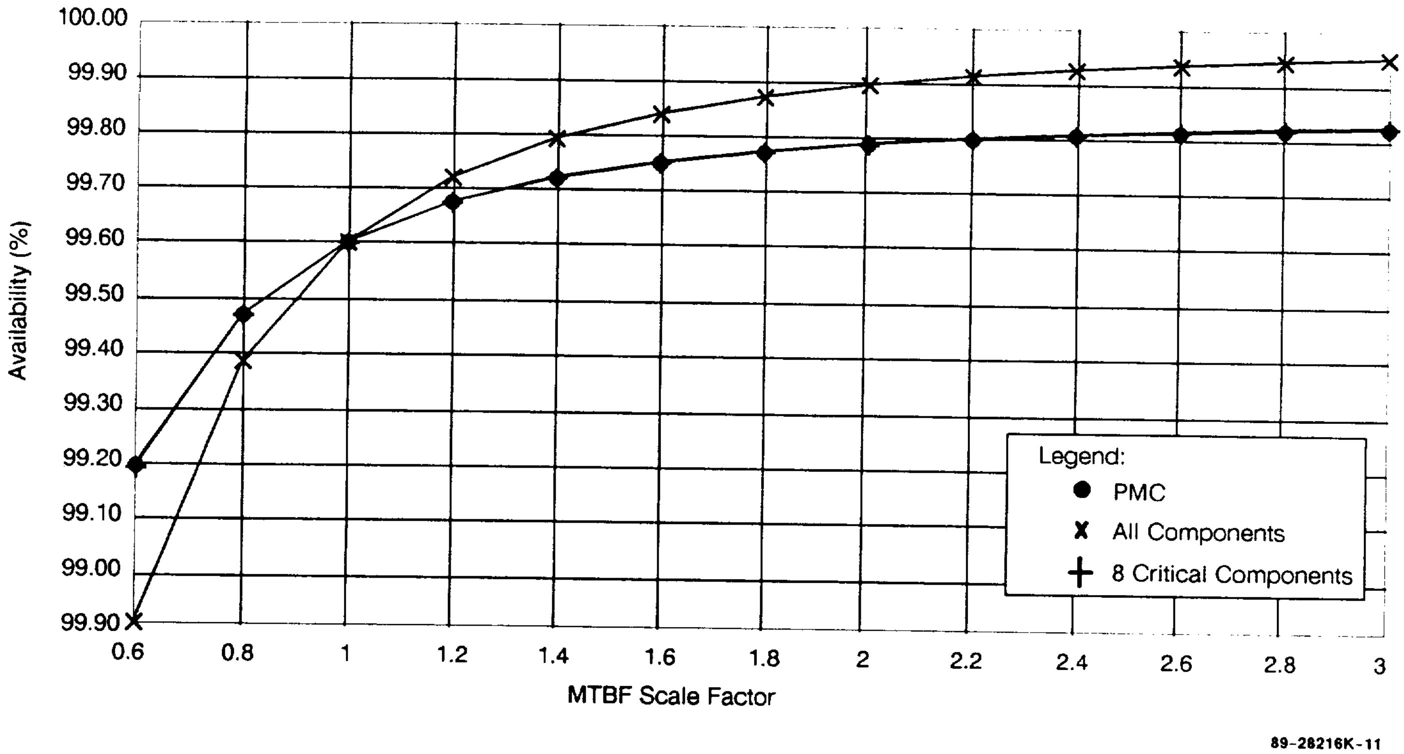

Figure 3-7. Availability Variation—Baseline EPS Model

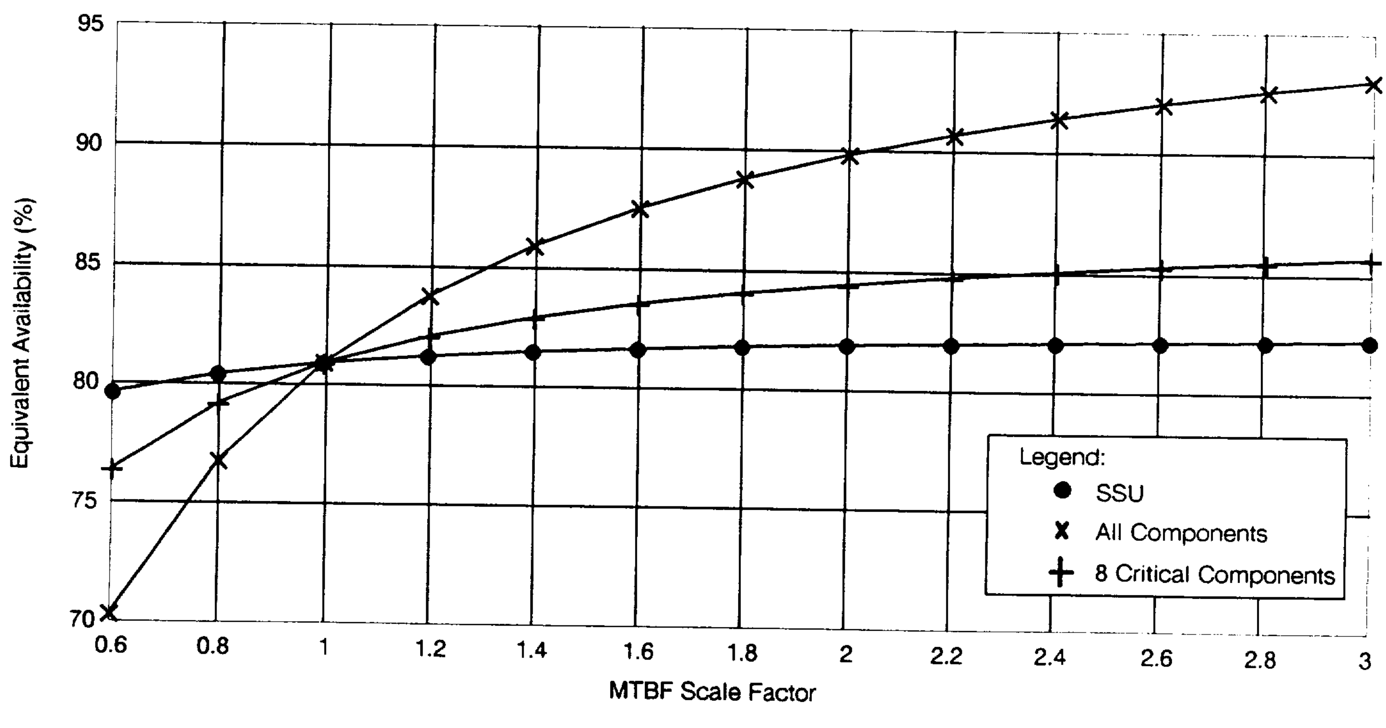

Figure 3-8. Equivalent Availability Variation—Baseline EPS Model

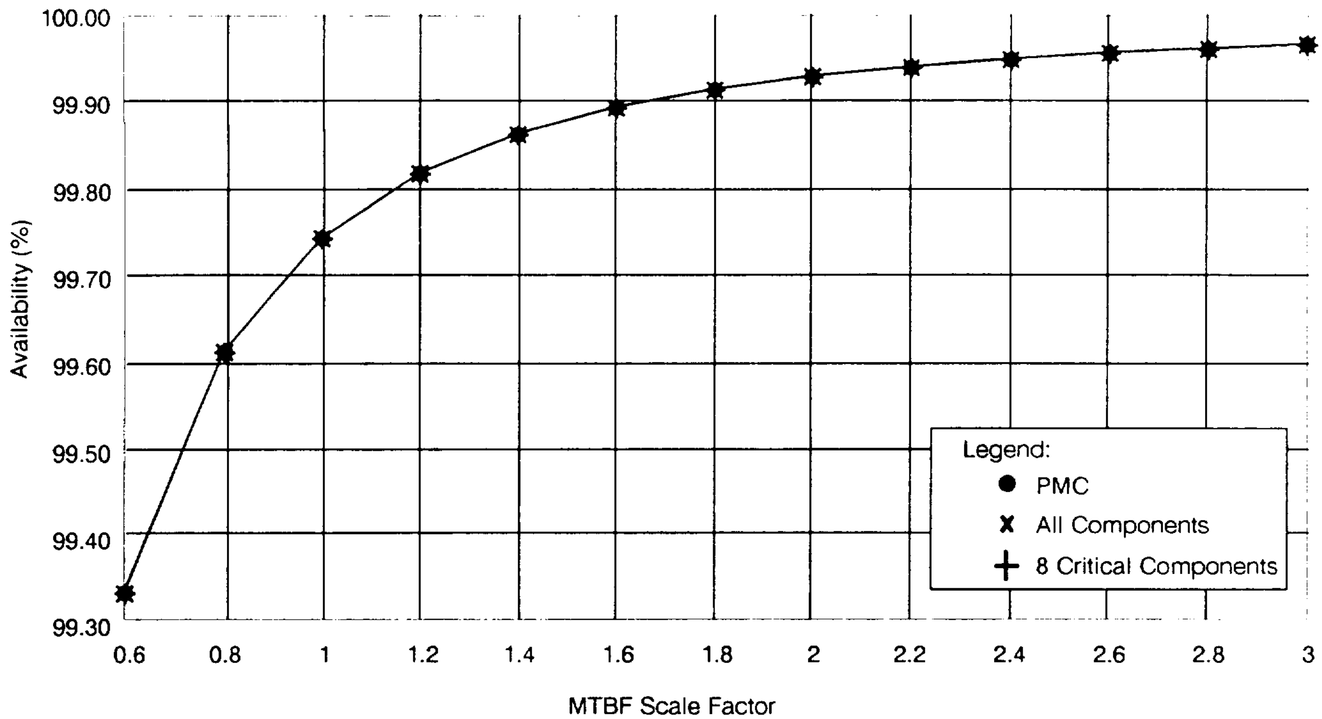

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Figure 3–9. Availability Variation—Baseline EPS Model with No Structural or Long-Life Components

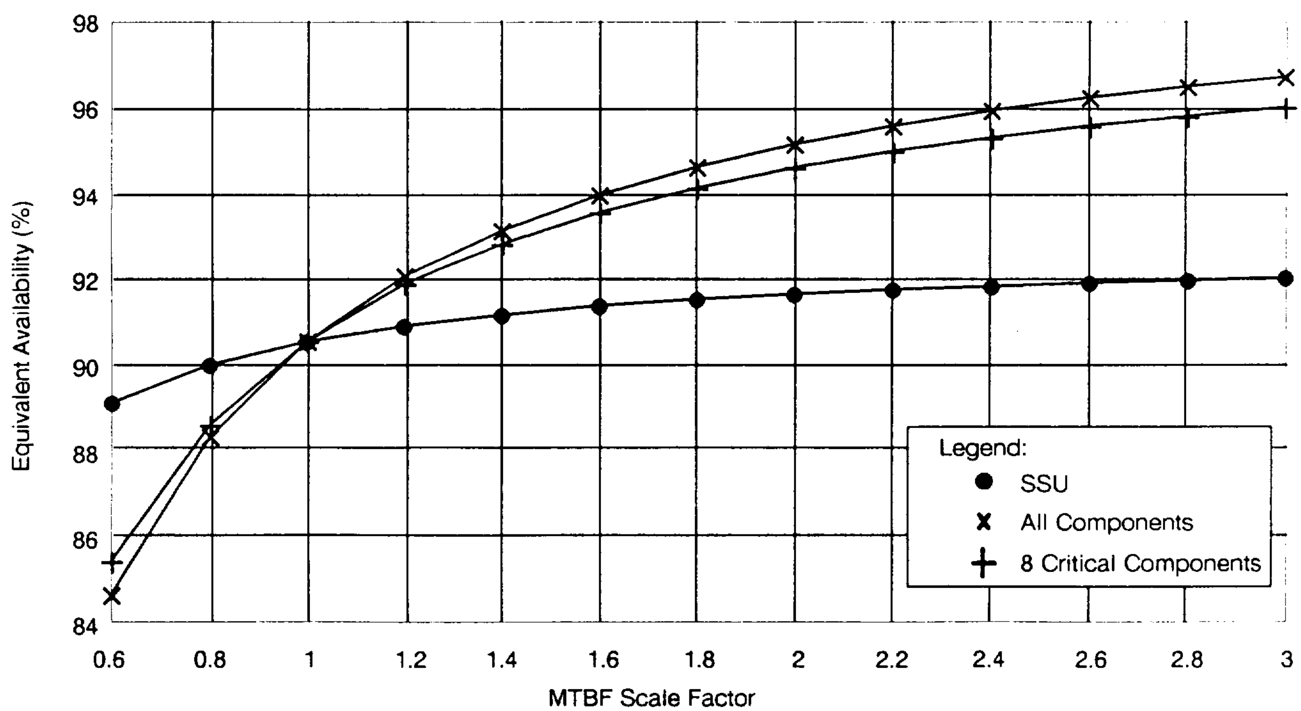

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Figure 3–10. Equivalent Availability Variation—Baseline EPS Model with No Structural or Long-Life Components

3.2.3 EPS Component MTBF Variation Using Replacement Ratio and K-Factor Adjustments

There are several effects on RAM when using component mean replacement intervals instead of component MTBFs in the baseline EPS model. The following paragraphs detail how the component mean replacement interval is determined and applied.

In the revisions to the *Space Station Freedom Power System Description Document* (NASA Lewis, Research Center, DR: SE-02; January 31, 1989), two adjustment factors for ORU MTBF values are provided: the K-factor and the replacement ratio. The K-factor adjusts a given ORU MTBF to reflect whether it is prone to induced failures, false indication of failures, and preventive maintenance. The replacement ratio reflects how often an ORU is expected to be removed and replaced (or remounted), regardless of whether it has failed.

The K-factor is applied by dividing the ORU MTBF by its K-factor. The resulting value is described as the mean time between maintenance actions. The replacement ratio factor is applied by dividing the ORU mean time between maintenance actions (ORU MTBF divided by its K-factor) by its replacement ratio. The resulting value is the ORU mean replacement interval (MRI).

Table 3-1 lists the modeled EPS components, their associated K-factors and replacement ratios, and the resulting component MRIs. Those components with asterisks have assumed values for these factors. The assumed values are required because the original data did not extend below the ORU level nor to the alpha gimbal ORUs.

By comparing the results of the analyses of the baseline model and the baseline model using the component MRIs, shown in Figures 3-11 and 3-12, it can be seen that there is about a 5% drop in equivalent availability and a significant decrease in EPS availability (0.3688%). Figure 3-13 provides the results of a criticality ranking of the baseline model using component MRIs. The effect of using the component MRIs has been to lessen the impact that some structural components have on equivalent availability in comparison with their impact on the baseline EPS model criticality ranking (Figure 3-5, section 3.2.1).

3.3 SPARING STRATEGY ANALYSIS

For the sparing analysis of the initial EPS study, component MDT was varied from 45 days (1,080 hours) to 6 hours (chosen as the nominal ORU hands-on repair time). From this coarse approach to an EPS MDT sensitivity analysis, basic information about which components should be spared on-orbit was obtained. This technique was refined for this study.

The effect of increasing the number of spares of a component type on its MDT is defined recursively as follows:

$$MDT_n = MDT_{n-1} - MTBF' \left(\frac{MLT}{MTBF' + MLT}\right)^n$$

where:

MDT_o = mean downtime of a component when o-spares are on-orbit

MDT_n = mean downtime of a component considering it has n-spares on-orbit; MDT_n is a function of the previous level of sparing, MDT_{n-1}

Table 3-1. Application of K-Factors and Replacement Ratios to Component Failure Rates

ORUs and Components	MTBF (hours)	K-Factor	Replacement Ratio	MRI (hours)
Photovoltaic Blanket and Box	131,400	2	0.80	82,125
Deployable Mast	131,400	2	0.80	82,125
Sequential Shunt Unit	87,600	2	0.80	54,750
Beta Gimbal Roll Ring	262,800	2	0.80	164,250
Beta Gimbal Transition Structure	262,800	1	0.80	328,500
Utility Plate*	350,400	1	0.80	438,000
Thermal Control System Condenser*	876,000	1	0.80	1,095,000
Thermal Control System Piping*	262,800	1	0.80	328.500
Thermal Control System Pump*	280,320	2	0.80	175,200
Condenser Mounting Strut*	262,800	1	0.80	328,500
Photovoltaic Radiator Panel Assembly	99,999,999			99,999,999
Integrated Equipment Assembly Transition Structure	262,800	1	0.12	2,190,000
Integrated Equipment Assembly Support Structure	262,800	1	0.80	328,500
Photovoltaic Cable Set	262,800	2	0.80	164,250
Photovoltaic Controller	43,800	2	0.80	27,375
Photovoltaic Controller Error Signal Generator*	87,600	2	0.80	54,750
10-kW dc Remote Bus Isolator (DCSU)*	262,800	2	0.80	164,250
25-kW dc Remote Bus Isolator (DCSU)*	262,800	2	0.80	164,250
Battery Monitor*	262,800	2	0.80	164,250
Charge Power Converter*	262,800	2	0.80	164,250
Discharge Power Converter*	262,800	2	0.80	164,250
Battery*	61,320	2	0.80	38,325
Main Inverter Unit	87,600	2	0.80	54,750
Outboard Power Distribution Control Unit	87,600	2	0.80	54,750
Alpha Gimbal Roll Ring*	262,800	2	0.80	164,250
Alpha Gimbal Bearing*	131,400	2	0.80	81,125
Alpha Gimbal Motor *	87,600	2	0.80	54,750
Alpha Gimbal Transition Structure*	262,800	1	0.80	328,500
Power Management Controller	43,800	2	0.80	27,375
25-kW ac Remote Bus Isolator*	262,800	2	0.80	164,250

*Components with assumed K-factor and replacement ratio values.

Data Source: *Space Station Freedom Power System Description Document*, DR:SE-02, January 31, 1989.

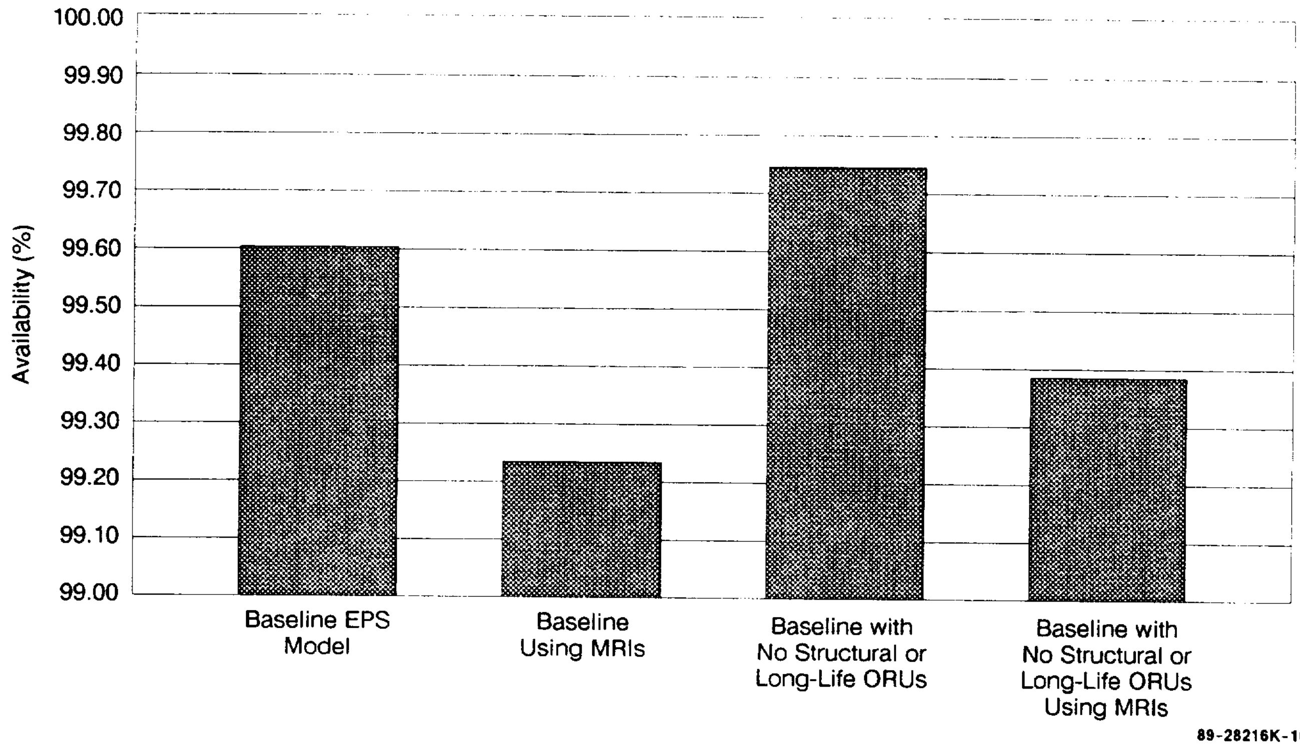

Figure 3–11. Availability Comparison—Baseline and Baseline Using Component MRIs

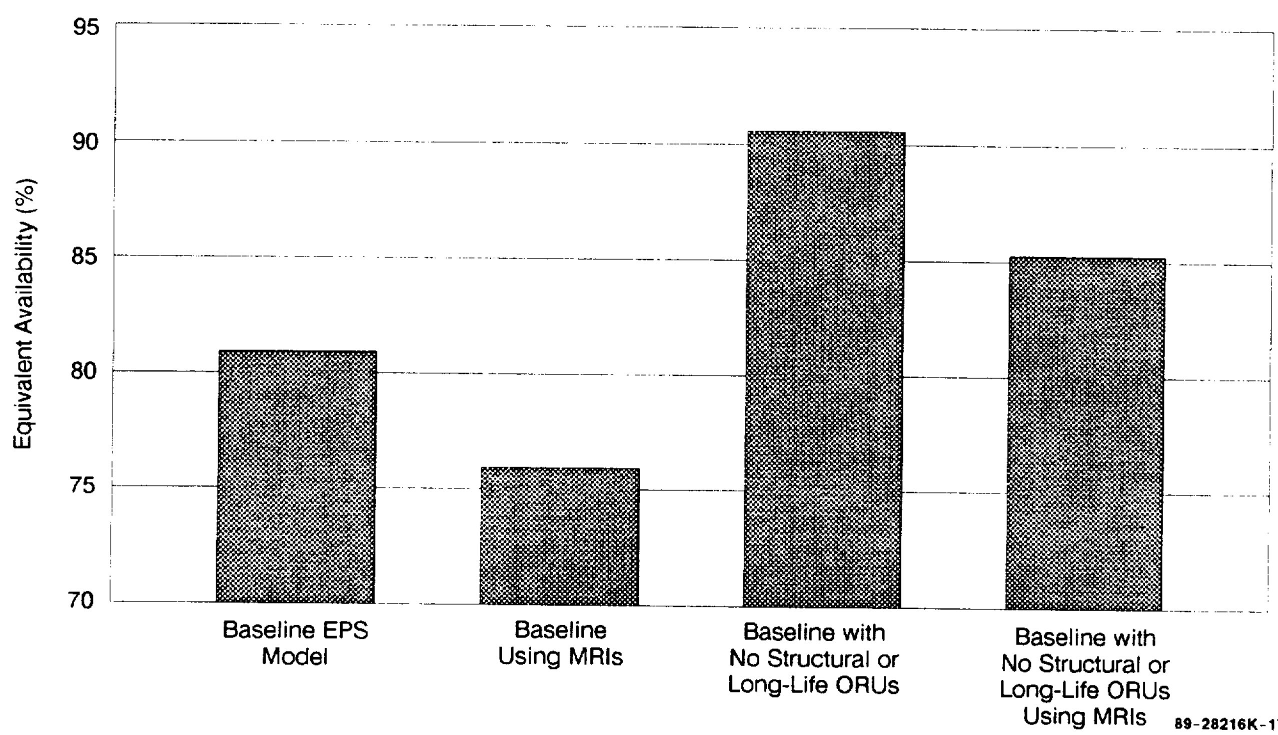

Figure 3–12. Equivalent Availability Comparison—Baseline and Baseline Using Component MRIs

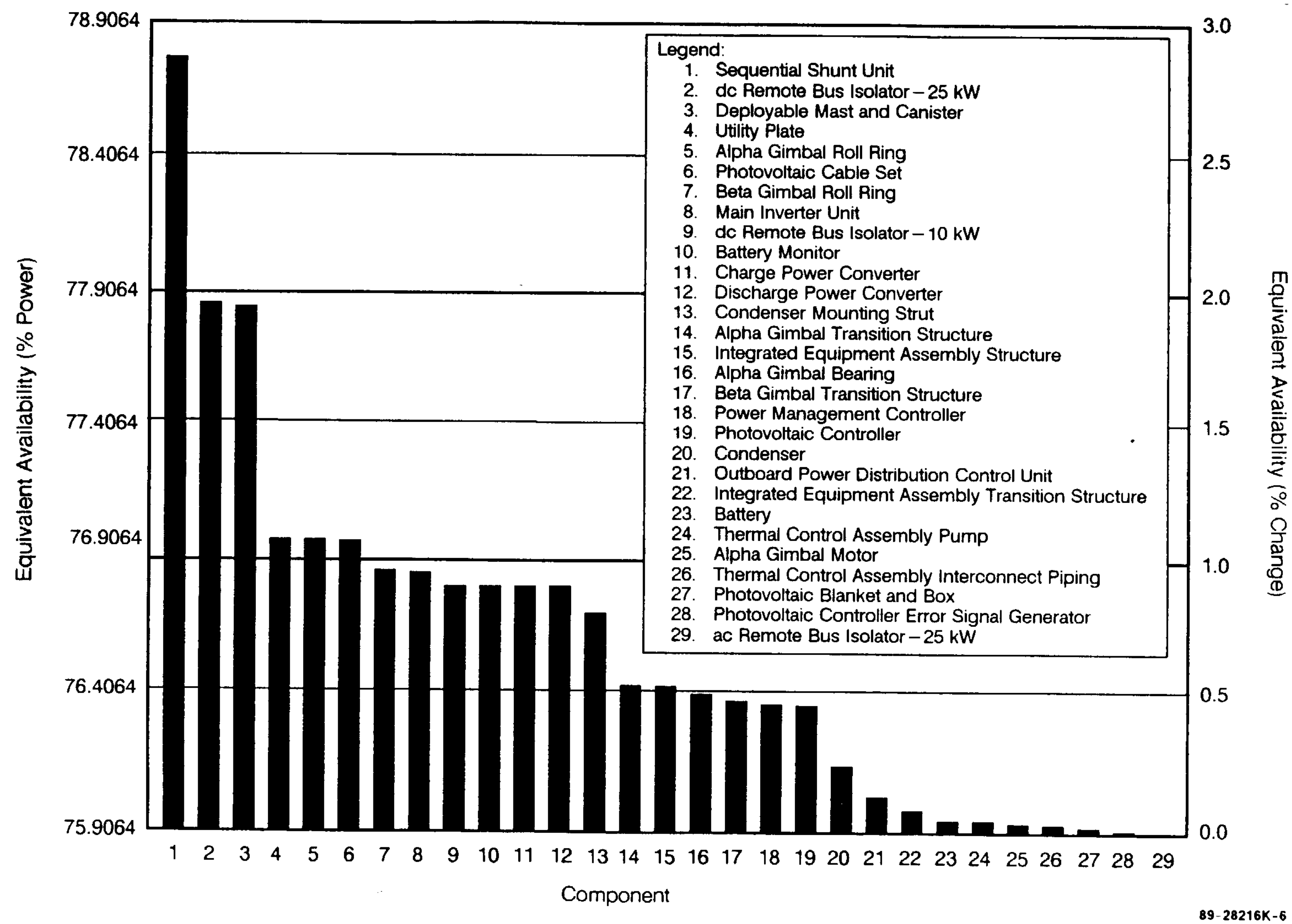

Figure 3–13. Baseline Criticality Rankings Using Component MRIs

MTBF' = mean time between failures of the component; if there are more than one active component of this type, MTBF' = MTBF/N where N = number of components of that type

MLT = mean lead time to bring a spare of the component to orbit

In essence, this relationship accounts for the availability effects that a given component sparing level has on that component. For example, with no spares the MDT of a component is 90 days if the component fails. With one spare on-orbit, the MDT is equal to the component mean time to restore until that spare is used. Once the spare is used, the MDT is again equal to about 90 days. This relation adjusts the component MDT to reflect the probability that all the spares may be used and the component may still fail before the next logistic resupply for that component.

Using this relationship, analyses were performed to determine which components should have on-orbit spares and in what order the spares should be brought on-orbit. This analysis is an automated tool associated with UNIRAM.

In essence, this type of sparing optimization entails picking the spare that "best" increases EPS capability (equivalent availability). The first task is to select which components are candidates for sparing.

A group of EPS components, from which the on-orbit component spares could be selected, was derived. Table 3-2 lists the components that were selected as sparing candidates and their associated component mass. Component mass is needed to allow the sparing analysis to be optimized using the mass of the spares. A component was a candidate if it had significant (> 0.5%) impact on a criticality ranking and it was not a structural or long-life component. Also, some consideration was given to the component storage volume, in that we assumed an alpha gimbal would not be a candidate for on-orbit sparing.

Two sparing analyses were performed for each of the following: the baseline EPS model, the baseline EPS model without structural and long-life ORUs, and a special analysis where the model was changed to reflect the EPS at only the ORU level. The first analysis optimized for equivalent availability change only. The second optimized for equivalent availability change per unit component mass. An EA per unit mass sparing optimization is important so that the average capability of the EPS can be maintained as high as desired with the lowest logistic costs (least resupply mass). These analyses provide information for comparing the various sparing strategies.

3.3.1 Sparing Results for Baseline EPS Model

In the analysis of the baseline EPS model, the maximum achievable equivalent availability, assuming all the candidate components of Table 3-2 are adequately spared,* was almost 88%. An equivalent availability goal of 85% was picked for sparing optimization. Table 3-3 lists the results of the two sparing optimization analyses. The components are listed in optimal order of selection preference, and the availabilities shown are cumulative.

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*The term "adequately spared" means that the number of on-orbit spares of that component is enough to cause the component MDT to approximately equal the component mean time to replace or repair (i.e., resupply time approaches zero).

Table 3-2. List of Candidate Spares

Component	Mass (lbm)
Photovoltaic Controller Error Signal Generator	0.25
Sequential Shunt Unit	37.50
dc Remote Bus Isolator—25 kW	14.00
Main Inverter Unit	205.00
dc Remote Bus Isolator—10 kW	3.00
Battery Monitor	53.33
Charge Power Converter	53.33
Discharge Power Converter	53.33
Photovoltaic Controller	111.00
Power Management Controller	143.00

The total mass for the EA-only analysis is 312.83 lbm and that for the EA per unit mass analysis is 164.16 lbm, showing a significant mass difference (148.67 lbm) between the two cases.

Table 3-3. Baseline Sparing Results

Optimal Order	Spare Added	Equivalent Availability (%)	Availability (%)
	EA-Only Analysis		
1	Sequential Shunt Unit	82.4465	99.6032
2	dc Remote Bus Isolator—25 kW	83.5851	99.6045
3	Main Inverter Unit	84.1685	99.6050
4	dc Remote Bus Isolator—10 kW	84.7203	99.6050
5	Battery Monitor	85.2756	99.6050
Total Sparing Mass: 312.83 lbm			
	EA per Unit Mass Analysis		
1	dc Remote Bus Isolator—10 kW	81.4201	99.6032
2	dc Remote Bus Isolator—25 kW	82.5264	99.6034
3	Sequential Shunt Unit	84.1180	99.6045
4	Second dc Remote Bus Isolator—10 kW	84.1931	99.6045
5	Battery Monitor	84.3701	99.6045
6	Charge Power Converter	85.2694	99.6045
Total Sparing Mass: 164.16 lbm			
Baseline (No Spares) Levels		80.9260	99.6032

3.3.2 Sparing Results for Baseline EPS Model Without Structural or Long-Life ORUs

For the baseline EPS model without structural or long-life ORUs, the initial equivalent availability is just over 90%. Adequately sparing the components listed in Table 3–2 provides an equivalent availability of slightly more than 98%. A sparing optimization goal of 95% equivalent availability was picked for this analysis. Table 3–4 lists the results of the two sparing optimization analyses. Again, the components are listed in optimal order of selection preference, and the availabilities shown are cumulative relative to the spares in place.

The total mass for the EA-only analysis was 312.83 lbm and that for the EA per unit mass analysis was 164.16 lbm. Again, this shows that there is a significant mass saving (148.67 lbm) between these two cases. Also, the spares selected for this analysis are the same as those listed in section 3.2.4.1 for two reasons: (1) the possible range of availability change in both cases is nearly the same, and (2) the goals in both cases constitute an equivalent availability increase which is nearly the same.

Table 3–4. Baseline Sparing Results with No Structural or Long-Life ORUs

Optimal Order	Component Spared	Equivalent Availability (%)	Availability (%)
	EA-Only Analysis		
1	Sequential Shunt Unit	92.2929	99.7451
2	dc Remote Bus Isolator—25 kW	93.6038	99.7452
3	Main Inverter Unit	94.2817	99.7452
4	dc Remote Bus Isolator—10 kW	94.9283	99.7453
5	Battery Monitor	95.5795	99.7453
Total Sparing Mass: 312.83 lbm			
	EA per Unit Mass Analysis		
1	dc Remote Bus Isolator—10 kW	91.1601	99.7451
2	dc Remote Bus Isolator—25 kW	92.4339	99.7452
3	Sequential Shunt Unit	94.2228	99.7453
4	Second dc Remote Bus Isolator—10 kW	94.3166	99.7453
5	Battery Monitor	94.9446	99.7453
6	Charge Power Converter	95.5765	99.7453
Total Sparing Mass: 164.16 lbm			
Baseline (No Spares) Levels		90.5823	99.7451

3.3.3 Sparing Results for Baseline EPS Model at the ORU Level

The baseline EPS model with components to the ORU level was analyzed, and Table 3–5 lists the candidate ORUs for sparing and their masses. The maximum achievable equivalent availability, assuming all the candidate components of Table 3–5 are adequately spared, was just over 87%. Using

Table 3-5. List of Candidate ORU-Level Spares

ORU	Mass (lbm)
Sequential Shunt Unit	37.5
dc Switching Unit	171.5
Main Inverter Unit	205.0
Battery Charge/Discharge Unit	160.0
Photovoltaic Controller	111.0
Power Management Controller	143.0
Outboard Power Distribution Control Unit	213.0
Main Bus Switching Unit	127.0

this value, an equivalent availability goal of 85% was picked. Table 3-6 lists the results of the EA-only and the EA per unit mass sparing optimization analyses. The components are listed in optimal order of selection preference, and the availabilities shown are cumulative. The total mass in the EA-only sparing analysis was 905.5 lbm. The total mass for the EA per unit mass sparing analysis was 783.0 lbm. There is a 122.5 lbm saving if the spares are selected on the basis of EA change per unit mass of the spares. On the other hand, the difference in masses between sparing at the ORU level and at the component level just below the ORU level is significant. In the EA-only case, the ORU-level increase in sparing mass is 592.67 lbm (312.83 lbm to 905.5 lbm), and that for the EA per unit mass is 618.84 lbm (783.0 lbm to 164.16 lbm).

3.4 EPS SUBSYSTEM AND COMPONENT REDUNDANCY ANALYSES

For the EPS subsystem and component redundancy, two analyses were performed. The first analyzed the effect of increasing the redundancy of the power management controller on EPS availability. The second analyzed the effect of increasing the redundancy of EPS PV modules from four to six.

3.4.1 Power Management Controller Redundancy Effects

As shown in Figure 3-9 of section 3.2.2, the power management controller is the key EPS component for determining the amount of the EPS availability measure. In order to decrease the probability of a 0% power level in this design, the power management controller must be made either more reliable or more available.

In this analysis the level of redundancy of the power management controller was increased from its baseline level of two PMCs in parallel to three and four PMCs in parallel successively. Figure 3-14 shows the effect of these redundancy changes in both the baseline EPS model and the baseline EPS model without structural or long-life ORUs. In both cases it can be seen that the greatest increase in availability stems from the addition of a single power management controller. In the baseline EPS model, the increase in availability is 0.2415%. In the baseline EPS model with no structural or long-life ORUs, the increase is 0.2420%.

Table 3-6. Baseline ORU-Level Sparing Results

Optimal Order	Spare Added	Equivalent Availability (%)	Availability (%)
	EA-Only Analysis		
1	dc Switching Unit	80.8102	99.5933
2	Sequential Shunt Unit	82.3412	99.5945
3	Battery Charge/Discharge Unit	83.5600	99.5945
4	Second dc Switching Unit	84.3505	99.5947
5	Main Inverter Unit	84.9744	99.5952
6	Second Battery Charge/Discharge Unit	85.4031	99.5952
Total Sparing Mass: 905.50 lbm			
	EA per Unit Mass Analysis		
1	Sequential Shunt Unit	79.6674	99.5930
2	dc Switching Unit	82.3415	99.5945
3	Battery Charge/Discharge Unit	83.5600	99.5945
4	Second Sequential Shunt Unit	83.8256	99.5947
5	Second dc Switching Unit	84.6211	99.5948
6	Main Inverter Unit	85.2485	99.5953
Total Sparing Mass: 783.00 lbm			
Baseline (No Spares) Levels		78.2417	99.5918

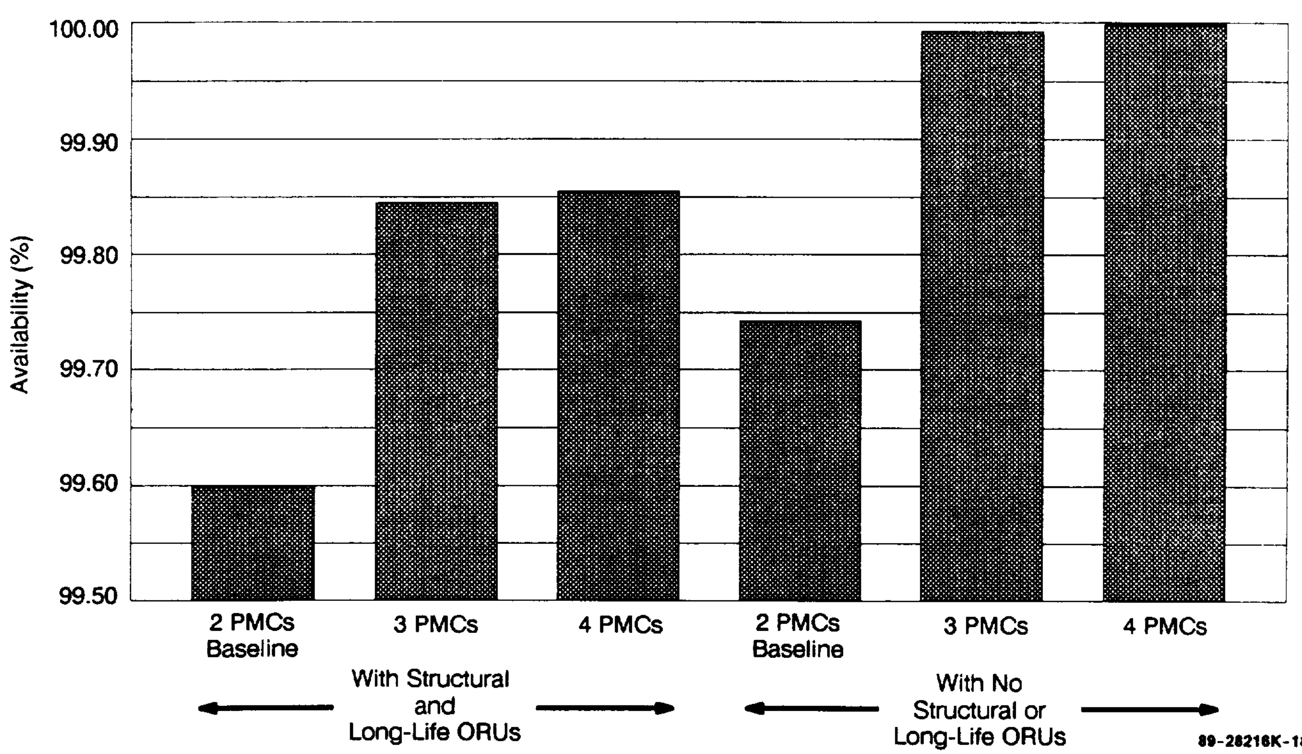

Figure 3-14. Availability Increase—With Additional PMC Redundancy

3.4.2 Analysis of Increasing Redundancy of PV Module

The redundancy analysis required modifying the existing baseline EPS model to add two PV modules for a total of six PV modules. Figure 3–15 provides a diagram of this design (refer to Figure 2–2 for the details of the PV module block N–PV). This would increase the user available power capabilities of the EPS to a maximum of 112.5 kW. In relation to 75 kW of power (four PV module baseline power level), this is a 150% capability. However, it also raises the total number of components in the baseline model from 402 components to 562 components (at the ORU level, this increases the number of modeled ORUs from 302 to 424). This represents a significant increase in the logistical (sparing and resupply) aspects of the EPS.

Figures 3–16 and 3–17 provide the results of the RAM analysis of a six PV module EPS design. As in the previous sections, these results are given along with the baseline model results for comparison. The significant aspect of the analysis is that the availability has not increased significantly (Figure 3–15) in relationship to the baseline availability. Again, this is due primarily to the EPS dependency on the availability of the PMCs (section 3.4.1).

Figures 3–18 and 3–19 show the discrete power levels caused by component failures in the 6–PV module EPS design and the cumulative availability associated with these power levels. Figure 3–18 provides these results for a six PV module EPS with structural and long-life ORU availability effects included. Figure 3–19 shows that removing structural and long-life ORU availability effects increases the availabilities of high power levels without a significant change in the low power level availabilities.

One problem did arise in this analysis. Because of the increased level of parallel redundancy and the subsequent increase in the number of unique failure-induced levels of power output, this model exceeded the current capability of the UNIRAM software. For this analysis, the model was analyzed in two parts, and the subsequent power states and state probabilities from these parts were combined using an external program. While this process is valid, it did preclude performing component criticality rankings and any sensitivity analyses.

3.5 ADDITIONAL MODEL ANALYSES

Two additional EPS models were analyzed. The first is an extension of the baseline EPS model, which includes power distribution components. The second model is an EPS alternative design, which uses three solar-dynamic modules and one PV module.

3.5.1 Baseline EPS Model with Power Distribution Components

Figures 3–20 and 3–21 provide the details of the model used in this analysis. There are two distinguishing features. The first feature, as shown in Figure 3–20, is that the total system output has been "connected" to a perfectly available 25-kW (33.33%) load. This connection provided an indication of the expected average power that will be available to loads up to this level. Figure 3–21 shows that the distribution system that is modeled is a dc system. This is in accordance with discussions with LeRC personnel but is not reflected in the version of *Space Station Freedom Power System Description Document* (DR:SE–02, January 31, 1989) that was used in this study. As with the six PV module EPS design (section 3.3.2), this model was beyond the software capabilities of UNIRAM; therefore, it was analyzed in two parts also, with constraints similar to those of the redundancy analysis.

The results of this analysis are listed in Table 3–7. As mentioned previously, total system output is connected to a 25-kW load. This means that the highest EA achievable for this model is 33.33%

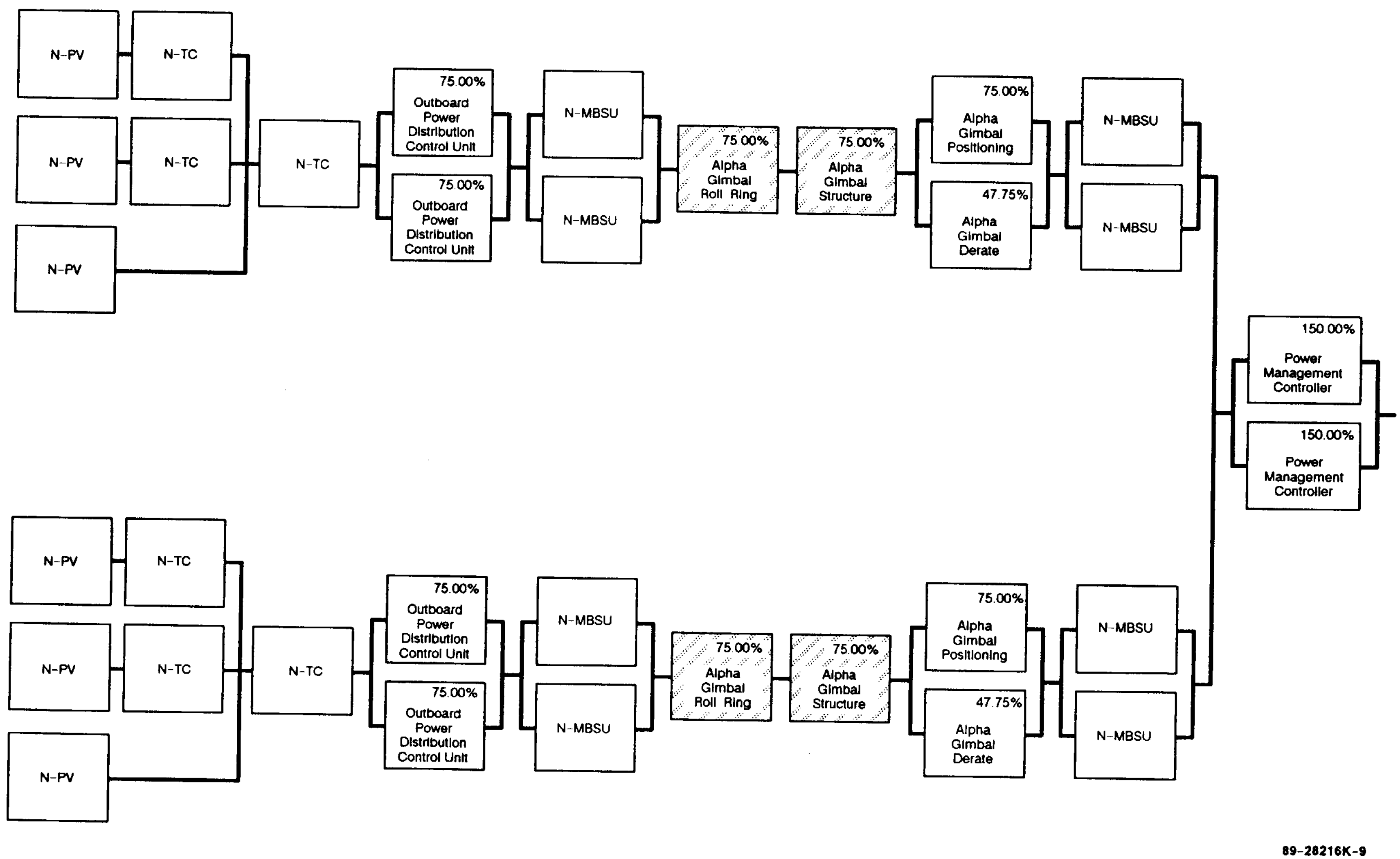

Figure 3-15. Six PV Module EPS Availability Block Diagram

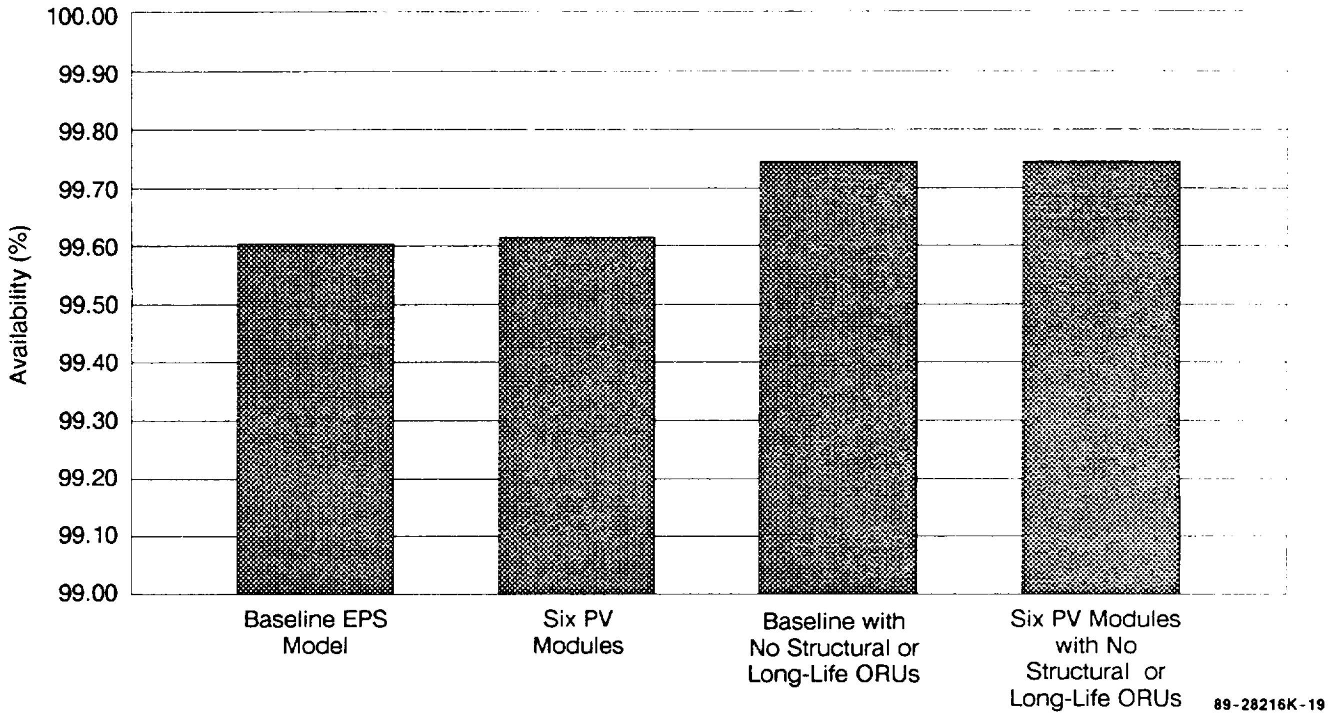

Figure 3-16. Availability Comparison—Baseline and Six PV Module EPS

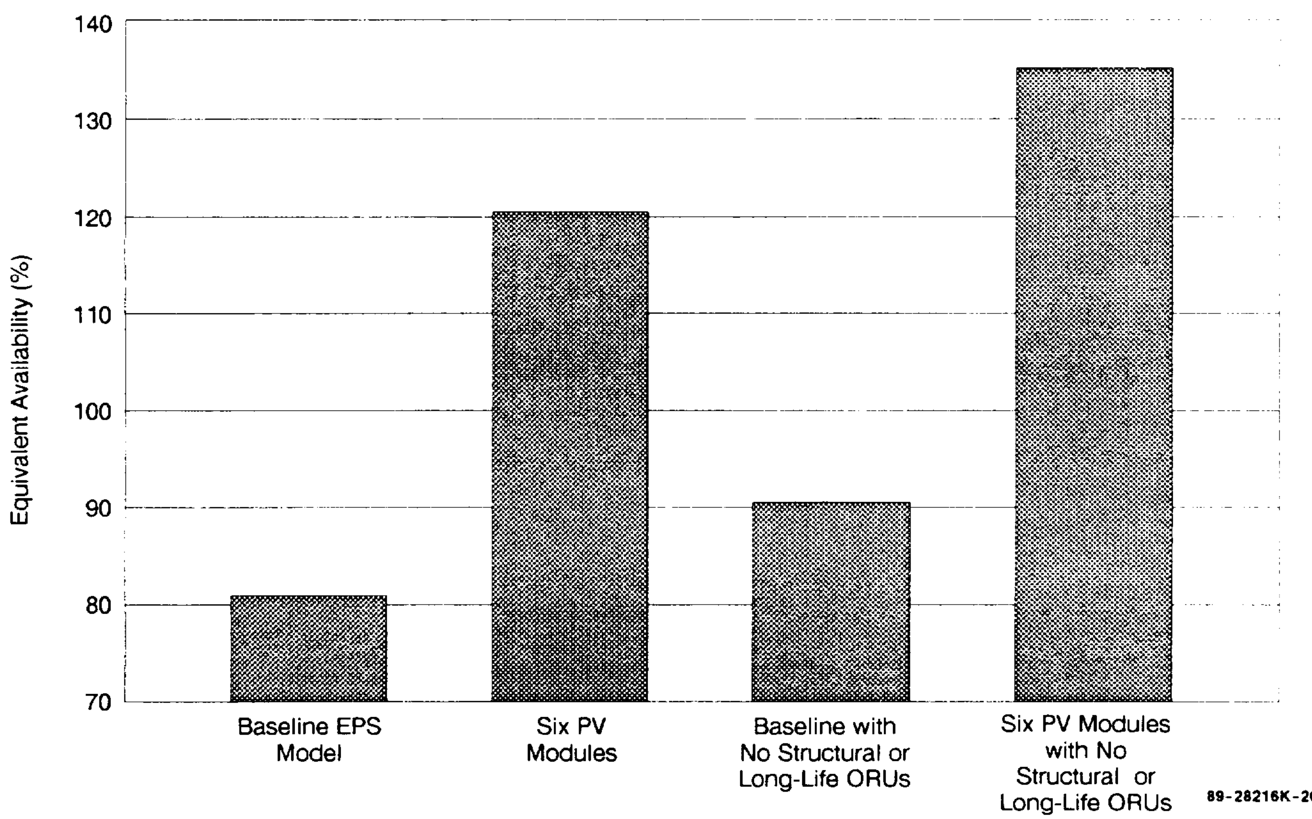

Figure 3-17. Equivalent Availability Comparison—Baseline and Six PV Module EPS

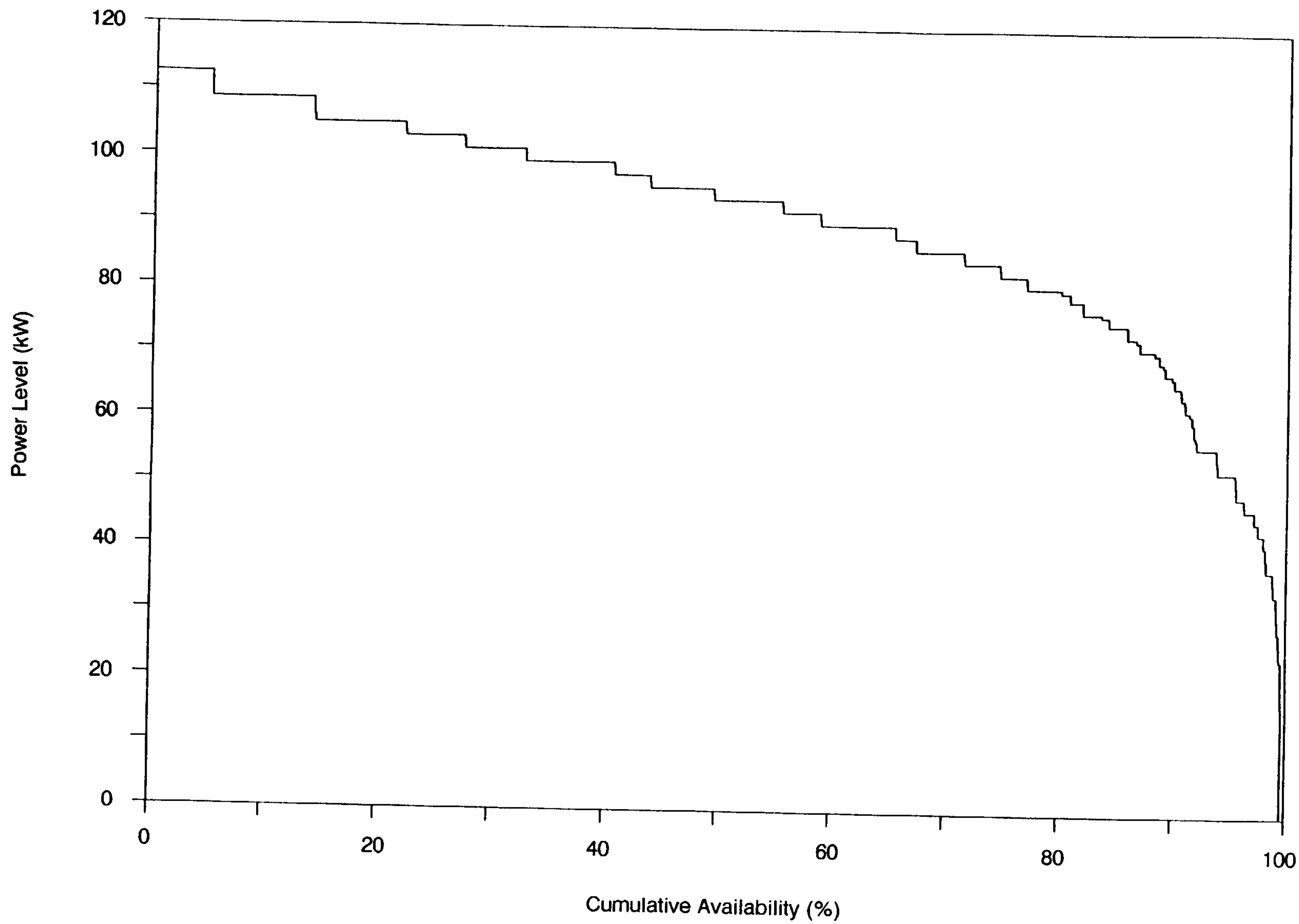

Figure 3-18. Six PV Module EPS Power Level Versus Cumulative Availability

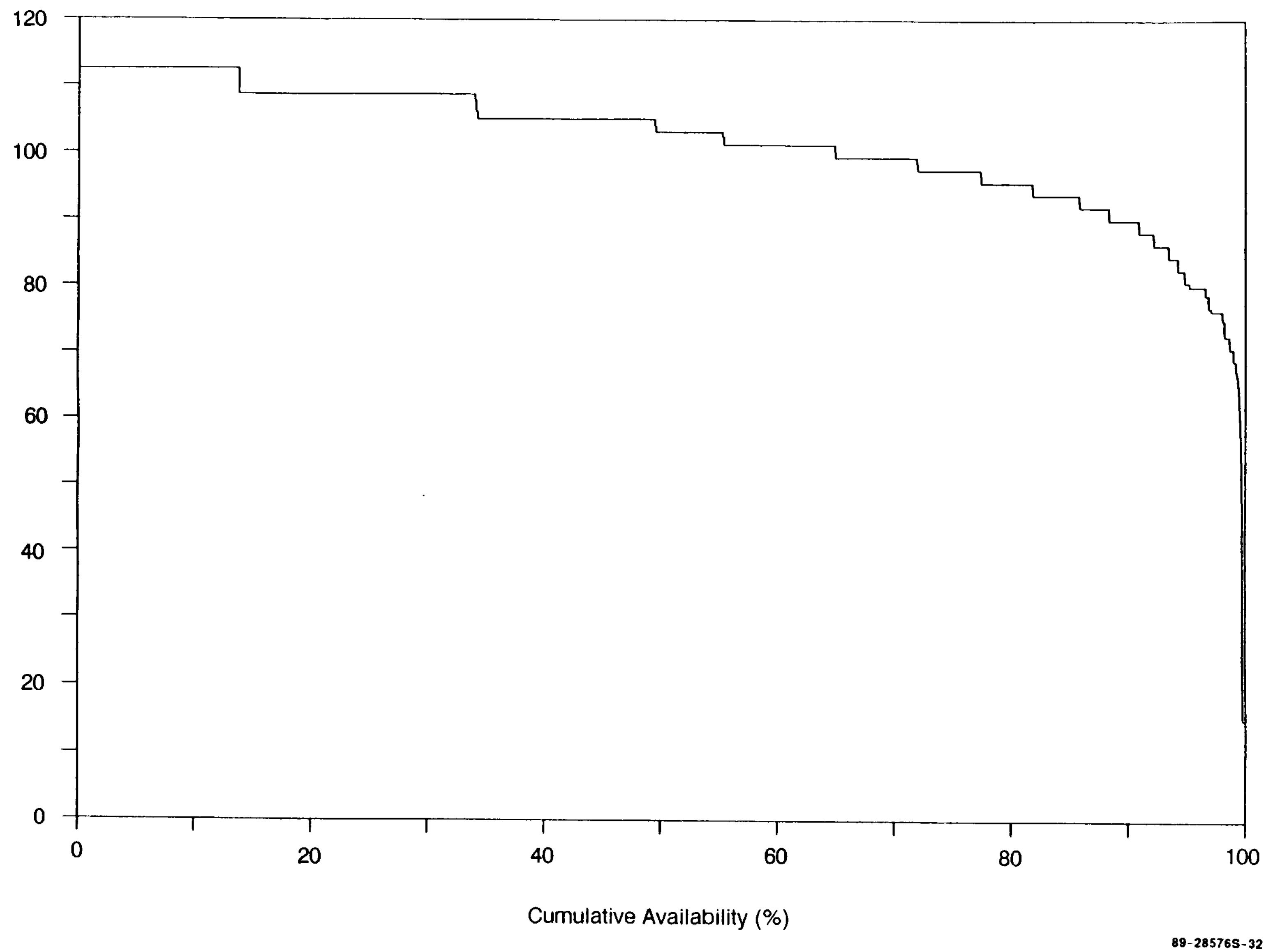

Figure 3-19. Six PV Module EPS with No Structural or Long-Life ORUs Power Level Versus Cumulative Availability

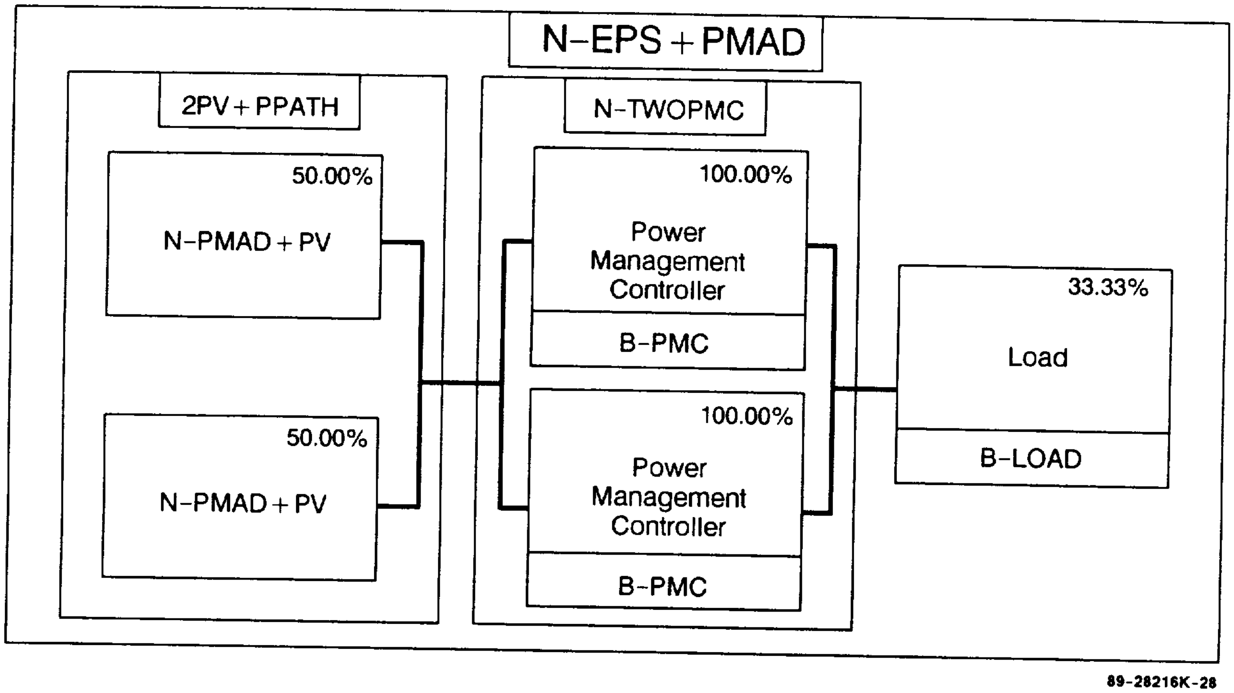

Figure 3–20. Baseline EPS Model with Power Distribution System Components

(25 kW/75 kW). Comparing the availability with the baseline availability, there is a slight decrease (0.006%) because of the increased number of components in the model when power distribution is included. The significance of the equivalent availability is that power of a sufficient level will probably be available to this load situation if it is available at all.

3.5.2 3SD–1PV EPS Design Analysis

Another EPS design was modeled to compare a solar-dynamic dominant EPS design with a photovoltaic design. Figure 3–22 provides a "high-level" view of the model of an SD module. An SD module is a serial type of power-generating system. This is in direct contrast to a PV module (Figure 2–2), which has high levels of parallelism in its design. From this, one would expect the availability of an SD type of EPS to be lower than that of the baseline EPS model.

Table 3–8 provides the solar-dynamic-specific RAM data used in this analysis. The 3SD–1PV UNIRAM model listing is in Appendix C, and the detailed availability block diagrams are in Appendix D.

Table 3–9 provides the availability and equivalent availability comparison data of the 3SD–1PV module EPS and the baseline EPS model. As can be seen, the availability does decrease (0.4325%) even though there is a 10-kW PV module in the design. Again, this is because of the serial nature of the SD design. Considering average capability (Figure 3–22), even though the SD design could provide 85 kW, its equivalent availability is nearly the same as that of the PV design. This too stems from the serial nature of the SD design. Also, the baseline EPS model photovoltaic blanket and box as well as battery component MDTs were set to 24 hours, thus minimizing the influence of these components on availability.

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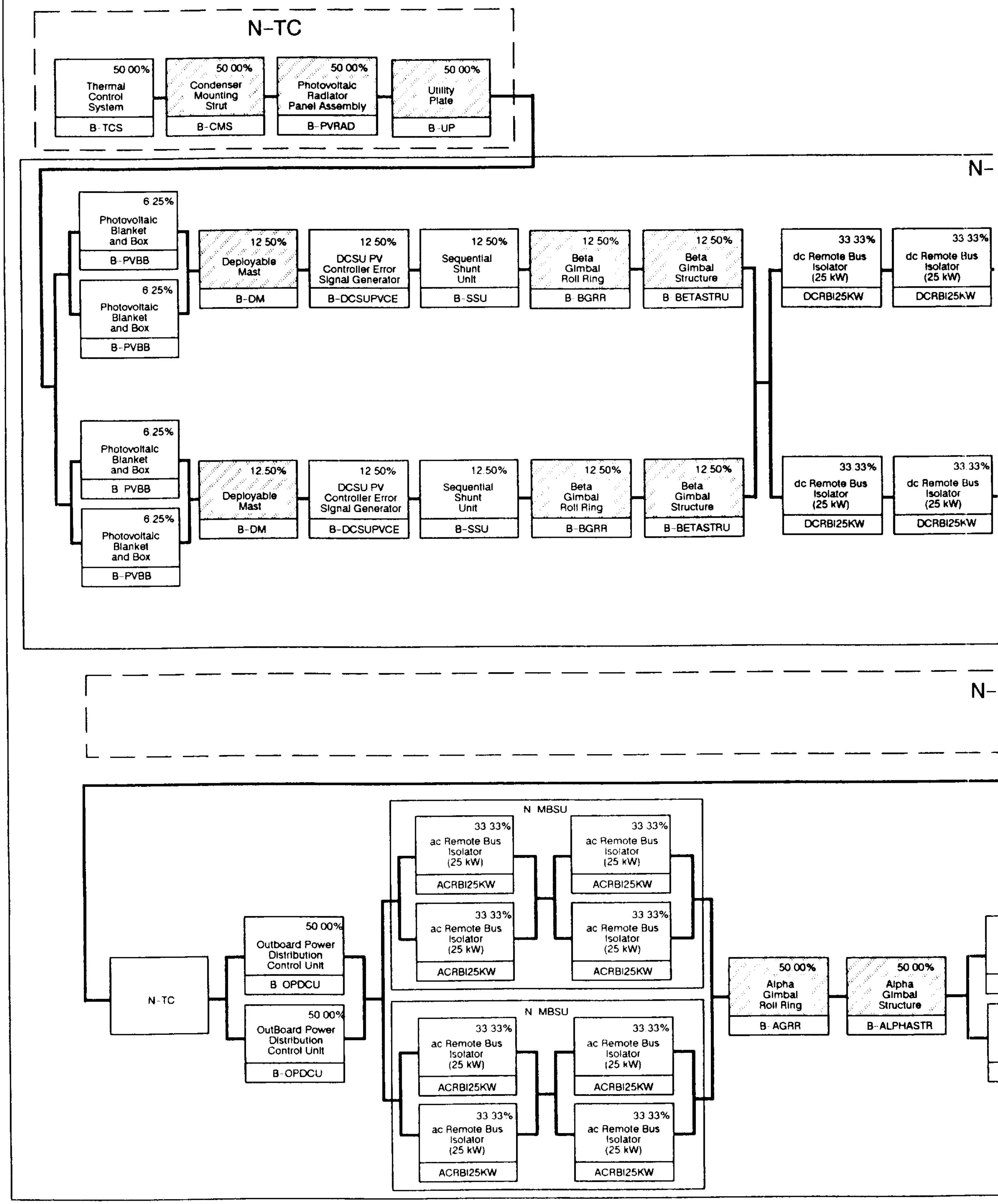

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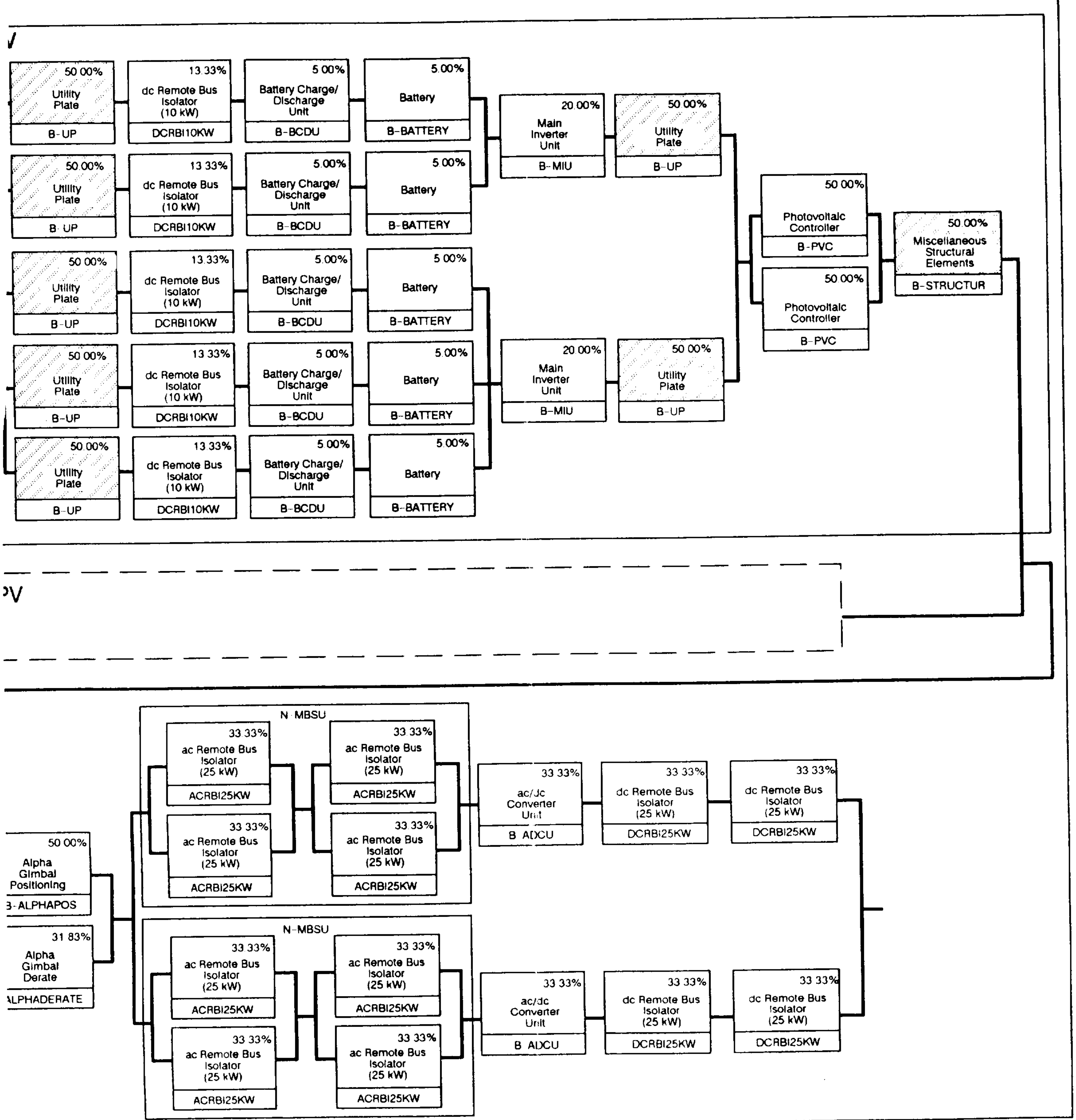


Figure 3-21. One-Half EPS with Distribution Components Block Diagram

Table 3-7. RAM Characteristics of Baseline EPS Model with Power Distribution Components

	Availability (%)	Equivalent Availability (%)
With 25-kW Load	99.5972	32.0875
Baseline Without Power Distribution Components	99.6032	80.9260

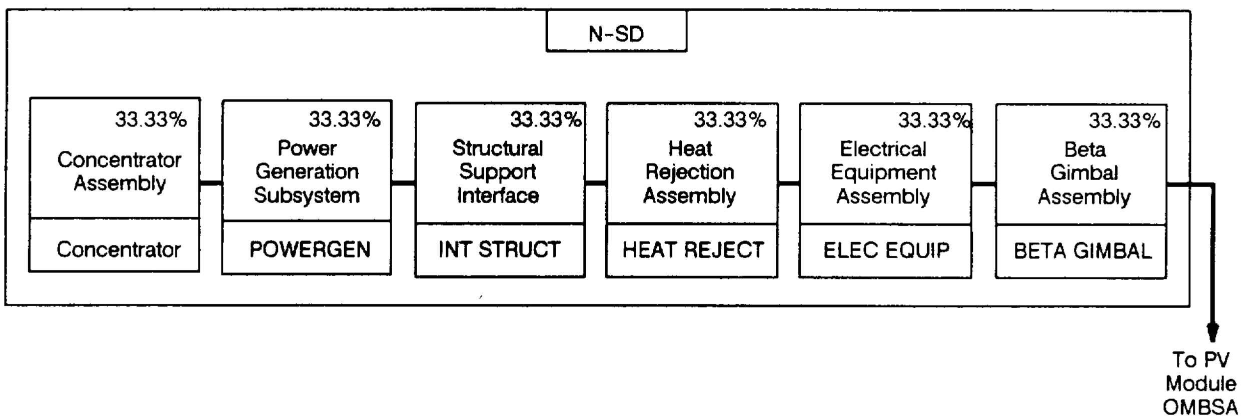


Figure 3-22. Solar-Dynamic Module

Figure 3-23 shows the discrete power levels caused by component failures in the 3SD-1PV EPS design and the cumulative availability associated with these power levels. Comparing Figure 3-23 to the baseline EPS model, Figure 3-3, it is apparent that the higher power levels are more available. However, it is also apparent that there are fewer intermediate power levels and the lower power levels have greater impact on the 3SD-1PV EPS average capability (equivalent availability).

Table 3-8. 3SD-1PV Module EPS—Solar-Dynamic-Specific Component RAM Data

Component Name, Model Acronym	MTBF (Hour)	MDT (Hour)
Reflective Surface, Reflective Surface	131,400	2,336
Concentrator Structure, Concentrator Strut	262,800	2,340
Insolation Meter	87,600	2,329.5
Concentrator Controls Cable, Concentrator Control	262,800	2,330
2-Axis Gimbal, 2-Axis Gimbal	262,800	2,334
Linear Actuator—Outer, Lin Act Outer	87,600	2,331
Linear Actuator—Inner, Lin Act Inner	87,600	2,331
Sun Sensor (2-Axis), Sun Sensor	87,600	2,329.5
Power Conversion Unit (PCU)/Receiver, PCU/Receiver	131,400	2,336
PCU Power Cable Set, PCU Power CS	262,800	2,334
PCU Signal/Data Cable Set, PCU Sig/Data CS	262,800	2,330
Control Valve Actuator, Cntrl Vlv Act	262,800	2,328.5
Parasitic Load Radiator, Parasitic Load Rad	87,600	2,329.5
Solar Dynamic Engine Controller, Engine Cntrlr	87,600	2,329.5
PCU-MP	87,600	2,339.5
Radiator Panel/Deployment Subassembly, Rad Panel Deploy	87,600	2,331
SD Utility Plate, SD Utility Plate	262,800	2,332.5
Fluid Manage Unit, Fluid Manage Unit	113,880	2,331
Hot Interconnect Lines, Hot Intercon Lines	262,800	2,329
Cold Interconnect Lines, Cold Intercon Lines	262,800	2,329
Pump Interconnect Lines, Pump Intercon Lines	262,800	2,329
Frequency Changer Unit, Frequency Changer	87,600	2,329.5
Solar Dynamic Cable Set, SD CS	262,800	2,340
Solar Dynamic/PMAD Cable Set, SD/PMAD CS	262,800	2,340
Solar Dynamic Controller, SD Controller	43,800	2,329.5

Table 3-9. RAM Characteristics of 3SD-1PV Module EPS

Model	Availability (%)	Equivalent Availability (%)*
3SD-1PV	99.1707	80.5240
Baseline EPS Model	99.6032	80.9260

*Relative to 75 kW.

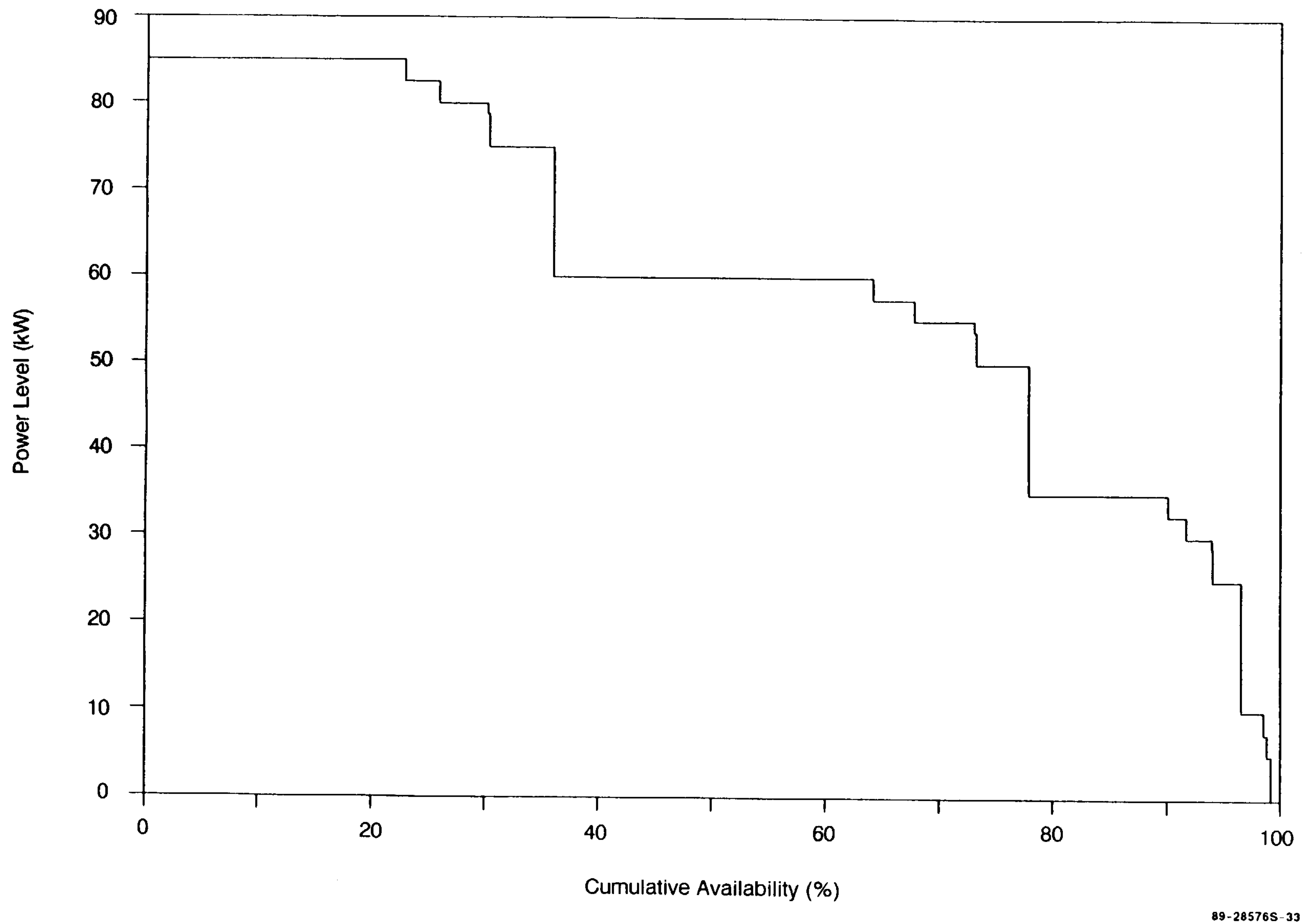


Figure 3-23. 3SD-1PV Module EPS Power Level Versus Cumulative Availability

CHAPTER FOUR

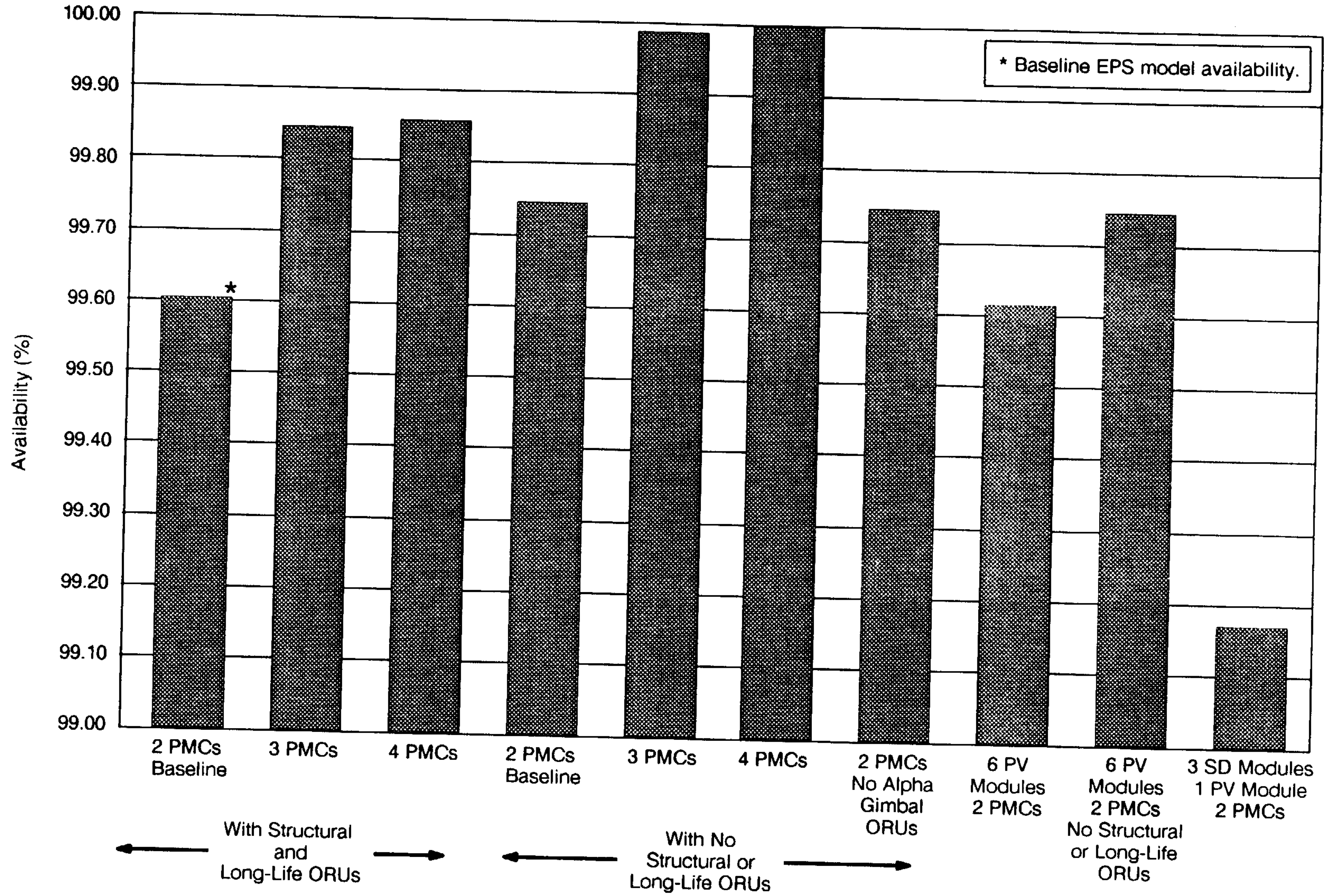
CONCLUSIONS AND RECOMMENDATIONS

Figures 4–1 and 4–2 provide a summary of some of the analysis results of this study. The following conclusions and recommendations can be drawn from the results and discussion of Chapter Three.

4.1 CONCLUSIONS

On the basis of the analysis performed for this study, five major conclusions have been reached:

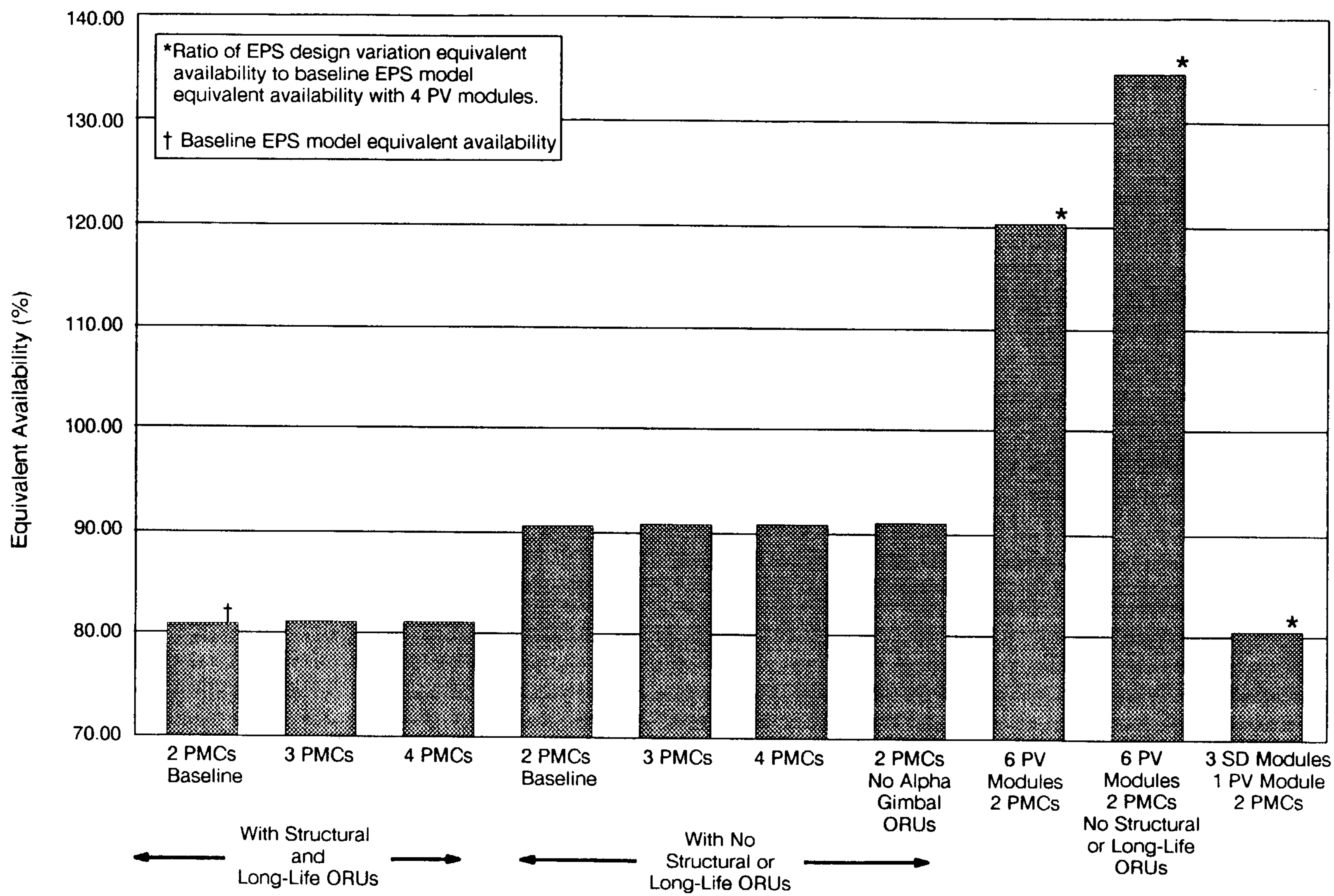
- From a RAM perspective, eight EPS components account for a significant portion of the EPS RAM characteristic changes when the component RAM parameters of these eight components were varied in relation to varying the RAM parameters of all the EPS components modeled. The eight significant (critical) components are the following:
  - Sequential Shunt Unit
  - dc Remote Bus Isolator—25 kW
  - Main Inverter Unit
  - dc Remote Bus Isolator—10 kW
  - Battery Charge Monitor
  - Charge Power Converter
  - Discharge Power Converter
  - Power Management Controller
- An EPS design using photovoltaic modules has better availability characteristics than does an EPS design that is based on solar-dynamic power.
- SD modules can augment the average EPS power capability; however, they contribute more availability at high power output states than at the intermediate or low power states.
- Increasing the level of redundancy in power-producing modules increases the average capability (equivalent availability) of the EPS but has little effect on minimizing the design's probability of reaching a 0% power level due to the dependency of this system on the PMC.
- The level of on-orbit EPS component sparing can change significantly its equivalent availability. Also, the increases in equivalent availability associated with sparing can be achieved



Note: With the exception of batteries and PV blankets, component MDTs are approximately 90 days.

89-28216K-24

Figure 4–1. Availability of EPS Model Variations



Note: With the exception of batteries and PV blankets, component MDTs are approximately 90 days.

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Figure 4–2. Equivalent Availability of EPS Model Variations

with significant savings in mass if only three ORUs are designed to be repairable on-orbit: the dc switching unit, the main bus switching unit, and the battery charge/discharge unit. With these ORUs, only the remote bus isolators and the battery charge/discharge converters and battery monitor need to be replaceable on-orbit.

- The power management controller has a significant effect on EPS availability. Increasing its redundancy by one additional power management controller significantly increases EPS availability.

4.2 RECOMMENDATIONS

On the basis of the results of this analysis and the level of maturity of the EPS design, the following four recommendations are made:

- It is highly recommended that at least three ORUs be designed to be repairable on-orbit. These ORUs are the dc switching unit, ac switching unit, and battery charge/discharge unit. A further recommendation is that these ORUs be sized to permit them to be brought into the pressurized SSF environment for their repair. The components within these ORUs that should be replaceable on-orbit should include dc remote bus isolators, ac remote bus isolators, battery charge/discharge converters, and the battery monitor.

- It is strongly recommended that a second redundant power management controller be added (for a total of three) to increase EPS availability.

- It is recommended that availability analyses of the type documented in this report continue to be used to affect the evolution of the EPS design. Availability is a good program management tool that localizes critical design areas and facilitates a high level of interprogram communication among the designers and the various program elements.

- It is recommended that a reliability-growth effort begin. The data and analyses from such an effort will complement an availability analysis and provide the cost-impact information necessary to support key decisions during the design process and trade-off decisions between reliability, maintainability, and logistic support (intravehicular and extravehicular activity budgets, mass lift costs, and shuttle availability).

APPENDIX A

UNIRAM METHODOLOGY AS APPLIED TO THE ELECTRIC POWER SYSTEM (EPS) AND SUMMARY OF THE INITIAL EPS STUDY

Appendix A provides information on the UNIRAM (unit reliability, availability, and maintainability) methodology. This appendix also provides a summary of the initial Space Station Freedom electric power system (EPS) availability study performed for NASA Lewis Research Center (LeRC) between July 1987 and June 1988. The EPS design and component RAM data used in this analysis differed significantly from the study documented in this report.*

A.1 UNIRAM METHODOLOGY AS APPLIED TO THE EPS

A.1.1 Introduction to UNIRAM

UNIRAM is an IBM PC-based software package with reliability, availability, and maintainability (RAM) modeling techniques to perform system RAM assessments. The UNIRAM software package was developed by ARINC Research Corporation for the Electric Power Research Institute (EPRI) to evaluate the RAM characteristics of electric power generation systems.

Two basic metrics used throughout the initial studies are defined as follows:

- ***Availability (A)***—A measure of the amount of time, within a given period, that a system will generate or deliver power. Another way of stating this is that availability is the probability of producing power at any level.

- ***Equivalent Availability (EA)***—A ratio of the power actually produced or delivered by a system to the power that would have been produced or delivered had there been no system power outages due to component failures or planned system shutdowns.

The EPS RAM assessment was performed using the following steps of the UNIRAM methodology:

- Assess the EPS design baseline for each study

- Model the EPS baseline

- Evaluate the EPS model to determine the baseline system RAM values and component criticality rankings

*The Power System Description Document (SE–02) used in this analysis was dated July 16, 1987. Other design change information was obtained through discussions with LeRC personnel in the course of this study.

- Perform assessments of EPS availability sensitivity to changes in redundancy and changes in sparing of orbital replacement units (ORUs) on-orbit
- Perform assessments of EPS availability sensitivity to changes in ORU reliability

A.1.2 EPS Study Methodology

A.1.2.1 EPS Design Assessment

The basis for each analysis of the EPS was a baseline design provided by NASA LeRC. On the basis of the functional descriptions, subsystem interconnects, and functional dependencies, these baselines were used to develop the EPS availability models required by UNIRAM.

A.1.2.2 Modeling Methodology

The UNIRAM modeling methodology as shown in Figure A–1 follows a five-step process and culminates in a UNIRAM input file, which is then analyzed using the UNIRAM software. The following paragraphs outline the steps in the methodology.

Develop an EPS Availability Block Diagram. The EPS availability block diagram (ABD) represents the system, which shows how ORUs are interconnected from the standpoint of availability. From this standpoint, an ORU does not have to be functionally related to another ORU to have a functional dependence on it. It is this functional dependence that is shown in an ABD and not necessarily the physical connections between ORUs. The blocks within an ABD are the basic subsystems. A basic subsystem is an aggregation of one or more components logically linked together to define how their failures can cause failure of the basic subsystem. A basic subsystem has only two output states: fully operational or failed.

Partition the ABDs Into Basic and Nested Subsystems. Partitioning ABDs into basic and nested subsystems is an iterative process. The process of nesting defines the logical connections of basic and nested subsystems and thus defines the failure states of the system being modeled. The first iteration of ABD partitioning forms nested subsystems from those basic subsystems that are functionally connected in series paths. The end points of these paths are often defined by manifolds (a manifold is a point at which multiple functional paths meet). Manifolding allows multiple levels of operation that are based on failures of subsystems within the functional paths that form that manifold. This iterative process continues until the system is defined by a single nested subsystem.

The basic subsystems are nested together as follows: The parallel redundant basic subsystems are collapsed into nested subsystems (the nested subsystem logically maps a system's functional dependence on its basic subsystems). The resulting series of basic and nested subsystems is then collapsed into larger nested subsystems. Ultimately, a single nested subsystem is formed that represents the full system being modeled.

Develop Fault Trees for Each Basic Subsystem. Each basic subsystem has an associated fault tree that defines the logical framework for the basic subsystem's dependence on individual ORUs for its operation. Figure A–2 illustrates the two basic fault tree types. The *and gate* logically represents the condition where both component A and component B must fail to fail the basic subsystem. However, through the use of an *or gate*, the failure of either component A or component B will cause the basic subsystem to fail.

Obtain ORU RAM Data. This step was performed concurrently with the previous two steps. NASA LeRC personnel supplied estimates of the required ORU reliabilities in the form of ORU

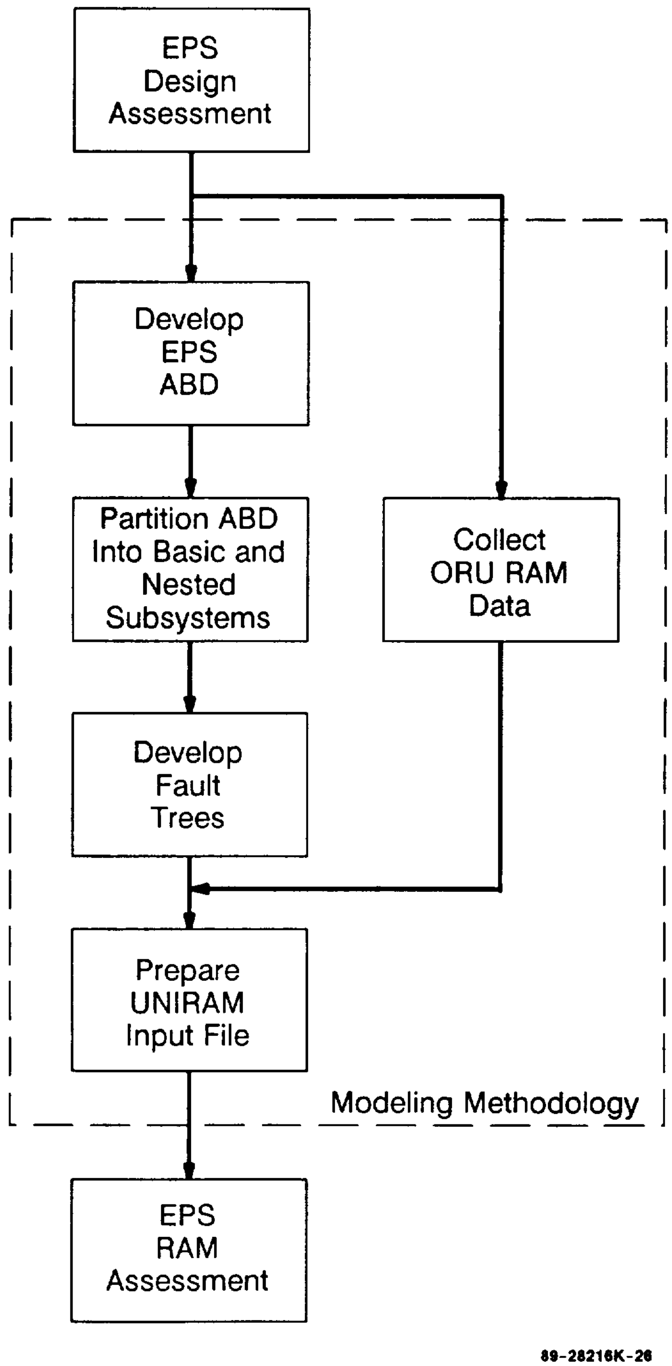

Figure A–1. UNIRAM Methodology as Applied to the EPS

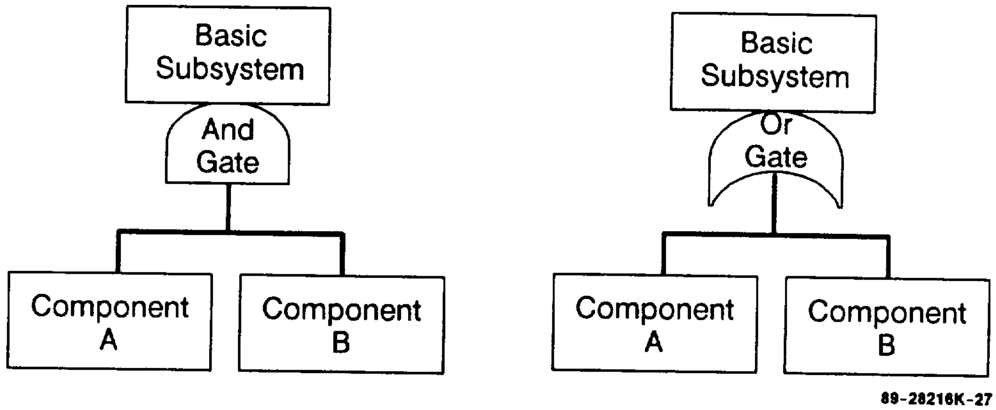

Figure A–2. Fault Tree Example

estimates of mean time between failures (MTBF). Mean time to repair (MTTR) values were defined to take into account logistic considerations and on-orbit repair time.

Prepare UNIRAM Input Files. The UNIRAM input files are prepared to include the total system capacity, the number of hours per year the system will be shut down (zero hours in the EPS models), and the number of basic subsystem definitions to follow. The basic subsystem definition incorporates the ORU definitions, the fault tree logic, and the capacity of the basic subsystem. The ORU definitions contain the ORU MTBF and MTTR data. Another data entry for each component is the time, in hours, that the basic component subsystem can function after the component has failed. This surge capability was used for the beta positioning ORUs to show that loss of these components is not significant until a given period of time has passed. The surge time increases the effective MTBF value of the basic subsystem. The nested subsystem definitions follow those of the basic subsystem to form the UNIRAM model input file.

A.1.2.3 Evaluate the EPS Model to Determine the Baseline EPS RAM Data and Component Criticality Rankings

The UNIRAM software was used to perform baseline analyses of each of the EPS system models. The analyses included system availabilities and equivalent availabilities; system output power levels (states) and their associated state probabilities; and ORU criticality ranking, which ranks ORUs by their effect on system equivalent availability if they were "perfectly" available. Other analyses to determine the effects of ORU MTBF and MTTR variation on a given system model were performed, using the EPS models.

A.1.2.4 Perform Assessments of EPS Availability Sensitivity to Changes in Redundancy and Sparing ORUs On-Orbit

The redundancy sensitivity analyses determined the effects of increasing redundancy in selected areas. The sparing sensitivity analyses determined the effects on the system of sparing ORUs either on-ground or on-orbit.

A.1.2.5 Perform Assessments of EPS Availability Sensitivity to Changes in ORU Reliability

The reliability and reliability sensitivity analyses performed on each of the models were similar to the sparing sensitivity analyses. However, instead of using a single change in ORU reliabilities, the ORU MTBFs were scaled individually and universally over a range of 0.4 to 3.0 times their baseline MTBF values.

A.2 SUMMARY OF THE INITIAL STUDY

An initial study of EPS availability was conducted on the EPS configuration shown in Figure 1-1. The data in this appendix summarize that initial study. Using the completed analyses of each of the initial system models, the power generation system results were combined with the power distribution system results. The combination provided an indication of the RAM performance of the EPS from each of the power generation systems to a load in the power management and distribution (PMAD) system. The insolar, eclipse without charge effects, and eclipse with charge effects baseline output states were combined with those of PMAD. Each combination resulted in a range of system output states through a power distribution control assembly (PDCA). In each combination, three analysis scenarios were used: (1) all ORU MTTRs equal 1,080 hours, (2) all ORUs are spared on-orbit, and (3) only eight critical ORUs are spared on orbit. In every case, the effect on the ability to supply 25 kW of load from a PMAD PDCA was evaluated.

Table A–1 lists the equivalent availabilities and the availabilities for the system variations considered in the initial study. The system variations are listed in order of descending system equivalent availability. The equivalent availability change among the system variations is large (a maximum difference of 13.99%), and the availability change among the system variations is small (a maximum difference of 0.08%). As expected, EPS equivalent availability is sensitive to both ORU reliability and maintainability.

EPS Power Management and Distribution System. The initial RAM assessment showed that there is little or no difference between PDCAs when considering the availability of power from any given PDCA in the PMAD system. The baseline availability of the PMAD system is 99.98%, but ORU on-orbit sparing and reliability changes increased the availability to greater than 99.99%. Because there are 28 PDCUs in the manned core, the only PMAD ORU considered viable as a potential on-orbit spare was the PDCU.

An analysis of the inner keel power distribution system was also performed. The availability of power from an inner keel PDCU was 97.90% when ORU MTTRs were 1,080 hours. When a PDCU was spared on-orbit, the availability of power from a PDCU on the inner keel increased to 99.99%.

EPS Integrated System. Table A–2 presents the equivalent availabilities for the initial EPS integrated system analyses. Because the PMAD system was modeled as delivering power to a perfectly available 25-kW load (33.33% of 75 kW, which is the total system capacity), the equivalent availability data are on a scale of 33.33%. EPS integrated system analyses were also performed for sparing only the eight critical ORUs on-orbit. The results of these analyses were the same as the results for sparing all ORUs on-orbit (MTTR = 6).

There were 418 ORUs used to model the EPS. The expected average annual failure rate under steady-state conditions is 35 ORUs per year.

Table A-1. Synopsis of EPS ORU Sparing and Reliability Sensitivity Analysis

Variation to System	Equivalent Availability (%)	Availability (%)
Insolar		
Spare All ORUs	99.77	>99.99
Double All ORU MTBFs and Spare Eight Critical ORUs	98.08	>99.99
Increase All ORU MTBFs by Factor of Five	97.78	>99.99
Spare Eight Critical ORUs	96.20	>99.99
Increase Eight Critical ORU MTBFs by Factor of Five	95.83	>99.99
Double All ORU MTBFs	94.53	99.98
Double Eight Critical ORU MTBFs	93.74	99.98
Baseline System Results	89.35	99.92
Eclipse Without Charge Effects		
Spare All ORUs	99.94	>99.99
Double All ORU MTBFs and Spare Eight Critical ORUs	98.49	>99.99
Increase All ORU MTBFs by Factor of Five	97.86	>99.99
Spare Eight Critical ORUs	96.96	>99.99
Increase Eight Critical ORU MTBFs by Factor of Five	95.48	>99.99
Double All ORU MTBFs	94.70	99.98
Double Eight Critical ORU MTBFs	93.23	99.98
Baseline System Results	89.58	99.92
Eclipse with Charge Effects		
Spare All ORUs	99.85	>99.99
Double All ORU MTBFs and Spare Eight Critical ORUs	96.24	>99.99
Increase All ORU MTBFs by Factor of Five	94.69	>99.99
Spare Eight Critical ORUs	92.55	>99.99
Increase Eight Critical ORU MTBFs by Factor of Five	89.04	>99.99
Double All ORU MTBFs	87.22	99.98
Double Eight Critical ORU MTBFs	83.89	99.98
Baseline System Results	75.96	99.92

Table A-2. EPS Integrated System Results

System Combination	Equivalent Availability (%)	
	MTTR = 1,080	MTTR = 6
PMAD and Insolar	33.29	33.33
PMAD and Eclipse (No Charge Effects)	33.29	33.33
PMAD and Eclipse	33.25	33.33

APPENDIX B

ELECTRIC POWER SYSTEM ANALYSIS DATA

This appendix contains the detailed data resulting from the Electric Power System (EPS) analysis. Table B–1 provides all model analysis availability and equivalent availability results excluding the sparing analysis results. Table B–2 provides the resulting EPS availability and equivalent availability data stemming from the mean time between failures (MTBF) sensitivity analysis of the baseline EPS model. Table B–3 is similar to Table B–2, but is for the baseline EPS model without structural or long-life components. The various criticality ranking, tabular results are listed in Tables B–4 through B–8. Tables B–9 through B–11 provide the various EPS model availability and cumulative availability results for the discrete power levels each model had because of component failures.

Table B-1. EPS Model Availability and Equivalent Availability Results

Analysis Case	Equivalent Availability (%)	Availability (%)
Baseline EPS Model	80.9260	99.6032
Baseline, no structural or long-life components	90.5829	99.7451
Baseline, no structural or long-life or alpha gimbal ORUs	91.0729	99.7451
Baseline using component mean replacement intervals (MRIs)	75.9064	99.2344
Baseline, no structural or long-life components using component MRIs	85.2670	99.3852
Baseline with three power management controllers (PMCs)	81.1223	99.8447
Baseline, no structural or long-life components, with three PMCs	90.8020	99.9871
Baseline with four PMCs	81.1322	99.8569
Baseline, no structural or long-life components, with four PMCs	90.8131	99.9993
6PV module EPS design*	120.4988 †	99.6147
6PV module EPS design, no structural or long-life components	135.2551 †	99.7452
3SD–1PV module EPS design*	80.5240	99.1707
Baseline with power generation components	32.0875	99.5972

* PV = photovoltaic
SD = solar dynamic
† Ratio of EPS design variation equivalent availability to baseline EPS model equivalent availability with four PV modules.

Table B-2. Effect of Component MTBF Scaling on Baseline Model EPS Equivalent Availability and Availability

Legend:

Equivalent Availability (%)
Availability (%)

EPS Component	Component Baseline MTBF (h)	MTBF Scaling Factor														
		0.4	0.6	0.8	1.0	1.2	1.4	1.6	1.8	2.0	2.2	2.4	2.6	2.8	3.0	3.2
PVBBC	131,400	80.9076	80.9178	80.9230	80.9260	80.9281	80.9296	80.9306	80.9315	80.9322	80.9327	80.9332	80.9336	80.9340	80.9342	80.9345
		99.6031	99.6032	99.6032	99.6032	99.6032	99.6032	99.6031	99.6031	99.6031	99.6031	99.6032	99.6031	99.6032	99.6031	99.6031
DMC	131,400	79.0080	80.0623	80.6000	80.9260	81.1448	81.3019	81.4200	81.5122	81.5860	81.6465	81.6971	81.7398	81.7765	81.8084	81.8363
		99.6010	99.6023	99.6029	99.6032	99.6033	99.6034	99.6036	99.6037	99.6037	99.6037	99.6037	99.6038	99.6038	99.6039	99.6039
PVCE	87,600	80.9091	80.9216	80.9248	80.9260	80.9266	80.9268	80.9270	80.9271	80.9272	80.9272	80.9272	80.9272	80.9272	80.9273	80.9273
		99.6031	99.6031	99.6031	99.6032	99.6032	99.6032	99.6032	99.6032	99.6032	99.6032	99.6032	99.6032	99.6032	99.6032	99.6032
SSUC	87,600	78.1113	79.6507	80.4431	80.9260	81.2512	81.4851	81.6614	81.7990	81.9094	82.0000	82.0757	82.1398	82.1948	82.2425	82.2844
		99.5997	99.6019	99.6027	99.6032	99.6034	99.6036	99.6037	99.6038	99.6039	99.6040	99.6040	99.6041	99.6041	99.6041	99.6042
BGRRC	262,800	79.9485	80.4887	80.7615	80.9260	81.0361	81.1149	81.1741	81.2202	81.2572	81.2874	81.3126	81.3340	81.3523	81.3682	81.3820
		99.6022	99.6027	99.6030	99.6032	99.6033	99.6033	99.6034	99.6034	99.6034	99.6035	99.6035	99.6035	99.6036	99.6036	99.6035
BGTS	262,800	79.9472	80.4881	80.7612	80.9260	81.0362	81.1152	81.1744	81.2206	81.2576	81.2879	81.3131	81.3345	81.3528	81.3688	81.3827
		99.6022	99.6027	99.6030	99.6032	99.6032	99.6033	99.6034	99.6034	99.6034	99.6034	99.6035	99.6035	99.6035	99.6035	99.6035
UPC	350,400	78.7848	79.9635	80.5629	80.9260	81.1695	81.3440	81.4754	81.5777	81.6597	81.7270	81.7830	81.8305	81.8713	81.9066	81.9376
		99.5197	99.5682	99.5905	99.6032	99.6113	99.6170	99.6212	99.6244	99.6270	99.6290	99.6307	99.6322	99.6334	99.6344	99.6354
Condenser	876,000	80.4470	80.7125	80.8458	80.9260	80.9795	81.0178	81.0466	81.0689	81.0868	81.1015	81.1137	81.1240	81.1329	81.1406	81.1473
		99.5719	99.5896	99.5981	99.6032	99.6064	99.6087	99.6105	99.6118	99.6129	99.6138	99.6145	99.6151	99.6157	99.6162	99.6165
TCAIP	262,800	80.8539	80.8986	80.9166	80.9260	80.9317	80.9354	80.9380	80.9400	80.9415	80.9427	80.9437	80.9445	80.9451	80.9457	80.9462
		99.5986	99.6015	99.6026	99.6032	99.6035	99.6037	99.6039	99.6040	99.6041	99.6042	99.6043	99.6043	99.6043	99.6044	99.6044
TCAP	280,320	80.8594	80.9005	80.9173	80.9260	80.9313	80.9349	80.9374	80.9393	80.9407	80.9418	80.9428	80.9435	80.9441	80.9447	80.9452
		99.5990	99.6016	99.6026	99.6032	99.6035	99.6037	99.6039	99.6040	99.6041	99.6041	99.6042	99.6042	99.6043	99.6043	99.6043
CMSC	262,800	79.3603	80.2234	80.6612	80.9260	81.1034	81.2305	81.3261	81.4006	81.4602	81.5091	81.5499	81.5844	81.6140	81.6397	81.6622
		99.4892	99.5562	99.5863	99.6032	99.6139	99.6213	99.6268	99.6309	99.6342	99.6369	99.6391	99.6409	99.6424	99.6438	99.6450
PVRADC	99,999,999	80.9260	80.9260	80.9260	80.9260	80.9260	80.9260	80.9260	80.9260	80.9260	80.9260	80.9260	80.9260	80.9260	80.9260	80.9260
		99.6032	99.6032	99.6032	99.6032	99.6032	99.6032	99.6032	99.6032	99.6032	99.6032	99.6032	99.6032	99.6032	99.6032	99.6032

(continued)

Table B–2 (continued)

Legend:

Equivalent Availability (%)
Availability (%)

EPS Component	Component Baseline MTBF (h)	MTBF Scaling Factor														
		0.4	0.6	0.8	1.0	1.2	1.4	1.6	1.8	2.0	2.2	2.4	2.6	2.8	3.0	3.2
IEATS	262,800	79.8765	80.4562	80.7492	80.9260	81.0444	81.1291	81.1927	81.2423	81.2820	81.3145	81.3416	81.3646	81.3843	81.4014	81.4163
		99.5942	99.5995	99.6018	99.6032	99.6040	99.6045	99.6051	99.6054	99.6056	99.6058	99.6060	99.6061	99.6063	99.6063	99.6064
IEAS	262,800	79.8765	80.4562	80.7492	80.9260	81.0444	81.1291	81.1927	81.2423	81.2820	81.3145	81.3416	81.3646	81.3843	81.4014	81.4163
		99.5942	99.5995	99.6018	99.6032	99.6040	99.6045	99.6051	99.6054	99.6056	99.6058	99.6060	99.6061	99.6063	99.6063	99.6064
PVCS	262,800	79.8738	80.4550	80.7487	80.9260	81.0447	81.1296	81.1934	81.2431	81.2829	81.3155	81.3427	81.3657	81.3854	81.4026	81.4176
		99.5941	99.5995	99.6018	99.6032	99.6041	99.6045	99.6050	99.6054	99.6056	99.6058	99.6060	99.6061	99.6063	99.6064	99.6065
PVC	43,800	80.0199	80.5967	80.8182	80.9260	80.9865	81.0237	81.0483	81.0654	81.0777	81.0870	81.0940	81.0994	81.1039	81.1074	81.1104
		99.5956	99.6006	99.6024	99.6032	99.6036	99.6038	99.6040	99.6042	99.6043	99.6043	99.6044	99.6044	99.6044	99.6045	99.6045
DCRBI10KW	262,800	79.9895	80.5071	80.7684	80.9260	81.0314	81.1069	81.1635	81.2077	81.2430	81.2719	81.2961	81.3165	81.3340	81.3492	81.3625
		99.6031	99.6031	99.6032	99.6032	99.6031	99.6032	99.6031	99.6031	99.6032	99.6031	99.6032	99.6032	99.6031	99.6031	99.6031
DCRBI25KW	262,800	78.9670	80.0467	80.5946	80.9260	81.1480	81.3072	81.4268	81.5200	81.5947	81.6559	81.7069	81.7501	81.7872	81.8193	81.8475
		99.6022	99.6028	99.6030	99.6032	99.6032	99.6032	99.6032	99.6032	99.6033	99.6033	99.6033	99.6033	99.6033	99.6033	99.6033
BATMON	262,800	79.9895	80.5071	80.7684	80.9260	81.0314	81.1069	81.1636	81.2077	81.2430	81.2719	81.2961	81.3165	81.3340	81.3492	81.3625
		99.6031	99.6031	99.6032	99.6032	99.6031	99.6032	99.6031	99.6031	99.6032	99.6031	99.6032	99.6032	99.6031	99.6031	99.6031
CPC	262,800	79.9895	80.5071	80.7684	80.9260	81.0314	81.1069	81.1636	81.2077	81.2430	81.2719	81.2961	81.3165	81.3340	81.3492	81.3625
		99.6031	99.6031	99.6032	99.6032	99.6031	99.6032	99.6031	99.6031	99.6032	99.6031	99.6032	99.6032	99.6031	99.6031	99.6031
DPC	262,800	79.9895	80.5071	80.7684	80.9260	81.0314	81.1069	81.1636	81.2077	81.2430	81.2719	81.2961	81.3165	81.3340	81.3492	81.3625
		99.6031	99.6031	99.6032	99.6032	99.6031	99.6032	99.6031	99.6031	99.6032	99.6031	99.6032	99.6032	99.6031	99.6031	99.6031
Battery	613,200	80.8839	80.9073	80.9190	80.9260	80.9307	80.9341	80.9366	80.9385	80.9401	80.9414	80.9424	80.9433	80.9441	80.9448	80.9453
		99.6031	99.6032	99.6032	99.6032	99.6031	99.6032	99.6032	99.6031	99.6031	99.6032	99.6031	99.6031	99.6031	99.6031	99.6031
MIUC	87,600	79.8117	80.4386	80.7448	80.9260	81.0457	81.1305	81.1938	81.2429	81.2820	81.3139	81.3405	81.3628	81.3820	81.3986	81.4131
		99.6009	99.6024	99.6029	99.6032	99.6033	99.6034	99.6034	99.6035	99.6036	99.6036	99.6036	99.6036	99.6036	99.6036	99.6036
OPDCU	87,600	80.6657	80.8345	80.8966	80.9260	80.9423	80.9522	80.9587	80.9632	80.9664	80.9688	80.9706	80.9721	80.9732	80.9741	80.9749
		99.5789	99.5948	99.6005	99.6032	99.6046	99.6055	99.6061	99.6065	99.6067	99.6070	99.6071	99.6072	99.6073	99.6074	99.6075

(continued)

Table B–2 (continued)

Legend:

Equivalent Availability (%)
Availability (%)

EPS Component	Component Baseline MTBF (h)	MTBF Scaling Factor 0.4	0.6	0.8	1.0	1.2	1.4	1.6	1.8	2.0	2.2	2.4	2.6	2.8	3.0	3.2
AGRRC	262,800	79.8727	80.4544	80.7485	80.9260	81.0448	81.1299	81.1937	81.2435	81.2834	81.3160	81.3432	81.3662	81.3860	81.4031	81.4182
		99.4932	99.5578	99.5868	99.6032	99.6136	99.6208	99.6261	99.6302	99.6333	99.6359	99.6380	99.6398	99.6413	99.6426	99.6438
AGB	131,400	80.3731	80.6768	80.8319	80.9260	80.9892	81.0347	81.0688	81.0955	81.1168	81.1343	81.1489	81.1613	81.1720	81.1812	81.1892
		99.6032	99.6031	99.6032	99.6032	99.6031	99.6031	99.6031	99.6031	99.6031	99.6031	99.6032	99.6031	99.6031	99.6031	99.6031
AGM	87,600	80.8562	80.9014	80.9181	80.9260	80.9304	80.9331	80.9348	80.9360	80.9368	80.9375	80.9380	80.9383	80.9386	80.9389	80.9391
		99.6032	99.6031	99.6032	99.6032	99.6032	99.6031	99.6031	99.6031	99.6031	99.6032	99.6032	99.6032	99.6032	99.6031	99.6031
AGTS	262,800	79.8714	80.4538	80.7483	80.9260	81.0449	81.1301	81.1941	81.2439	81.2838	81.3165	81.3438	81.3668	81.3866	81.4038	81.4188
		99.4931	99.5577	99.5868	99.6032	99.6136	99.6208	99.6262	99.6302	99.6334	99.6359	99.6381	99.6398	99.6414	99.6427	99.6438
PMC	43,800	80.0162	80.5952	80.8177	80.9260	80.9867	81.0241	81.0489	81.0660	81.0784	81.0876	81.0947	81.1002	81.1046	81.1082	81.1111
		98.4833	99.1960	99.4699	99.6032	99.6779	99.7239	99.7543	99.7754	99.7906	99.8020	99.8107	99.8175	99.8229	99.8273	99.8309
ACRBI25KW	262,800	80.9203	80.9245	80.9256	80.9260	80.9262	80.9263	80.9263	80.9263	80.9264	80.9264	80.9264	80.9264	80.9264	80.9264	80.9264
		99.6031	99.6032	99.6031	99.6032	99.6032	99.6031	99.6032	99.6032	99.6032	99.6032	99.6032	99.6032	99.6032	99.6032	99.6032
Eight Critical		71.2787	76.4652	79.2190	80.9260	82.0876	82.9291	83.5667	84.0666	84.4689	84.7998	85.0767	85.3118	85.5139	85.6895	85.8435
Components		98.4760	99.1935	99.4690	99.6032	99.6783	99.7247	99.7553	99.7765	99.7920	99.8034	99.8121	99.8190	99.8245	99.8290	99.8326
All		59.3193	70.4347	76.8062	80.9260	83.8059	85.9315	87.5644	88.8581	89.9081	90.7775	91.5089	92.1330	92.6716	93.1412	93.5543
Components		97.5642	98.9117	99.3835	99.6032	99.7231	99.7958	99.8432	99.8758	99.8992	99.9166	99.9298	99.9401	99.9483	99.9549	99.9604

Table B-3. Effect of Component MTBF Scaling on Baseline EPS Model—With No Structural or Long-Life ORUs

Legend:

Equivalent Availability (%)
Availability (%)

EPS Component	Component Baseline MTBF (h)	MTBF Scaling Factor 0.4	0.6	0.8	1.0	1.2	1.4	1.6	1.8	2.0	2.2	2.4	2.6	2.8	3.0	3.2
PVBBC	131,400	90.5611	90.5728	90.5786	90.5822	90.5845	90.5861	90.5874	90.5884	90.5891	90.5899	90.5904	90.5908	90.5912	90.5916	90.5918
		99.7451	99.7451	99.7451	99.7451	99.7451	99.7451	99.7451	99.7451	99.7451	99.7451	99.7452	99.7451	99.7452	99.7451	99.7451
DMC	131,400	90.5822	90.5822	90.5822	90.5822	90.5822	90.5822	90.5822	90.5822	90.5822	90.5822	90.5822	90.5822	90.5822	90.5822	90.5822
		99.7451	99.7451	99.7451	99.7451	99.7451	99.7451	99.7451	99.7451	99.7451	99.7451	99.7451	99.7451	99.7451	99.7451	99.7451
PVCE	87,600	90.5631	90.5772	90.5808	90.5822	90.5828	90.5831	90.5832	90.5834	90.5834	90.5835	90.5835	90.5835	90.5835	90.5835	90.5836
		99.7451	99.7452	99.7451	99.7451	99.7451	99.7451	99.7451	99.7451	99.7451	99.7451	99.7451	99.7451	99.7451	99.7451	99.7451
SSUC	87,600	87.4153	89.1470	90.0386	90.5822	90.9481	91.2113	91.4097	91.5646	91.6889	91.7908	91.8760	91.9481	92.0100	92.0638	92.1108
		99.7451	99.7452	99.7451	99.7451	99.7451	99.7452	99.7451	99.7451	99.7451	99.7451	99.7451	99.7452	99.7451	99.7451	99.7451
BGRRC	262,800	90.5822	90.5822	90.5822	90.5822	90.5822	90.5822	90.5822	90.5822	90.5822	90.5822	90.5822	90.5822	90.5822	90.5822	90.5822
		99.7451	99.7451	99.7451	99.7451	99.7451	99.7451	99.7451	99.7451	99.7451	99.7451	99.7451	99.7451	99.7451	99.7451	99.7451
BGTS	262,800	90.5822	90.5822	90.5822	90.5822	90.5822	90.5822	90.5822	90.5822	90.5822	90.5822	90.5822	90.5822	90.5822	90.5822	90.5822
		99.7451	99.7451	99.7451	99.7451	99.7451	99.7451	99.7451	99.7451	99.7451	99.7451	99.7451	99.7451	99.7451	99.7451	99.7451
UPC	350,400	90.5822	90.5822	90.5822	90.5822	90.5822	90.5822	90.5822	90.5822	90.5822	90.5822	90.5822	90.5822	90.5822	90.5822	90.5822
		99.7451	99.7451	99.7451	99.7451	99.7451	99.7451	99.7451	99.7451	99.7451	99.7451	99.7451	99.7451	99.7451	99.7451	99.7451
Condensor	876,000	90.5822	90.5822	90.5822	90.5822	90.5822	90.5822	90.5822	90.5822	90.5822	90.5822	90.5822	90.5822	90.5822	90.5822	90.5822
		99.7451	99.7451	99.7451	99.7451	99.7451	99.7451	99.7451	99.7451	99.7451	99.7451	99.7451	99.7451	99.7451	99.7451	99.7451
TCAIP	262,800	90.5822	90.5822	90.5822	90.5822	90.5822	90.5822	90.5822	90.5822	90.5822	90.5822	90.5822	90.5822	90.5822	90.5822	90.5822
		99.7451	99.7451	99.7451	99.7451	99.7451	99.7451	99.7451	99.7451	99.7451	99.7451	99.7451	99.7451	99.7451	99.7451	99.7451
TCAP	280,320	90.5822	90.5822	90.5822	90.5822	90.5822	90.5822	90.5822	90.5822	90.5822	90.5822	90.5822	90.5822	90.5822	90.5822	90.5822
		99.7451	99.7451	99.7451	99.7451	99.7451	99.7451	99.7451	99.7451	99.7451	99.7451	99.7451	99.7451	99.7451	99.7451	99.7451
CMSC	262,800	90.5822	90.5822	90.5822	90.5822	90.5822	90.5822	90.5822	90.5822	90.5822	90.5822	90.5822	90.5822	90.5822	90.5822	90.5822
		99.7451	99.7451	99.7451	99.7451	99.7451	99.7451	99.7451	99.7451	99.7451	99.7451	99.7451	99.7451	99.7451	99.7451	99.7451
PVRADC	9,999,9999	90.5822	90.5822	90.5822	90.5822	90.5822	90.5822	90.5822	90.5822	90.5822	90.5822	90.5822	90.5822	90.5822	90.5822	90.5822
		99.7451	99.7451	99.7451	99.7451	99.7451	99.7451	99.7451	99.7451	99.7451	99.7451	99.7451	99.7451	99.7451	99.7451	99.7451

(continued)

Table B–3 (continued)

Legend:

Equivalent Availability (%)
Availability (%)

EPS Component	Component Baseline MTBF (h)	MTBF Scaling Factor 0.4	0.6	0.8	1.0	1.2	1.4	1.6	1.8	2.0	2.2	2.4	2.6	2.8	3.0	3.2
IEATS	262,800	90.5822	90.5822	90.5822	90.5822	90.5822	90.5822	90.5822	90.5822	90.5822	90.5822	90.5822	90.5822	90.5822	90.5822	90.5822
		99.7451	99.7451	99.7451	99.7451	99.7451	99.7451	99.7451	99.7451	99.7451	99.7451	99.7451	99.7451	99.7451	99.7451	99.7451
IEAS	262,800	90.5822	90.5822	90.5822	90.5822	90.5822	90.5822	90.5822	90.5822	90.5822	90.5822	90.5822	90.5822	90.5822	90.5822	90.5822
		99.7451	99.7451	99.7451	99.7451	99.7451	99.7451	99.7451	99.7451	99.7451	99.7451	99.7451	99.7451	99.7451	99.7451	99.7451
PVCS	262,800	90.5822	90.5822	90.5822	90.5822	90.5822	90.5822	90.5822	90.5822	90.5822	90.5822	90.5822	90.5822	90.5822	90.5822	90.5822
		99.7451	99.7451	99.7451	99.7451	99.7451	99.7451	99:7451	99.7451	99.7451	99.7451	99.7451	99.7451	99.7451	99.7451	99.7451
PVC	43,800	89.5686	90.2137	90.4615	90.5822	90.6498	90.6915	90.7189	90.7381	90.7518	90.7621	90.7700	90.7761	90.7811	90.7850	90.7883
		99.7451	99.7451	99.7451	99.7451	99.7452	99.7451	99.7451	99.7452	99.7451	99.7452	99.7452	99.7451	99.7452	99.7451	99.7452
DCRBI10KWC	262,800	89.4875	90.0924	90.3979	90.5822	90.7054	90.7936	90.8599	90.9115	90.9529	90.9867	91.0149	91.0388	91.0593	91.0770	91.0926
		99.7451	99.7452	99.7452	99.7451	99.7451	99.7452	99.7451	99.7451	99.7451	99.7451	99.7451	99.7451	99.7451	99.7451	99.7451
DCRBI25KWC	262,800	88.3299	89.5709	90.2010	90.5822	90.8376	91.0207	91.1583	91.2657	91.3516	91.4221	91.4808	91.5306	91.5732	91.6102	91.6426
		99.7451	99.7452	99.7452	99.7451	99.7451	99.7451	99.7452	99.7452	99.7451	99.7451	99.7451	99.7452	99.7451	99.7451	99.7451
BATMON	262,800	89.4875	90.0924	90.3979	90.5822	90.7054	90.7936	90.8599	90.9115	90.9529	90.9867	91.0149	91.0387	91.0593	91.0770	91.0926
		99.7451	99.7452	99.7451	99.7451	99.7451	99.7451	99.7452	99.7451	99.7451	99.7451	99.7451	99.7451	99.7451	99.7451	99.7451
CPC	262,800	89.4875	90.0924	90.3979	90.5822	90.7054	90.7936	90.8599	90.9115	90.9529	90.9867	91.0149	91.0387	91.0593	91.0770	91.0926
		99.7451	99.7452	99.7451	99.7451	99.7451	99.7451	99.7452	99.7451	99.7451	99.7451	99.7451	99.7451	99.7451	99.7451	99.7451
DPC	262,800	89.4875	90.0924	90.3979	90.5822	90.7054	90.7936	90.8599	90.9115	90.9529	90.9867	91.0149	91.0387	91.0593	91.0770	91.0926
		99.7451	99.7452	99.7451	99.7451	99.7451	99.7451	99.7452	99.7451	99.7451	99.7451	99.7451	99.7451	99.7451	99.7451	99.7451
Battery	6,1320	90.5328	90.5602	90.5739	90.5822	90.5876	90.5915	90.5945	90.5968	90.5986	90.6001	90.6013	90.6024	90.6033	90.6041	90.6048
		99.7451	99.7452	99.7451	99.7451	99.7451	99.7451	99.7451	99.7451	99.7451	99.7451	99.7451	99.7451	99.7451	99.7451	99.7451
MIUC	87,600	89.2965	90.0187	90.3725	90.5822	90.7207	90.8191	90.8925	90.9495	90.9948	91.0319	91.0627	91.0887	91.1110	91.1302	91.1471
		99.7451	99.7451	99.7451	99.7451	99.7451	99.7451	99.7451	99.7451	99.7451	99.7451	99.7451	99.7452	99.7451	99.7451	99.7452
OPDCU	87,600	90.2907	90.4797	90.5492	90.5822	90.6004	90.6115	90.6188	90.6238	90.6274	90.6301	90.6321	90.6337	90.6350	90.6360	90.6369
		99.7436	99.7448	99.7450	99.7451	99.7452	99.7451	99.7451	99.7452	99.7452	99.7452	99.7451	99.7452	99.7452	99.7451	99.7452

(continued)

Table B-3 (continued)

Legend:

Equivalent Availability (%)
Availability (%)

EPS Component	Component Baseline MTBF (h)	MTBF Scaling Factor 0.4	0.6	0.8	1.0	1.2	1.4	1.6	1.8	2.0	2.2	2.4	2.6	2.8	3.0	3.2
AGRRC	262,800	90.5822	90.5822	90.5822	90.5822	90.5822	90.5822	90.5822	90.5822	90.5822	90.5822	90.5822	90.5822	90.5822	90.5822	90.5822
		99.7451	99.7451	99.7451	99.7451	99.7451	99.7451	99.7451	99.7451	99.7451	99.7451	99.7451	99.7451	99.7451	99.7451	99.7451
AGB	131,400	89.8824	90.2667	90.4630	90.5822	90.6622	90.7196	90.7629	90.7966	90.8236	90.8458	90.8643	90.8800	90.8934	90.9051	90.9153
		99.7451	99.7451	99.7451	99.7451	99.7451	99.7451	99.7451	99.7451	99.7451	99.7451	99.7451	99.7451	99.7451	99.7451	99.7451
AGM	87,600	90.4938	90.5511	90.5721	90.5822	90.5877	90.5910	90.5932	90.5947	90.5958	90.5967	90.5973	90.5978	90.5981	90.5984	90.5987
		99.7451	99.7451	99.7451	99.7451	99.7451	99.7451	99.7451	99.7451	99.7451	99.7451	99.7451	99.7451	99.7451	99.7451	99.7451
AGTS	262,800	90.5822	90.5822	90.5822	90.5822	90.5822	90.5822	90.5822	90.5822	90.5822	90.5822	90.5822	90.5822	90.5822	90.5822	90.5822
		99.7451	99.7451	99.7451	99.7451	99.7451	99.7451	99.7451	99.7451	99.7451	99.7451	99.7451	99.7451	99.7451	99.7451	99.7451
PMC	43,800	89.5638	90.2119	90.4609	90.5822	90.6501	90.6920	90.7197	90.7388	90.7527	90.7630	90.7709	90.7771	90.7820	90.7860	90.7893
		98.6237	99.3375	99.6116	99.7451	99.8200	99.8661	99.8965	99.9176	99.9329	99.9442	99.9530	99.9598	99.9652	99.9696	99.9732
ACRBI25KWC	262,800	90.5749	90.5803	90.5817	90.5822	90.5824	90.5825	90.5826	90.5826	90.5826	90.5826	90.5826	90.5826	90.5827	90.5827	90.5827
		99.7451	99.7451	99.7451	99.7451	99.7451	99.7451	99.7451	99.7451	99.7451	99.7451	99.7451	99.7451	99.7451	99.7451	99.7451
Eight Critical Components		79.5463	85.4666	88.6220	90.5822	91.9178	92.8864	93.6209	94.1970	94.6610	95.0427	95.3622	95.6335	95.8669	96.0697	96.2475
		98.6236	99.3375	99.6116	99.7451	99.8200	99.8661	99.8966	99.9177	99.9329	99.9443	99.9530	99.9598	99.9652	99.9697	99.9732
All Components		77.8188	84.7017	88.3383	90.5822	92.1034	93.2022	94.0330	94.6829	95.2052	95.6342	95.9927	96.2969	96.5581	96.7849	96.9837
		98.6218	99.3372	99.6116	99.7451	99.8200	99.8662	99.8966	99.9177	99.9329	99.9443	99.9530	99.9599	99.9653	99.9697	99.9733

Table B–4. Baseline EPS Model Component Criticality Ranking

Component	Criticality Ranking Factor
Sequential Shunt Unit	1.9907
Utility Plate	1.4777
dc Remote Bus Isolator—25 kW	1.3452
Deployable Mast	1.3307
Condenser Mounting Strut	1.0747
Alpha Gimbal Transition Structure	0.7187
Alpha Gimbal Roll Ring	0.7177
Photovoltaic Cable Set	0.7169
Integrated Equipment Assembly Transition Structure	0.7151
Integrated Equipment Assembly Structure	0.7151
Main Inverter Unit	0.6658
Beta Gimbal Transition Structure	0.6649
Beta Gimbal Roll Ring	0.6649
dc Remote Bus Isolator—10 kW	0.6363
Battery Monitor	0.6363
Charge Power Converter	0.6363
Discharge Power Converter	0.6363
Alpha Gimbal Bearing	0.3850
Condenser	0.3221
Power Management Controller	0.2068
Photovoltaic Controller	0.2059
Power Distribution Control Unit—Outboard	0.0544
Battery	0.0281
Thermal Control Assembly Interconnect Piping	0.0265
Thermal Control Assembly Pump	0.0254
Alpha Gimbal Motor	0.0146
Photovoltaic Blanket and Box	0.0123
Photovoltaic Controller Error Signal Generator	0.0013
ac Remote Bus Isolator—25 kW	0.0004

Table B–5. Baseline EPS Model Without Structural or Long-Life ORUs Component Criticality Ranking

Component	Criticality Ranking Factor
Sequential Shunt Unit	2.2404
dc Remote Bus Isolator—25 kW	1.5484
Main Inverter Unit	0.8156
dc Remote Bus Isolator—10 kW	0.7442
Battery Monitor	0.7442
Charge Power Converter	0.7442
Discharge Power Converter	0.7442
Alpha Gimbal Bearing	0.4872
Power Management Controller	0.2314
Photovoltaic Controller	0.2303
Power Distribution Control Unit—Outboard	0.0608
Battery	0.0328
Alpha Gimbal Motor	0.0184
Photovoltaic Blanket and Box	0.0140
Photovoltaic Controller Error Signal Generator	0.0014
ac Remote Bus Isolator	0.0005

Table B-6. Baseline EPS Model ORU Criticality Ranking

Component	Criticality Ranking Factor
dc Switching Unit	3.9376
Sequential Shunt Unit	1.8748
Battery Charge/Discharge Unit	1.8481
Utility Plate	1.4250
Deployable Mast	1.2535
Condenser Mounting Strut	1.0391
Alpha Gimbal Transition Structure	0.6948
Alpha Gimbal Roll Ring	0.6939
Photovoltaic Cable Set	0.6934
Integrated Equipment Assembly Transition Structure	0.6916
Integrated Equipment Assembly Structure	0.6916
Main Inverter Unit	0.6581
Beta Gimbal Transition Structure	0.6273
Beta Gimbal Roll Ring	0.6265
dc Remote Bus Isolator—10 kW	0.6174
Alpha Gimbal Bearing	0.3480
Condenser	0.3114
Power Management Controller	0.1999
Photovoltaic Controller	0.1991
Main Bus Switching Unit	0.1052
Power Distribution Control Unit—Outboard	0.0526
Battery	0.0272
Thermal Control Assembly Interconnect Piping	0.0257
Thermal Control Assembly Pump	0.0246
Alpha Gimbal Motor	0.0146
Photovoltaic Blanket and Box	0.0114

Table B-7. Baseline EPS Model Using Component MRIs—Component Criticality Ranking

Component	Criticality Ranking Factor
Sequential Shunt Unit	2.8782
dc Remote Bus Isolator—25 kW	1.9640
DMC	1.9495
Utility Plate	1.0806
Alpha Gimbal Roll Ring	1.0772
Photovoltaic Cable Set	1.0736
Beta Gimbal Roll Ring	0.9634
Main Inverter Unit	0.9555
dc Remote Bus Isolator—10 kW	0.9064
Battery Monitor	0.9064
Charge Power Converter	0.9064
Discharge Power Converter	0.9064
Condenser Mounting Strut	0.8058
Alpha Gimbal Transition Structure	0.5393
Integrated Equipment Assembly Structure	0.5354
Alpha Gimbal Bearing	0.5072
Beta Gimbal Transition Structure	0.4827
Power Management Controller	0.4694
Photovoltaic Controller	0.4664
Condenser	0.2416
Power Distribution Control Unit—Outboard	0.1267
Integrated Equipment Assembly Transition Structure	0.0803
Battery	0.0401
Thermal Control Assembly Pump	0.0401
Alpha Gimbal Motor	0.0294
Thermal Control Assembly Interconnect Piping	0.0262
Photovoltaic Blanket and Box	0.0173
Photovoltaic Controller Error Signal Generator	0.0046
ac Remote Bus Isolator—25 kW	0.0013

Table B-8. Solar Dynamic EPS Model Component Criticality Ranking

Component	Criticality Ranking Factor
Linear Actuator—Outer	1.8351
Linear Actuator—Inner	1.8351
Radiator Panel Deployment Assembly	1.8351
Parasitic Load Radiator	1.8339
Frequency Changer	1.8339
Alpha Gimbal Bearing	1.4233
Beta Gimbal Bearing	1.4035
Reflective Surface	1.2262
PCU Receiver	1.2262
Alpha Gimbal Transition Structure	0.7116
Alpha Gimbal Roll Ring	0.7107
Beta Gimbal Transition Structure	0.7019
Beta Gimbal Roll Ring	0.7010
Concentrator Strut	0.6142
SD Cable Set	0.6142
SD/PMAD Cable Set	0.6142
Two-Axis Gimbal	0.6127
PCU Power Cable Set	0.6127
Interface Structural Support	0.6126
SD Utility Plate	0.6123
ac Remote Bus Isolator—3 Phase	0.6119
ac Remote Bus Isolator—1 Phase	0.6119
Concentrator Controller	0.6116
PCU Signal and Data Cable Set	0.6116
Control Valve Actuator	0.6112
Power Management Controller	0.5936
Sequential Shunt Unit	0.2674
dc Remote Bus Isolator—25 kW	0.1846
Deployable Mast	0.1787
SD Controller	0.1764
Photovoltaic Utility Plate	0.1224
Fluid Management Unit	0.0970
Integrated Equipment Assembly Transition Structure	0.0923
Integrated Equipment Assembly Structure	0.0921
Condenser Mounting Strut	0.0919
dc Remote Bus Isolator—10 kW	0.0655
Battery Monitor	0.0655

(continued)

Table B-8 (continued)

Component	Criticality Ranking Factor
Charge Power Converter	0.0655
Discharge Power Converter	0.0655
Alpha Gimbal Motor	0.0539
Outboard Power Distribution Control Unit	0.0538
Beta Gimbal Drive Motor	0.0532
Hot Interconnection Lines	0.0484
Cold Interconnection Lines	0.0484
Pump Interconnection Lines	0.0484
Power Conversion Unit	0.0467
Concentrator Sun Sensor	0.0464
Engine Controller	0.0464
Condenser	0.0276
Photovoltaic Controller	0.0265
Main Inverter Unit	0.0104
Battery	0.0029
Thermal Control Assembly Interconnect Piping	0.0023
Thermal Control Assembly Pump	0.0022
Photovoltaic Blanket and Box	0.0017
ac Remote Bus Isolator—25 kW	0.0005

Table B–9. **Power Level, State Availability, and Cumulative Availability for the Baseline EPS with and Without Structural and Long-Life ORUs**

Power Level (kW)	Baseline State Availability (%)	Cumulative Availability (%)	Baseline with No Structural or Long-Life ORUs State Availability (%)	Cumulative Availability (%)
75.0000	13.3749	13.3749	26.4792	26.4792
71.2500	15.9131	29.2880	25.9006	52.3798
70.3125	0.0507	29.3387	0.0963	52.4762
67.5000	9.2742	38.6129	13.1094	65.5855
66.5625	0.0453	38.6582	0.0707	65.6562
65.6250	9.0912	47.7494	7.2110	72.8672
63.7500	4.8632	52.6126	6.8281	79.6952
62.8125	0.0196	52.6322	0.0271	79.7223
62.4975	0.0013	52.6335	0.0021	79.7244
61.8750	8.1124	60.7459	5.2901	85.0145
61.3725	1.1295	61.8754	1.8124	86.8268
60.9375	0.0295	61.9048	0.0225	86.8493
60.0000	2.2983	64.2031	3.0528	89.9022
59.0625	0.0093	64.2125	0.0134	89.9156
58.7475	0.0007	64.2132	0.0010	89.9166
58.1250	3.5283	67.7415	2.0352	91.9519
57.8100	0.0000	67.7415	0.0000	91.9519
57.6225	0.6719	68.4134	0.8864	92.8382
57.1875	0.0186	68.4320	0.0117	92.8499
56.6850	0.0021	68.4341	0.0033	92.8532
56.2500	6.8831	75.3172	2.3954	95.2486
55.3125	0.0037	75.3209	0.0050	95.2536
54.9975	0.0002	75.3212	0.0003	95.2538
54.3750	1.6798	77.0010	1.0090	96.2628
54.0600	0.0000	77.0010	0.0000	96.2628
53.8725	0.1917	77.1927	0.2319	96.4947
53.4375	0.0058	77.1985	0.0033	96.4980
53.1225	0.0004	77.1989	0.0003	96.4983
52.9350	0.0006	77.1996	0.0008	96.4991
52.5000	4.9793	82.1789	1.1612	97.6603
51.9975	0.3839	82.5628	0.2468	97.9071
51.5625	0.0178	82.5806	0.0049	97.9120
51.2475	0.0001	82.5807	0.0001	97.9121
50.6250	0.6723	83.2530	0.3733	98.2854
50.3100	0.0000	83.2530	0.0000	98.2854
50.1225	0.0913	83.3443	0.1203	98.4057

(continued)

Table B–9 (continued)

Power Level (kW)	Baseline State Availability (%)	Cumulative Availability (%)	Baseline with No Structural or Long-Life ORUs State Availability (%)	Cumulative Availability (%)
49.9950	0.0000	83.3443	0.0000	98.4057
49.6875	0.0028	83.3471	0.0017	98.4074
49.3725	0.0001	83.3472	0.0001	98.4075
49.1850	0.0001	83.3473	0.0001	98.4076
48.8700	0.0001	83.3473	0.0001	98.4077
48.7500	1.9231	85.2704	0.3734	98.7811
48.4350	0.0000	85.2704	0.0000	98.7811
48.2475	0.1142	85.3846	0.0603	98.8414
47.8125	0.0089	85.3935	0.0018	98.8432
47.7450	0.0238	85.4174	0.0310	98.8742
47.4975	0.0000	85.4174	0.0000	98.8743
47.3100	0.0005	85.4179	0.0003	98.8746
46.8750	2.3443	87.7622	0.2569	99.1315
46.5600	0.0000	87.7622	0.0000	99.1315
46.3725	0.0265	87.7887	0.0308	99.1623
45.9375	0.0009	87.7896	0.0005	99.1628
45.6225	0.0000	87.7896	0.0000	99.1628
45.4350	0.0001	87.7897	0.0001	99.1629
45.0000	0.8952	88.6849	0.1613	99.3242
44.6850	0.0000	88.6849	0.0000	99.3242
44.4975	0.0159	88.7008	0.0086	99.3328
44.0625	0.0023	88.7031	0.0004	99.3332
43.7475	0.0002	88.7033	0.0000	99.3333
43.5600	0.0000	88.7034	0.0000	99.3333
43.1250	1.2581	89.9615	0.0990	99.4322
42.8100	0.0000	89.9615	0.0000	99.4322
42.6225	0.1942	90.1556	0.0347	99.4669
42.1875	0.0050	90.1607	0.0004	99.4674
41.8725	0.0000	90.1607	0.0000	99.4674
41.6850	0.0000	90.1607	0.0000	99.4674
41.2500	0.3326	90.4933	0.0505	99.5179
40.9350	0.0000	90.4933	0.0000	99.5179
40.7475	0.0111	90.5044	0.0062	99.5242
40.3125	0.0011	90.5055	0.0002	99.5244
39.9975	0.0001	90.5056	0.0000	99.5244
39.8100	0.0000	90.5056	0.0000	99.5244
39.3750	0.3464	90.8520	0.0242	99.5485
39.0600	0.0000	90.8520	0.0000	99.5485

(continued)

Table B-9 (continued)

Power Level (kW)	Baseline State Availability (%)	Cumulative Availability (%)	Baseline with No Structural or Long-Life ORUs State Availability (%)	Cumulative Availability (%)
38.8725	0.0478	90.8997	0.0066	99.5552
38.4375	0.0016	90.9014	0.0001	99.5553
38.1225	0.0000	90.9014	0.0000	99.5553
37.9350	0.0002	90.9016	0.0000	99.5553
37.5000	3.4339	94.3355	0.0958	99.6511
37.1850	0.0000	94.3355	0.0000	99.6511
36.9975	0.0009	94.3364	0.0004	99.6515
36.5625	0.0003	94.3367	0.0000	99.6515
36.2475	0.0000	94.3367	0.0000	99.6515
36.0600	0.0000	94.3367	0.0000	99.6515
35.6250	0.1638	94.5005	0.0105	99.6620
35.1225	0.0065	94.5070	0.0009	99.6629
34.6875	0.0003	94.5073	0.0000	99.6629
34.3725	0.0000	94.5074	0.0000	99.6629
33.7500	1.9132	96.4206	0.0421	99.7050
33.4350	0.0000	96.4206	0.0000	99.7050
33.2475	0.0266	96.4472	0.0015	99.7064
32.8125	0.0063	96.4536	0.0002	99.7066
32.4975	0.0000	96.4536	0.0000	99.7066
32.3100	0.0000	96.4536	0.0000	99.7066
31.8750	0.0451	96.4987	0.0024	99.7090
31.3725	0.0044	96.5031	0.0005	99.7096
30.9375	0.0002	96.5033	0.0000	99.7096
30.0000	0.5306	97.0340	0.0106	99.7201
29.6850	0.0000	97.0340	0.0000	99.7201
29.0625	0.0018	97.0357	0.0000	99.7202
28.7475	0.0000	97.0357	0.0000	99.7202
28.5600	0.0000	97.0357	0.0000	99.7202
28.1250	1.0500	98.0858	0.0108	99.7310
27.6225	0.0004	98.0861	0.0000	99.7310
27.1875	0.0000	98.0862	0.0000	99.7310
26.2500	0.2538	98.3400	0.0053	99.7363
25.3125	0.0002	98.3402	0.0000	99.7363
24.9975	0.0001	98.3403	0.0000	99.7363
24.3750	0.3066	98.6469	0.0026	99.7389
23.8725	0.1164	98.7634	0.0024	99.7414
23.4375	0.0014	98.7648	0.0000	99.7414
22.5000	0.0714	98.8362	0.0013	99.7427

(continued)

Table B-9 (continued)

Power Level (kW)	Baseline State Availability (%)	Cumulative Availability (%)	Baseline with No Structural or Long-Life ORUs State Availability (%)	Cumulative Availability (%)
21.5625	0.0002	98.8363	0.0000	99.7427
20.6250	0.0426	98.8789	0.0004	99.7430
19.6875	0.0001	98.8791	0.0000	99.7430
18.7500	0.4823	99.3613	0.0014	99.7444
17.8125	0.0000	99.3613	0.0000	99.7444
16.8750	0.0295	99.3908	0.0003	99.7447
15.9375	0.0000	99.3909	0.0000	99.7447
15.0000	0.1168	99.5077	0.0003	99.7450
14.0625	0.0004	99.5081	0.0000	99.7450
13.1250	0.0023	99.5105	0.0000	99.7450
12.1875	0.0000	99.5105	0.0000	99.7450
11.2500	0.0159	99.5264	0.0000	99.7450
9.3750	0.0650	99.5914	0.0001	99.7451
8.4375	0.0000	99.5914	0.0000	99.7451
7.5000	0.0108	99.6023	0.0000	99.7451
4.6875	0.0000	99.6023	0.0000	99.7451
3.7500	0.0009	99.6032	0.0000	99.7451
0.0000	0.3968	100.0000	0.2549	100.0000

Table B-10. Power Level, State Availability, and Cumulative Availability for the Six PV Module EPS with and Without Structural and Long-Life ORUs

Power Level (kW)	Baseline State Availability (%)	Cumulative Availability (%)	Baseline with No Structural or Long-Life ORUs State Availability (%)	Cumulative Availability (%)
112.5000	5.0502	5.0502	13.7917	13.7917
108.7500	9.0129	14.0631	20.2354	34.0271
107.8125	0.0287	14.0918	0.0752	34.1023
106.2450	0.0573	14.1491	0.1432	34.2455
105.0000	7.9453	22.0944	15.2135	49.4590
104.0625	0.0428	22.1372	0.0922	49.5512
103.1250	5.1645	27.3017	5.6903	55.2415
102.4950	0.0511	27.3528	0.1051	55.3466
101.5575	0.0002	27.3530	0.0004	55.3470
101.2500	5.3636	32.7166	9.5662	64.9132
100.3125	0.0313	32.7479	0.0580	64.9712
99.9900	0.0002	32.7481	0.0004	64.9716
99.3750	7.6807	40.4288	6.9574	71.9290
98.7450	0.0222	40.4510	0.0405	71.9695
98.4375	0.0264	40.4774	0.0280	71.9975
97.8075	0.0001	40.4775	0.0002	71.9977
97.5000	3.1639	43.6414	5.3402	77.3379
96.8700	0.0293	43.6707	0.0295	77.3674
96.5625	0.0187	43.6894	0.0330	77.4004
95.6250	5.6246	49.3140	4.3768	81.7772
94.9950	0.0106	49.3246	0.0199	81.7971
94.6875	0.0320	49.3566	0.0279	81.8250
94.0575	0.0000	49.3566	0.0001	81.8251
93.7500	6.0041	55.3607	3.9435	85.7686
93.1200	0.0175	55.3782	0.0145	85.7831
92.8125	0.0099	55.3881	0.0167	85.7998
92.1825	0.0001	55.3882	0.0001	85.7999
91.8750	3.3454	58.7336	2.4921	88.2920
91.2450	0.0042	58.7378	0.0074	88.2994
90.9375	0.0191	58.7569	0.0145	88.3139
90.3075	0.0000	58.7569	0.0000	88.3139
90.0000	6.6143	65.3712	2.5826	90.8965
89.3700	0.0050	65.3762	0.0038	90.9003
89.0625	0.0248	65.4010	0.0133	90.9136
88.4325	0.0000	65.4010	0.0000	90.9136
88.1250	1.7767	67.1777	1.2581	92.1717
87.4950	0.0188	67.1965	0.0064	92.1781

(continued)

Table B-10 (continued)

Power Level (kW)	Baseline State Availability (%)	Cumulative Availability (%)	Baseline with No Structural or Long-Life ORUs State Availability (%)	Cumulative Availability (%)
87.1875	0.0102	67.2067	0.0076	92.1857
86.5575	0.0000	67.2067	0.0000	92.1857
86.2500	4.2239	71.4306	1.2559	93.4416
85.6200	0.0024	71.4330	0.0020	93.4436
85.3125	0.0236	71.4566	0.0080	93.4516
84.6825	0.0000	71.4566	0.0000	93.4516
84.3750	3.1655	74.6221	0.7643	94.2159
83.7450	0.0093	74.6314	0.0023	94.2182
83.4375	0.0049	74.6363	0.0034	94.2216
82.8075	0.0000	74.6363	0.0000	94.2216
82.5000	2.3401	76.9764	0.6017	94.8233
81.8700	0.0007	76.9771	0.0005	94.8238
81.5625	0.0123	76.9894	0.0033	94.8271
81.2475	0.0009	76.9903	0.0016	94.8287
80.9325	0.0000	76.9903	0.0000	94.8287
80.6250	2.9936	79.9839	0.4174	95.2461
80.1225	0.7757	80.7596	1.3423	96.5884
79.9950	0.0024	80.7620	0.0005	96.5889
79.6875	0.0117	80.7737	0.0021	96.5910
79.0575	0.0000	80.7737	0.0000	96.5910
78.7500	1.1746	81.9483	0.2627	96.8537
78.1200	0.0047	81.9530	0.0005	96.8542
77.8125	0.0062	81.9592	0.0015	96.8557
77.4975	0.0008	81.9600	0.0011	96.8568
77.1825	0.0000	81.9600	0.0000	96.8568
76.8750	1.6125	83.5725	0.1729	97.0297
76.5600	0.0000	83.5725	0.0000	97.0297
76.3725	0.6922	84.2647	0.9847	98.0144
76.2450	0.0012	84.2659	0.0002	98.0146
75.9375	0.0092	84.2751	0.0011	98.0157
75.4350	0.0022	84.2773	0.0037	98.0194
75.3075	0.0000	84.2773	0.0000	98.0194
75.0000	1.5959	85.8732	0.1283	98.1477
74.9925	0.0000	85.8732	0.0000	98.1477
74.9700	0.0013	85.8745	0.0001	98.1478
74.0625	0.0027	85.8772	0.0006	98.1484
73.8675	0.0022	85.8794	0.0035	98.1519
73.7475	0.0003	85.8797	0.0004	98.1523
73.4325	0.0000	85.8797	0.0000	98.1523

(continued)

Table B-10 (continued)

Power Level (kW)	Baseline State Availability (%)	Cumulative Availability (%)	Baseline with No Structural or Long-Life ORUs State Availability (%)	Cumulative Availability (%)
73.1250	0.8141	86.6938	0.0748	98.2271
72.8100	0.0000	86.6938	0.0000	98.2271
72.6225	0.3013	86.9951	0.3791	98.6062
72.4950	0.0003	86.9954	0.0001	98.6063
72.1875	0.0039	86.9993	0.0003	98.6066
71.8725	0.0005	86.9998	0.0003	98.6069
71.6850	0.0013	87.0011	0.0018	98.6087
71.5575	0.0000	87.0011	0.0000	98.6087
71.2500	1.2738	88.2749	0.0580	98.6667
70.7475	0.3966	88.6715	0.2769	98.9436
70.6200	0.0002	88.6717	0.0000	98.9436
70.3125	0.0050	88.6767	0.0003	98.9439
69.9975	0.0002	88.6769	0.0002	98.9441
69.6825	0.0000	88.6769	0.0000	98.9441
69.3750	0.3707	89.0476	0.0291	98.9732
69.0600	0.0000	89.0476	0.0000	98.9732
68.8725	0.1430	89.1906	0.1874	99.1606
68.7450	0.0013	89.1919	0.0000	99.1606
68.4375	0.0018	89.1937	0.0001	99.1607
68.1225	0.0003	89.1940	0.0002	99.1609
67.9350	0.0004	89.1944	0.0005	99.1614
67.8075	0.0000	89.1944	0.0000	99.1614
67.5000	0.6039	89.7983	0.0206	99.1820
67.1850	0.0000	89.7983	0.0000	99.1820
66.9975	0.2360	90.0343	0.1355	99.3175
66.8700	0.0001	90.0344	0.0000	99.3175
66.5625	0.0034	90.0378	0.0001	99.3176
66.2475	0.0001	90.0379	0.0001	99.3177
66.0600	0.0009	90.0388	0.0006	99.3183
65.9325	0.0000	90.0388	0.0000	99.3183
65.6250	0.5213	90.5601	0.0127	99.3310
65.3100	0.0000	90.5601	0.0000	99.3310
65.1225	0.0569	90.6173	0.0688	99.3998
64.9950	0.0003	90.6173	0.0000	99.3998
64.6875	0.0007	90.6180	0.0000	99.3998
64.3725	0.0001	90.6181	0.0000	99.3998
64.1850	0.0002	90.6183	0.0002	99.4000
64.0575	0.0000	90.6183	0.0000	99.4000
63.7500	0.2902	90.9085	0.0081	99.4081

(continued)

Table B–10 (continued)

Power Level (kW)	Baseline State Availability (%)	Cumulative Availability (%)	Baseline with No Structural or Long-Life ORUs State Availability (%)	Cumulative Availability (%)
63.4350	0.0000	90.9085	0.0000	99.4081
63.2475	0.0673	90.9758	0.0354	99.4435
63.1200	0.0000	90.9758	0.0000	99.4435
62.8125	0.0012	90.9770	0.0000	99.4435
62.4975	0.0003	90.9773	0.0001	99.4436
62.3100	0.0003	90.9776	0.0002	99.4438
62.1825	0.0000	90.9776	0.0000	99.4438
61.8750	0.3561	91.3337	0.0050	99.4488
61.5600	0.0000	91.3337	0.0000	99.4488
61.3725	0.2535	91.5872	0.0599	99.5087
61.2450	0.0000	91.5872	0.0000	99.5087
60.9375	0.0014	91.5886	0.0000	99.5087
60.6225	0.0000	91.5886	0.0000	99.5087
60.4350	0.0001	91.5887	0.0001	99.5088
60.0000	0.1236	91.7123	0.0028	99.5116
59.6850	0.0000	91.7123	0.0000	99.5116
59.4975	0.0320	91.7443	0.0184	99.5300
59.3700	0.0002	91.7445	0.0000	99.5300
59.0625	0.0005	91.7450	0.0000	99.5300
58.7475	0.0001	91.7451	0.0000	99.5300
58.5600	0.0001	91.7452	0.0000	99.5300
58.4325	0.0000	91.7452	0.0000	99.5300
58.1250	0.1391	91.8843	0.0015	99.5315
57.8100	0.0000	91.8843	0.0000	99.5315
57.6225	0.1259	92.0102	0.0212	99.5527
57.4950	0.0000	92.0102	0.0000	99.5527
57.1875	0.0007	92.0109	0.0000	99.5527
56.8725	0.0000	92.0109	0.0000	99.5527
56.6850	0.0004	92.0113	0.0001	99.5528
56.2500	1.7795	93.7908	0.0513	99.6041
55.9350	0.0000	93.7908	0.0000	99.6041
55.7475	0.0091	93.7999	0.0046	99.6087
55.3125	0.0002	93.8001	0.0000	99.6087
54.9975	0.0000	93.8001	0.0000	99.6087
54.8100	0.0000	93.8001	0.0000	99.6087
54.6825	0.0000	93.8001	0.0000	99.6087
54.3750	0.0632	93.8633	0.0006	99.6093
54.0600	0.0000	93.8633	0.0000	99.6093
53.8725	0.0328	93.8961	0.0049	99.6142

(continued)

Table B-10 (continued)

Power Level (kW)	Baseline State Availability (%)	Cumulative Availability (%)	Baseline with No Structural or Long-Life ORUs State Availability (%)	Cumulative Availability (%)
53.7450	0.0000	93.8961	0.0000	99.6142
53.4375	0.0002	93.8963	0.0000	99.6142
53.1225	0.0001	93.8964	0.0000	99.6142
52.9350	0.0001	93.8965	0.0000	99.6142
52.5000	1.5381	95.4346	0.0372	99.6514
52.1850	0.0000	95.4346	0.0000	99.6514
51.9975	0.0632	95.4978	0.0044	99.6558
51.5625	0.0050	95.5028	0.0001	99.6559
51.2475	0.0000	95.5028	0.0000	99.6559
51.0600	0.0000	95.5028	0.0000	99.6559
50.6250	0.0236	95.5264	0.0002	99.6561
50.3100	0.0000	95.5264	0.0000	99.6561
50.1225	0.0159	95.5423	0.0022	99.6583
49.9950	0.0092	95.5515	0.0003	99.6586
49.6875	0.0001	95.5516	0.0000	99.6586
49.3725	0.0000	95.5516	0.0000	99.6586
49.1850	0.0000	95.5516	0.0000	99.6586
48.8700	0.0001	95.5517	0.0001	99.6587
48.7500	0.6607	96.2124	0.0143	99.6730
48.4350	0.0000	96.2124	0.0000	99.6730
48.2475	0.0177	96.2301	0.0010	99.6740
47.8125	0.0029	96.2330	0.0001	99.6741
47.7450	0.0298	96.2628	0.0326	99.7067
47.4975	0.0000	96.2628	0.0000	99.7067
47.3100	0.0001	96.2629	0.0000	99.7067
46.8750	0.8629	97.1258	0.0104	99.7171
46.5600	0.0000	97.1258	0.0000	99.7171
46.3725	0.0042	97.1300	0.0005	99.7176
45.9375	0.0000	97.1300	0.0000	99.7176
45.6225	0.0000	97.1300	0.0000	99.7176
45.4350	0.0000	97.1300	0.0000	99.7176
45.0000	0.3127	97.4427	0.0071	99.7247
44.6850	0.0000	97.4427	0.0000	99.7247
44.4975	0.0025	97.4452	0.0001	99.7248
44.0625	0.0008	97.4460	0.0000	99.7248
43.7475	0.0000	97.4460	0.0000	99.7248
43.5600	0.0000	97.4460	0.0000	99.7248
43.1250	0.5089	97.9549	0.0051	99.7299
42.8100	0.0000	97.9549	0.0000	99.7299

(continued)

Table B-10 (continued)

Power Level (kW)	Baseline State Availability (%)	Cumulative Availability (%)	Baseline with No Structural or Long-Life ORUs State Availability (%)	Cumulative Availability (%)
42.6225	0.0182	97.9731	0.0003	99.7302
42.1875	0.0019	97.9750	0.0000	99.7302
41.8725	0.0000	97.9750	0.0000	99.7302
41.6850	0.0000	97.9750	0.0000	99.7302
41.2500	0.1235	98.0985	0.0026	99.7328
40.9350	0.0000	98.0985	0.0000	99.7328
40.7475	0.0017	98.1002	0.0001	99.7329
40.3125	0.0004	98.1006	0.0000	99.7329
39.9975	0.0000	98.1006	0.0000	99.7329
39.8100	0.0000	98.1006	0.0000	99.7329
39.3750	0.1447	98.2453	0.0013	99.7342
39.0600	0.0000	98.2453	0.0000	99.7342
38.8725	0.0039	98.2492	0.0001	99.7343
38.4375	0.0007	98.2499	0.0000	99.7343
38.1225	0.0000	98.2499	0.0000	99.7343
37.9350	0.0000	98.2499	0.0000	99.7343
37.5000	0.5363	98.7862	0.0022	99.7365
37.1850	0.0000	98.7862	0.0000	99.7365
36.9975	0.0001	98.7863	0.0000	99.7365
36.5625	0.0001	98.7864	0.0000	99.7365
36.2475	0.0000	98.7864	0.0000	99.7365
36.0600	0.0000	98.7864	0.0000	99.7365
35.6250	0.0688	98.8552	0.0007	99.7372
35.1225	0.0005	98.8557	0.0000	99.7372
34.6875	0.0001	98.8558	0.0000	99.7372
34.3725	0.0000	98.8558	0.0000	99.7372
33.7500	0.2656	99.1214	0.0008	99.7380
33.4350	0.0000	99.1214	0.0000	99.7380
33.2475	0.0021	99.1235	0.0000	99.7380
32.8125	0.0009	99.1244	0.0000	99.7380
32.4975	0.0000	99.1244	0.0000	99.7380
32.3100	0.0000	99.1244	0.0000	99.7380
31.8750	0.0196	99.1440	0.0002	99.7382
31.3725	0.0004	99.1444	0.0000	99.7382
30.9375	0.0001	99.1445	0.0000	99.7382
30.0000	0.0690	99.2135	0.0002	99.7384
29.6850	0.0000	99.2135	0.0000	99.7384
29.0625	0.0002	99.2137	0.0000	99.7384
28.7475	0.0000	99.2137	0.0000	99.7384

(continued)

Table B-10 (continued)

Power Level (kW)	Baseline State Availability (%)	Cumulative Availability (%)	Baseline with No Structural or Long-Life ORUs State Availability (%)	Cumulative Availability (%)
28.5600	0.0000	99.2137	0.0000	99.7384
28.1250	0.1330	99.3467	0.0002	99.7386
27.6225	0.0000	99.3467	0.0000	99.7386
27.1875	0.0000	99.3467	0.0000	99.7386
26.2500	0.0334	99.3801	0.0001	99.7387
25.3125	0.0000	99.3801	0.0000	99.7387
24.9975	0.0001	99.3802	0.0000	99.7387
24.3750	0.0370	99.4172	0.0000	99.7387
23.8725	0.1247	99.5419	0.0025	99.7412
23.4375	0.0002	99.5421	0.0000	99.7412
22.5000	0.0088	99.5509	0.0000	99.7412
21.5625	0.0000	99.5509	0.0000	99.7412
20.6250	0.0052	99.5561	0.0000	99.7412
19.6875	0.0000	99.5561	0.0000	99.7412
18.7500	0.0379	99.5940	0.0000	99.7412
17.8125	0.0000	99.5940	0.0000	99.7412
16.8750	0.0035	99.5975	0.0000	99.7412
15.9375	0.0000	99.5975	0.0000	99.7412
15.0000	0.0081	99.6056	0.0000	99.7412
14.0625	0.0000	99.6056	0.0000	99.7412
13.1250	0.0003	99.6059	0.0000	99.7412
12.1875	0.0000	99.6059	0.0000	99.7412
11.2500	0.0011	99.6075	0.0000	99.7412
9.3750	0.0044	99.6114	0.0000	99.7412
8.4375	0.0000	99.6114	0.0000	99.7412
7.5000	0.0007	99.6121	0.0000	99.7412
4.6875	0.0000	99.6121	0.0000	99.7412
3.7500	0.0001	99.6122	0.0000	99.7412
0.0000	0.3853	99.9975	0.2548	99.9960

Table B-11. Power Level, State Availability, and Cumulative Availability for a 3SD-1PV Module EPS

Power Level (kW)	State Availability (%)	Cumulative Availability (%)
85.0000	22.7846	22.7846
84.9950	0.0682	22.8528
82.5000	2.9738	25.8265
82.4950	0.0089	25.8354
80.0000	4.2791	30.1145
79.9950	0.0128	30.1273
78.7500	0.1491	30.2764
78.7450	0.0004	30.2768
77.5000	0.0016	30.2784
77.4950	0.0000	30.2784
75.0000	5.7192	35.9977
74.9975	0.0008	35.9984
74.9950	0.0075	36.0059
74.9925	0.0000	36.0059
60.0000	28.0787	64.0847
59.9975	0.0009	64.0856
59.9950	0.0279	64.1135
57.5000	3.6647	67.7783
57.4975	0.0001	67.7784
57.4950	0.0036	67.7821
54.0000	5.2734	73.0554
54.9975	0.0002	73.0556
54.9950	0.0052	73.0609
53.7500	0.1837	73.2446
53.7475	0.0000	73.2446
53.7450	0.0002	73.2448
52.5000	0.0019	73.2467
52.4975	0.0000	73.2467
52.4950	0.0000	73.2467
50.0000	4.6200	77.8667
49.9975	0.0007	77.8674
49.9950	0.0083	77.8756
35.0000	12.1871	90.0627
34.9975	0.0003	90.0630
32.5000	1.5906	91.6536
32.4975	0.0000	91.6537
30.0000	2.2888	93.9425
29.9975	0.0001	93.9426

(continued)

Table B-11 (continued)

Power Level (kW)	State Availability (%)	Cumulative Availability (%)
28.7500	0.0797	94.0223
28.7475	0.0000	94.0223
27.5000	0.0008	94.0231
27.4975	0.0000	94.0231
25.0000	2.5729	96.5960
24.9975	0.0003	96.5963
10.0000	1.9431	98.5394
7.5000	0.2536	98.7930
5.0000	0.3649	99.1579
3.7500	0.0127	99.1706
2.5000	0.0001	99.1707
0.0000	0.8293	100.0000

APPENDIX C

UNIRAM MODELS AND INPUT FILES USED IN THIS STUDY

The UNIRAM input file listings and sparing analysis input file listings are provided for each model used in this analysis.

C.1 UNIRAM SOURCE FILE FOR THE BASELINE EPS MODEL

```
SPACE STATION EPS: POWER GENERATION - CASE 1 - JULY 24, 1989
0 0 75
24
B-PVBB
100 16 1 0
PVBBC
0 1 131400 1 24 0
B-DM
100 8 1 0
DMC
0 1 131400 1 2334 0
B-DCSUPVCE
100 8 1 1
3 0
PVCE
1 1 87600 1 2329.5 0
B-SSU
100 8 1 0
SSUC
0 1 87600 1 2329.5 0
B-BGRR
100 8 1 0
BGRRC
0 1 262800 1 2331 0
B-BETASTRU
100 8 1 0
BGTS
0 1 262800 1 2334 0
B-UP
50 1 1 0
UPC
0 1 350400 1 2331 0
B-TCS
50 1 3 3
-1 0
2 1
-1 2
CONDENSOR
1 1 876000 1 2334 0
TCAIP
3 1 262800 1 2329 0
TCAP
3 1 280320 1 2329.5 0
B-CMS
50 1 1 0
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PRECEDING PAGE BLANK NOT FILMED

PAGE C-2 INTENTIONALLY BLANK

CMSC
0 1 262800 1 2331 0
B-PVRAD
50 1 1 0
PVRADC
0 1 99999999 1 0.01 0
B-STRUCTUR
50 1 3 1
-1 0
IEATS
1 1 262800 1 2334 0
IEAS
1 1 262800 1 2334 0
PVCS
1 1 262800 1 2340 0
B-PVC
50 1 1 0
PVC
0 1 43800 1 2329.5 0
DCRBI10KW
100 7.5 1 0
DCRBI10KWC
0 1 262800 1 2329.5 0
DCRBI25KW
100 3 1 0
DCRBI25KWC
0 1 262800 1 2329.5 0
B-BCDU
100 20 3 1
-1 0
BATMON
1 1 262800 1 2329.5 0
CPC
1 1 262800 1 2329.5 0
DPC
1 1 262800 1 2329.5 0
B-BATTERY
100 20 1 0
BATTERY
0 1 61320 1 24 0
B-MIU
20 1 1 0
MIUC
0 1 87600 1 2329.5 0
B-OPDCU
50 1 1 0
OPDCU

0 1 87600 1 2329.5 0
B-AGRR
50 1 1 0
AGRRC
0 1 262800 1 2331 0
B-ALPHAPOS
50 1 2 2
-1 0
2 1
AGB
1 1 131400 1 2334 0
AGM
2 1 87600 1 2331 0
ALPHADERATE
63.66 2 1 0
BYPASS
0 1 99999999 1 0.01 0
B-ALPHASTR
50 1 1 0
AGTS
0 1 262800 1 2334 0
B-PMC
100 1 1 0
PMC
0 1 43800 1 2328.5 0
ACRBI25KW
33.33 1 1 0
ACRBI25KWC
0 1 262800 1 2331 0
29
N-PVBBS
2 1
1 2
N-PVCONTROL
4 3
2 1
3 1
4 1
N-BETAGIMBAL
4 2
5 1
6 1
N-ARRAYWING
4 3
25 1
26 1
27 1

N-TC
4 4
7 1
8 1
9 1
10 1
N-BATSTRING
4 4
7 1
13 1
15 1
16 1
N-BATTERY2
3 2
30 1
30 1
N-BATTERY3
3 3
30 1
30 1
30 1
N-DCSUBAT2
4 3
14 1
14 1
31 1
N-DCSUBAT3
4 3
14 1
14 1
32 1
N-PVSUPPLY
3 2
28 1
28 1
N-DCPOWER
3 2
33 1
34 1
N-MIU + UP
4 2
7 1
17 1
N-MIU2
3 2
37 1
37 1

N-PVC2
2 1
12 2
N-PV
4 5
11 1
35 1
36 1
38 1
39 1
N-PVOUT
4 2
29 1
40 1
N-PVINOUT
3 2
40 1
41 1
N-2ACRBI
3 2
24 1
24 1
N-MBSU
4 2
43 1
43 1
N-OMBSA
3 2
44 1
44 1
N-IMBSA
3 2
44 1
44 1
N-OPDCA
2 1
18 2
N-ALPHAD
3 2
20 1
21 1
N-ALPHAGIMBAL
4 3
19 1
22 1
48 1

N-TWOPVMOD
4 6
29 1
42 1
45 1
46 1
47 1
49 1
N-TOTPOWER
3 2
50 1
50 1
N-TWOPMC
2 1
23 2
N-EPS
4 2
51 1
52 1
0
0
0

C.2 SPARING CANDIDATE INPUT FILE FOR THE BASELINE EPS MODEL

```
PVCE
3 1 169.5 2160 24 0 10 0.25 0
SSUC
4 1 169.5 2160 8 0 10 37.5 0
DCRBI25KWC
14 1 177 2160 16 0 10 14.0 0
MIUC
17 1 169.5 2160 8 0 10 205 0
DCRBI10KWC
13 1 177 2160 20 0 10 3.0 0
BATMON
15 1 177 2160 20 0 10 53.33 0
CPC
15 2 177 2160 20 0 10 53.33 0
DPC
15 3 177 2160 20 0 10 53.33 0
PVC
12 1 169.5 2160 8 0 10 111.0 0
PMC
23 1 168.5 2160 2 0 10 143.0 0
OPDCU
18 1 169.5 2160 4 0 10 213.0 0
ACRBI25KWC
24 1 171 2160 16 0 10 14.0 0
```

C.3 UNIRAM SOURCE FILE FOR THE ORU-LEVEL MODEL

```
SPACE STATION EPS: POWER GENERATION - CASE 1 - JULY 24, 1989
0 0 75
24
B-PVBB
100 16 1 0
PVBBC
0 1 131400 1 24 0
B-DM
100 8 1 0
DMC
0 1 131400 1 2334 0
B-DCSUPVCE
100 8 1 1
3 0
PVCE
1 1 87600 1 2329.5 0
B-SSU
100 8 1 0
SSUC
0 1 87600 1 2329.5 0
B-BGRR
100 8 1 0
BGRRC
0 1 262800 1 2331 0
B-BETASTRU
100 8 1 0
BGTS
0 1 262800 1 2334 0
B-UP
50 1 1 0
UPC
0 1 350400 1 2331 0
B-TCS
50 1 3 3
-1 0
2 1
-1 2
CONDENSOR
1 1 876000 1 2334 0
TCAIP
3 1 262800 1 2329 0
TCAP
3 1 280320 1 2329.5 0
B-CMS
50 1 1 0
```

CMSC
0 1 262800 1 2331 0
B-PVRAD
50 1 1 0
PVRADC
0 1 99999999 1 0.01 0
B-STRUCTUR
50 1 3 1
-1 0
IEATS
1 1 262800 1 2334 0
IEAS
1 1 262800 1 2334 0
PVCS
1 1 262800 1 2340 0
B-PVC
50 1 1 0
PVC
0 1 43800 1 2329.5 0
DCRBI10KW
100 7.5 1 0
DCRBI10KWC
0 1 262800 1 2329.5 0
B-DCSU
100 3 1 0
DCSU
0 1 87600 1 2329.5 0
B-BCDU
100 20 1 0
BCDU
0 1 87600 1 2329.5 0
B-BATTERY
100 20 1 0
BATTERY
0 1 61320 1 24 0
B-MIU
20 1 1 0
MIUC
0 1 87600 1 2329.5 0
B-OPDCU
50 1 1 0
OPDCU
0 1 87600 1 2329.5 0
B-AGRR
50 1 1 0
AGRRC
0 1 262800 1 2331 0

B–ALPHAPOS
50 1 2 2
–1 0
2 1
AGB
1 1 131400 1 2334 0
AGM
2 1 87600 1 2331 0
ALPHADERATE
63.66 2 1 0
BYPASS
0 1 99999999 1 0.01 0
B–ALPHASTR
50 1 1 0
AGTS
0 1 262800 1 2334 0
B–PMC
100 1 1 0
PMC
0 1 43800 1 2328.5 0
B–MBSU
66.67 1 1 0
MBSU
0 1 87600 1 2331 0
29
N–PVBBS
2 1
1 2
N–PVCONTROL
4 2
2 1
4 1
N–BETAGIMBAL
4 2
5 1
6 1
N–ARRAYWING
4 3
25 1
26 1
27 1
N–TC
4 4
7 1
8 1
9 1
10 1

C-2

N-BATSTRING
4 4
7 1
13 1
15 1
16 1
N-BATTERY2
3 2
30 1
30 1
N-BATTERY3
3 3
30 1
30 1
30 1
N-DCSUBAT2
4 3
14 1
14 1
31 1
N-DCSUBAT3
4 3
14 1
14 1
32 1
N-PVSUPPLY
3 2
28 1
28 1
N-DCPOWER
3 2
33 1
34 1
N-MIU + UP
4 2
7 1
17 1
N-MIU2
3 2
37 1
37 1
N-PVC2
2 1
12 2

N-PV
4 5
11 1
35 1
36 1
38 1
39 1
N-PVOUT
4 2
29 1
40 1
N-PVINOUT
3 2
40 1
41 1
N-2ACRBI
3 2
24 1
24 1
N-MBSU
4 2
43 1
43 1
N-OMBSA
3 2
24 1
24 1
N-IMBSA
3 2
24 1
24 1
N-OPDCA
2 1
18 2
N-ALPHAD
3 2
20 1
21 1
N-ALPHAGIMBAL
4 3
19 1
22 1
48 1

N-TWOPVMOD
4 6
29 1
42 1
45 1
46 1
47 1
49 1
N-TOTPOWER
3 2
50 1
50 1
N-TWOPMC
2 1
23 2
N-EPS
4 2
51 1
52 1
0
0
0

C.4 SPARING CANDIDATE INPUT FILE FOR THE ORU-LEVEL BASELINE EPS MODEL

SSUC
4 1 169.5 2160 8 0 10 37.5 0
DCSU
14 1 177 2160 16 0 10 171.5 0
MIUC
17 1 169.5 2160 8 0 10 205 0
BCDU
15 1 177 2160 20 0 10 160.0 0
PVC
12 1 169.5 2160 8 0 10 111.0 0
PMC
23 1 168.5 2160 2 0 10 143.0 0
OPDCU
18 1 169.5 2160 4 0 10 213.0 0
MBSU
24 1 171 2160 16 0 10 127.0 0

C.5 UNIRAM SOURCE FILE FOR THE SIX PV MODULE EPS DESIGN

```
SPACE STATION EPS: POWER GENERATION - CASE 5/1 - 6 PV MODULE, JULY 24, 1989
0 0 75
24
B-PVBB
100 16 1 0
PVBBC
0 1 131400 1 24 0
B-DM
100 8 1 0
DMC
0 1 131400 1 2334 0
B-DCSUPVCE
100 8 1 1
3 0
PVCE
1 1 87600 1 2329.5 0
B-SSU
100 8 1 0
SSUC
0 1 87600 1 2329.5 0
B-BGRR
100 8 1 0
BGRRC
0 1 262800 1 2331 0
B-BETASTRU
100 8 1 0
BGTS
0 1 262800 1 2334 0
B-UP
75 1 1 0
UPC
0 1 350400 1 2331 0
B-TCS
75 1 3 3
-1 0
2 1
-1 2
CONDENSOR
1 1 876000 1 2334 0
TCAIP
3 1 262800 1 2329 0
TCAP
3 1 280320 1 2329.5 0
B-CMS
75 1 1 0
```

CMSC
0 1 262800 1 2331 0
B-PVRAD
75 1 1 0
PVRADC
0 1 99999999 1 0.01 0
B-STRUCTUR
50 1 3 1
-1 0
IEATS
1 1 262800 1 2334 0
IEAS
1 1 262800 1 2334 0
PVCS
1 1 262800 1 2340 0
B-PVC
50 1 1 0
PVC
0 1 43800 1 2329.5 0
DCRBI10KW
100 7.5 1 0
DCRBI10KWC
0 1 262800 1 2329.5 0
DCRBI25KW
100 3 1 0
DCRBI25KWC
0 1 262800 1 2329.5 0
B-BCDU
100 20 3 1
-1 0
BATMON
1 1 262800 1 2329.5 0
CPC
1 1 262800 1 2329.5 0
DPC
1 1 262800 1 2329.5 0
B-BATTERY
100 20 1 0
BATTERY
0 1 61320 1 24 0
B-MIU
20 1 1 0
MIUC
0 1 87600 1 2329.5 0
B-OPDCU
75 1 1 0
OPDCU
0 1 87600 1 2329.5 0

B-AGRR
75 1 1 0
AGRRC
0 1 262800 1 2331 0
B-ALPHAPOS
75 1 2 2
-1 0
2 1
AGB
1 1 131400 1 2334 0
AGM
2 1 87600 1 2331 0
ALPHADERATE
63.66 2 1 0
BYPASS
0 1 99999999. 1 0.01 0
B-ALPHASTR
75 1 1 0
AGTS
0 1 262800 1 2334 0
B-PMC
100 1 1 0
PMC
0 1 43800 1 2328.5 0
ACRBI25KW
33.33 1 1 0
ACRBI25KWC
0 1 262800 1 2331 0
29
N-PVBBS
2 1
1 2
N-PVCONTROL
4 3
2 1
3 1
4 1
N-BETAGIMBAL
4 2
5 1
6 1
N-ARRAYWING
4 3
25 1
26 1
27 1

N-TC
4 4
7 1
8 1
9 1
10 1
N-BATSTRING
4 4
7 1
13 1
15 1
16 1
N-BATTERY2
3 2
30 1
30 1
N-BATTERY3
3 3
30 1
30 1
30 1
N-DCSUBAT2
4 3
14 1
14 1
31 1
N-DCSUBAT3
4 3
14 1
14 1
32 1
N-PVSUPPLY
3 2
28 1
28 1
N-DCPOWER
3 2
33 1
34 1
N-MIU + UP
4 2
7 1
17 1
N-MIU2
3 2
37 1
37 1

N-PVC2
2 1
12 2
N-PV
4 5
11 1
35 1
36 1
38 1
39 1
N-PVOUT
4 2
29 1
40 1
N-PVINOUT
3 3
40 1
41 1
41 1
N-2ACRBI
3 2
24 1
24 1
N-MBSU
4 2
43 1
43 1
N-OMBSA
3 2
44 1
44 1
N-IMBSA
3 2
44 1
44 1
N-OPDCA
2 1
18 2
N-ALPHAD
3 2
20 1
21 1
N-ALPHAGIMBAL
4 3
19 1
22 1
48 1

N-TWOPVMOD
4 6
29 1
42 1
45 1
46 1
47 1
49 1
N-TOTPOWER
3 2
50 1
50 1
N-TWOPMC
2 1
23 2
N-EPS
4 2
51 1
52 1
0
0
0

C.6 UNIRAM SOURCE FILE FOR THE 3SD-1PV MODULE EPS DESIGN

```
SPACE STATION EPS: 3 SD MODULES + 1 10KW PV MODULE - JULY 24, 1989
0 0 75
27
B-PVBB
25 7.5 1 0
PVBBC
0 1 131400 1 24 0
B-DM
50 7.5 1 0
DMC
0 1 131400 1 2334 0
B-DCSUPVCE
50 7.5 1 1
3 0
PVCE
1 1 87600 1 2329.5 0
B-SSU
50 7.5 1 0
SSUC
0 1 87600 1 2329.5 0
B-PVUP
50 1 1 0
PVUPC
0 1 350400 1 2331 0
B-TCS
50 1 3 3
-1 0
2 1
-1 2
CONDENSOR
1 1 876000 1 2334 0
TCAIP
3 1 262800 1 2329 0
TCAP
3 1 280320 1 2329.5 0
B-CMS
100 7.5 1 0
CMSC
0 1 262800 1 2331 0
B-PVRAD
100 7.5 1 0
PVRADC
0 1 99999999 1 0.01 0
```

B-STRUCTUR
100 7.5 3 1
-1 0
IEATS
1 1 262800 1 2334 0
IEAS
1 1 262800 1 2334 0
PVCS
1 1 262800 1 2340 0
B-PVC
100 1.5 1 0
PVC
0 1 43800 1 2329.5 0
DCRBI10KW
100 7.5 1 0
DCRBI10KWC
0 1 262800 1 2329.5 0
DCRBI25KW
100 3 1 0
DCRBI25KWC
0 1 262800 1 2329.5 0
B-BCDU
5 1 3 1
-1 0
BATMON
1 1 262800 1 2329.5 0
CPC
1 1 262800 1 2329.5 0
DPC
1 1 262800 1 2329.5 0
B-BATTERY
5 1 1 0
BATTERY
0 1 61320 1 24 0
B-MIU
20 1 1 0
MIUC
0 1 87600 1 2329.5 0
B-OPDCU
100 1.5 1 0
OPDCU
0 1 87600 1 2329.5 0
B-AGRR
100 1.5 1 0
AGRRC
0 1 262800 1 2331 0

B-ALPHAPOS
100 1.5 2 2
-1 0
2 1
AGB
1 1 131400 1 2334 0
AGM
2 1 87600 1 2331 0
B-ALPHASTR
100 1.5 1 0
AGTS
0 1 262800 1 2334 0
B-PMC
100 1 1 0
PMC
0 1 43800 1 2328.5 0
ACRBI25KW
33.33 1 1 0
ACRBI25KWC
0 1 262800 1 2331 0
Concentrator
100 3 7 3
-1 0
-1 1
2 1
Reflective Surface
1 1 131400 1 2336 0
Concentrator Strut
1 1 262800 1 2340 0
Concentrator Control
1 1 262800 1 2330 0
2-Axis Gimbal
2 1 262800 1 2334 0
Lin Act Outer
2 1 87600 1 2331 0
Line Act Inner
2 1 87600 1 2331 0
Sun Sensor
3 1 87600 1 2329.5 0
Power Gen
100 3 7 4
-1 0
-1 1
2 2
2 2
PCU/Receiver
1 1 131400 1 2336 0

PCU Power CS
1 1 262800 1 2334 0
PCU SIG/DATA CS
1 1 262800 1 2330 0
Cntrl Vlv Act
1 1 262800 1 2328.5 0
Parasitic Load Rad
1 1 87600 1 2329.5 0
Engine Cntrlr
3 1 87600 1 2329.5 0
PCU - MP
4 1 87600 1 2339.5 0
Heat Reject
100 3 6 4
-1 0
-1 1
2 2
-1 3
Rad Panel Deploy
1 1 87600 1 2331 0
SD Utility Plate
2 1 262800 1 2332.5 0
Fluid Manage Unit
4 1 113880 1 2331 0
Hot Intercon Lines
4 1 262800 1 2329 0
Cold Intercon Lines
4 1 262800 1 2329 0
Pump Intercon Lines
4 1 262800 1 2329 0
Elec Equip
100 3 6 2
-1 0
2 1
ACRBI 3 Phase
1 1 262800 1 2331 0
Frequency Changer
1 1 87600 1 2329.5 0
SD CS
1 1 262800 1 2340 0
SD/PMAD CS
1 1 262800 1 2340 0
SD Controller
2 1 43800 1 2329.5 0
ACRBI 1 Phase
1 1 262800 1 2331 0

BETA Gimbal
100 3 4 2
-1 0
2 1
BG Bearing
1 1 131400 1 2334 0
BG Roll Ring
1 1 262800 1 2331 0
BGTS
1 1 262800 1 2334 0
BG Drive Motor
2 1 87600 1 2331 0
Int Struct
100 3 1 0
Int Struct Support
0 1 262800 1 2334 0
27
N-PVBBS
2 1
1 2
N-PVCONTROL
4 3
2 1
3 1
4 1
N-ARRAYWING
4 3
26 1
28 1
29 1
N-TC
4 4
5 1
6 1
7 1
8 1
N-BATSTRING
4 4
5 1
11 1
13 1
14 1
N-BATTERY3
3 3
32 1
32 1
32 1

N-DCSUBAT3
4 3
12 1
12 1
33 1
N-PVSUPPLY
3 2
30 1
30 1
N-MIU + UP
4 2
5 1
15 1
N-MIU2
3 2
36 1
36 1
N-PVC2
2 1
10 2
N-PV
4 5
9 1
34 1
35 1
37 1
38 1
N-PVOUT
4 2
31 1
39 1
N-SD
4 6
22 1
23 1
24 1
25 1
26 1
27 1
N-PV + SD
3 2
40 1
41 1
N-2SD
3 2
41 1
41 1

N-2ACRBI
3 2
21 1
21 1
N-MBSU
4 2
44 1
44 1
N-OMBSA
3 2
45 1
45 1
N-IMBSA
3 2
45 1
45 1
N-OPDCA
2 1
16 2
N-ALPHAGIMBAL
4 3
17 1
18 1
19 1
N-PVSDMOD
4 5
42 1
46 1
47 1
48 1
49 1
N-2SDMOD
4 5
43 1
46 1
47 1
48 1
49 1
N-TOTPOWER
3 2
50 1
51 1
N-TWOPMC
2 1
20 2

N-EPS
4 2
52 1
53 1
0
0
0

C.7 SPARING CANDIDATE INPUT FILE FOR 3SD-1PV MODULE EPS DESIGN

Lin Act Outer
22 5 171 2160 3 0 10 22 0
Lin Act Inner
22 6 171 2160 3 0 10 22 0
Parasitic Load Rad
23 5 169.5 2160 3 0 10 132 0
Frequency Changer
25 2 169.5 2160 3 0 10 240 0
Sun Sensor
22 7 169.5 2160 6 0 10 3 0
ACRBI 3 Phase
25 1 171 2160 3 0 10 14 0
ACRBI 1 Phase
25 6 171 2160 3 0 10 14 0
Concentrator Control
22 3 170 2160 3 0 10 11 0
PCU SIG/DATA CS
23 3 170 2160 3 0 10 10 0
Cntrl Vlv Act
23 4 168.5 2160 3 0 10 4 0
PMC
20 1 168.5 2160 2 0 10 91.52 0
ACRBI25KW
21 1 169.5 2160 2 0 10 14.0 0
SSUC
4 1 169.5 2160 2 0 10 37.5 0
PVCE
3 1 169.5 2160 2 0 10 .25 0
DCRBI25KWC
12 1 169.5 2160 2 0 10 14 0
SD Controller
25 5 169.5 2160 6 0 10 117.5 0
Engine Controller
23 6 169.5 2160 6 0 10 50.0 0

APPENDIX D

AVAILABILITY BLOCK DIAGRAMS AND BASIC SUBSYSTEM DIAGRAMS

The availability block diagrams (ABDs) for the baseline Electric Power System (EPS) model and the solar-dynamic EPS model are presented in this appendix. Also the basic subsystem fault trees are included.

Figure D-1 is the ABD for the full baseline EPS model. Figure D-2 provides the ABD details for the N-TWO PV MODULE subsystem block diagram as shown on Figure D-1.

Figure D-3 is the ABD for the full solar-dynamic (SD) EPS. Figure D-4 provides the ABD details for the SD Module subsystem block of Figure D-3. The ABD details of the block in Figure D-3 are provided in Figure D-2 in the N-PV block; however, the capacity of the PV blanket and box subsystems have been reduced to 10 kW to reflect their capacity in the proposed solar-dynamic EPS design.

Figures D-5 through D-33 are the fault trees for the EPS ABDs previously mentioned. Figures D-5 through D-28 are fault trees for the basic subsystems associated with the baseline EPS model and Figures D-29 through D-33 are the fault trees specific to the solar dynamic EPS basic subsystems not already included in Figures D-5 through D-33.

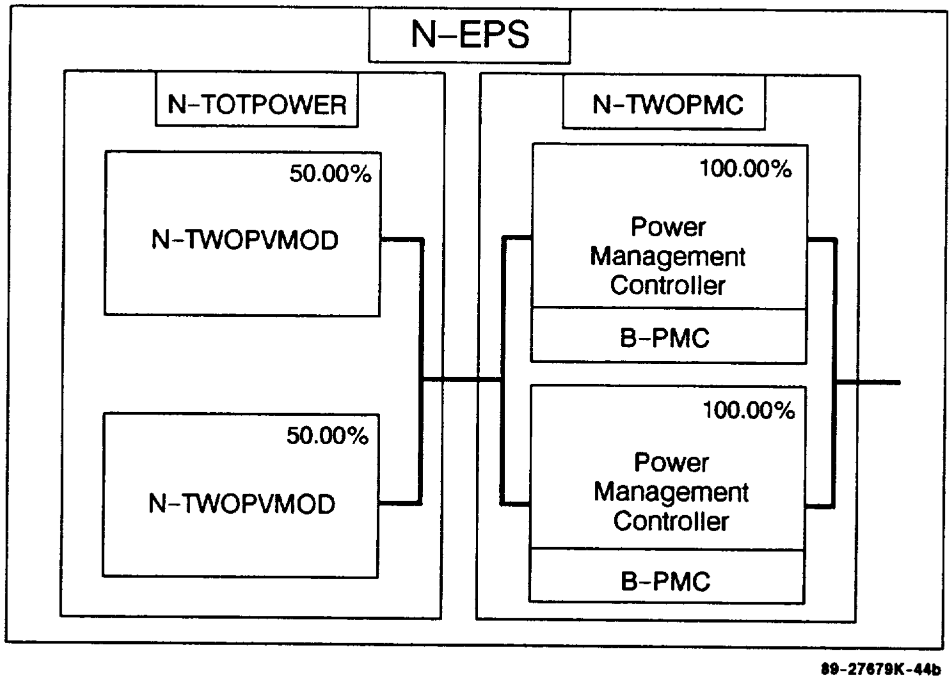
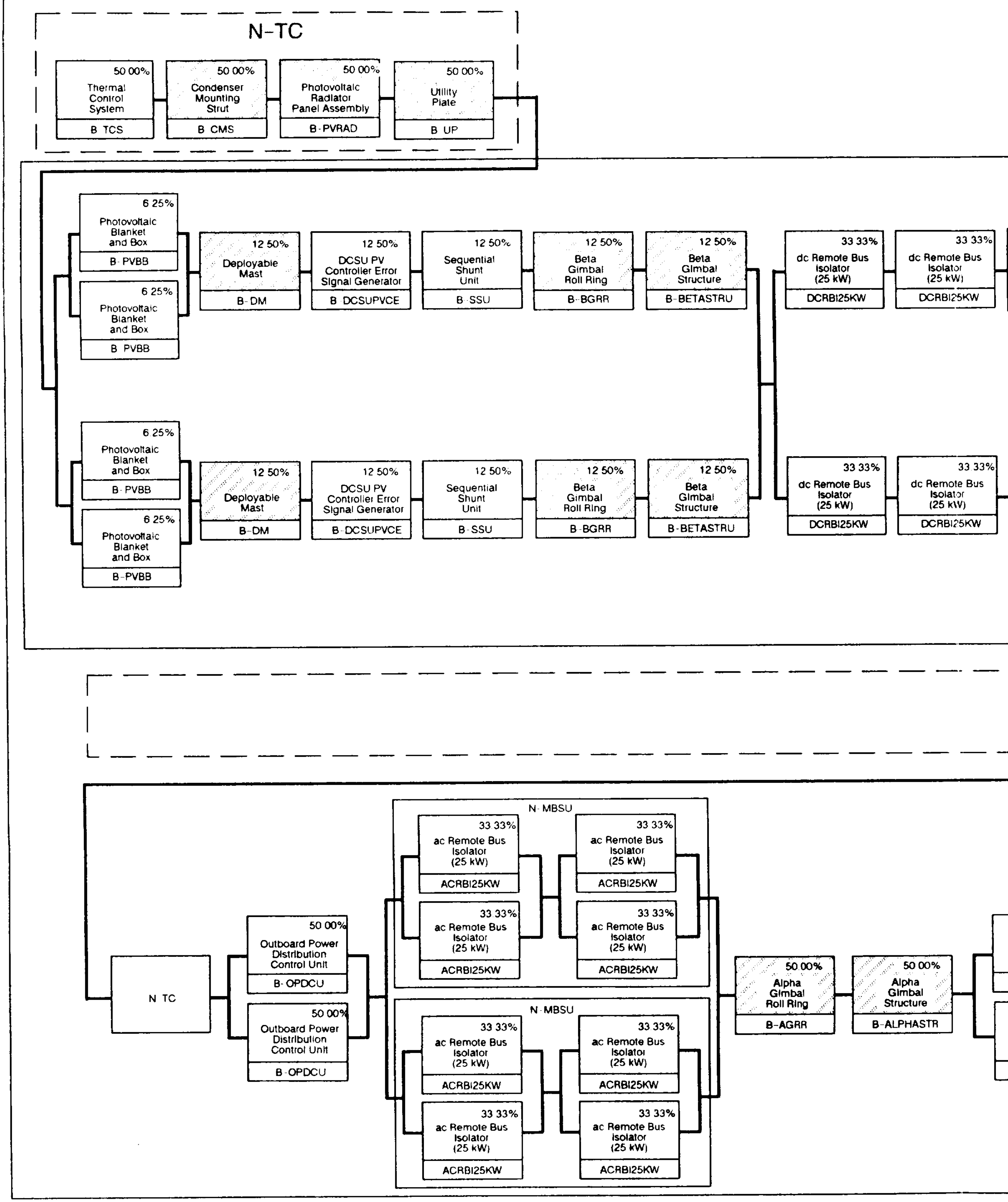


Figure D-1. Baseline EPS Availability Block Diagram (ABD)

FOLDOUT FRAME



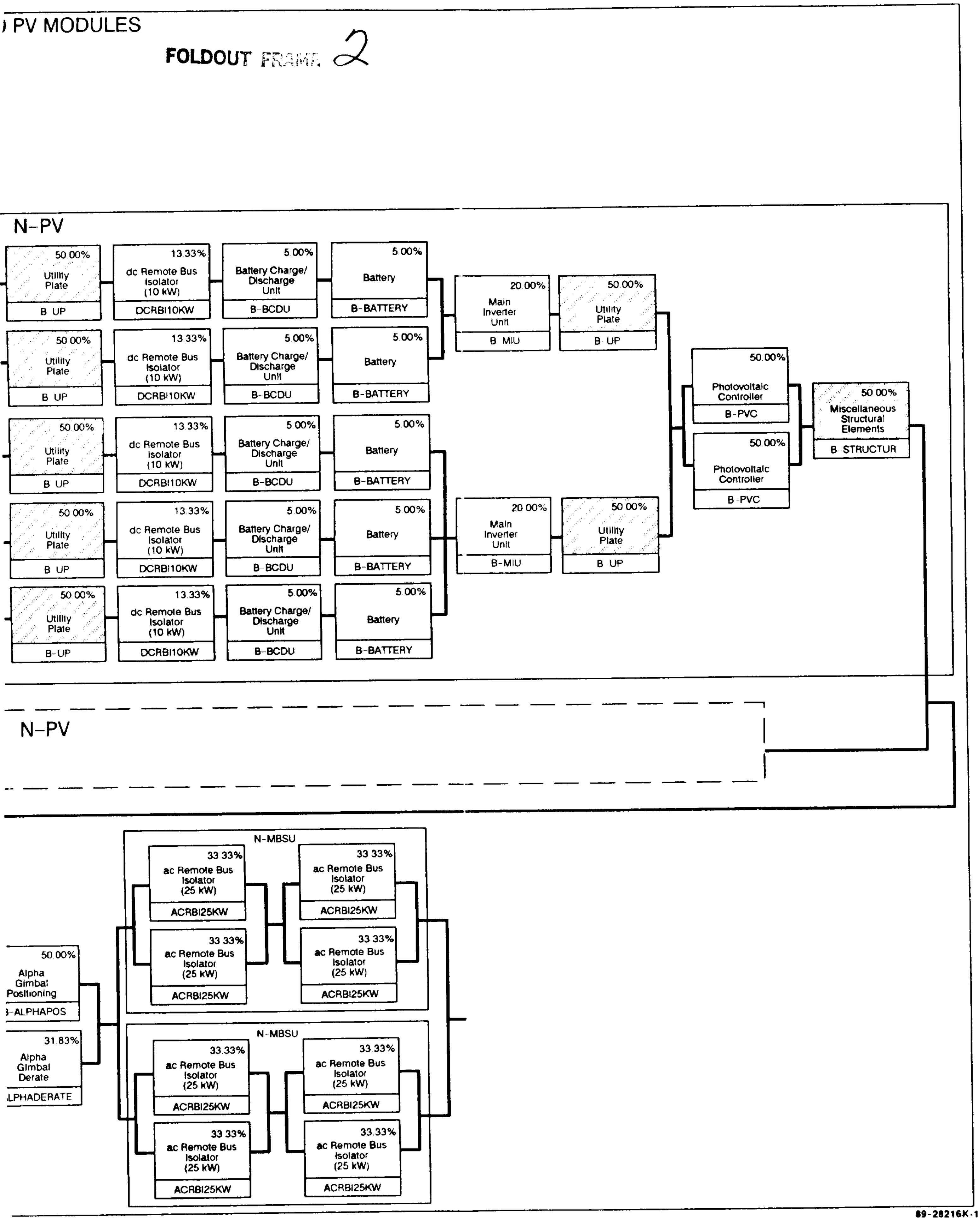


Figure D-2. One-Half EPS Power Generation Block Diagram

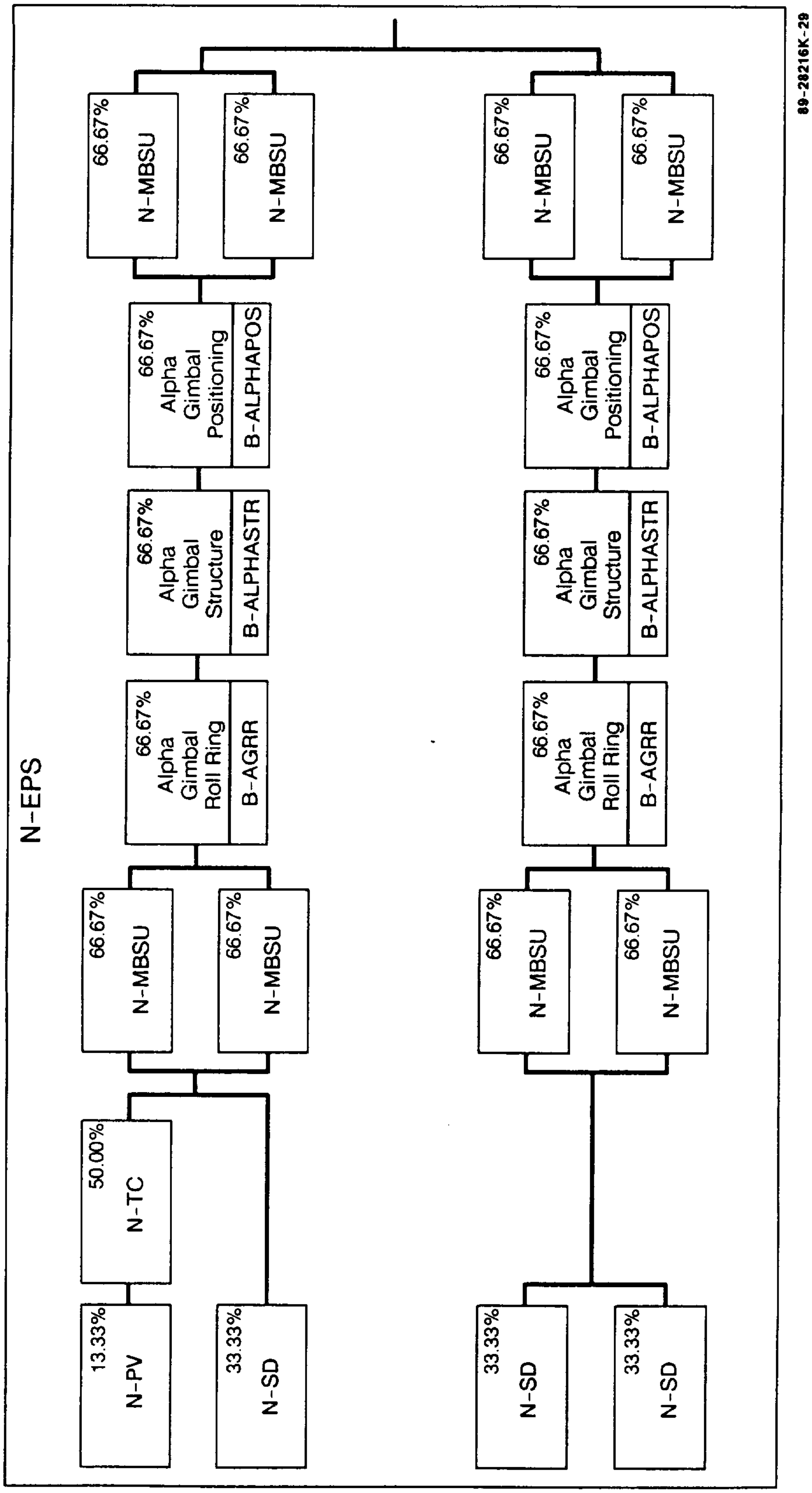


Figure D-3. 3 SD-1 PV Module EPS Model

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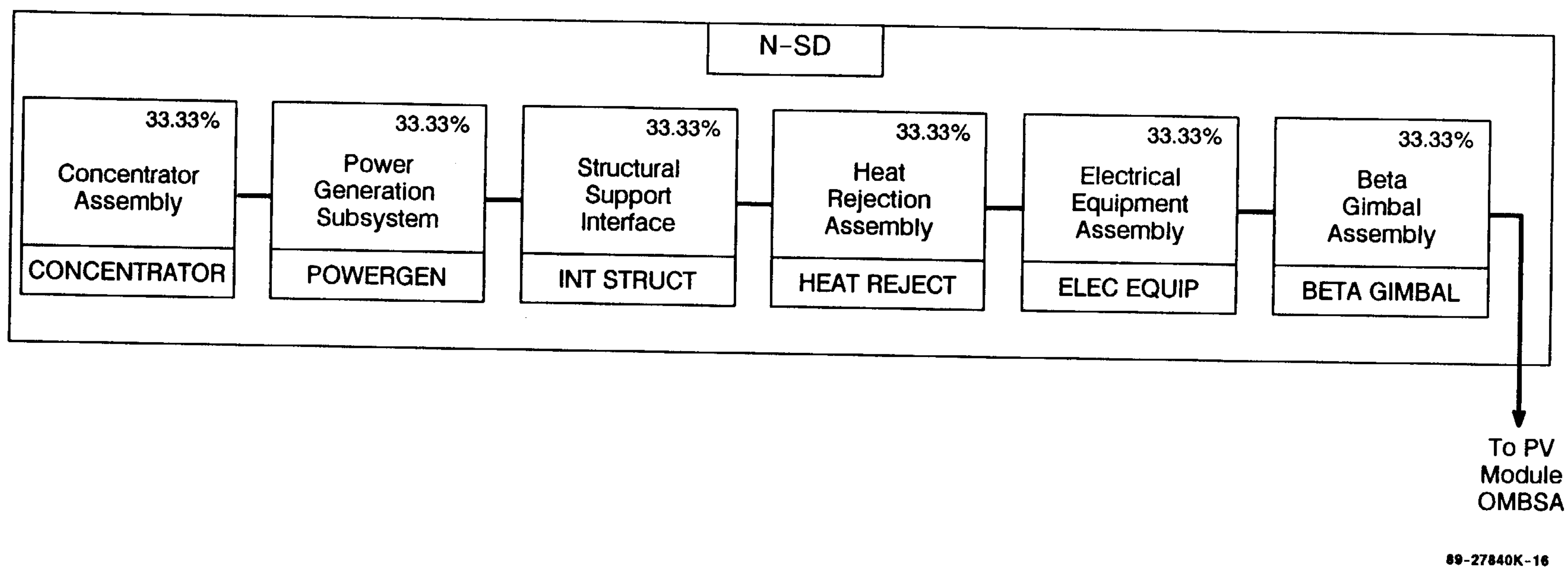


Figure D–4. Solar Dynamic Module ABD

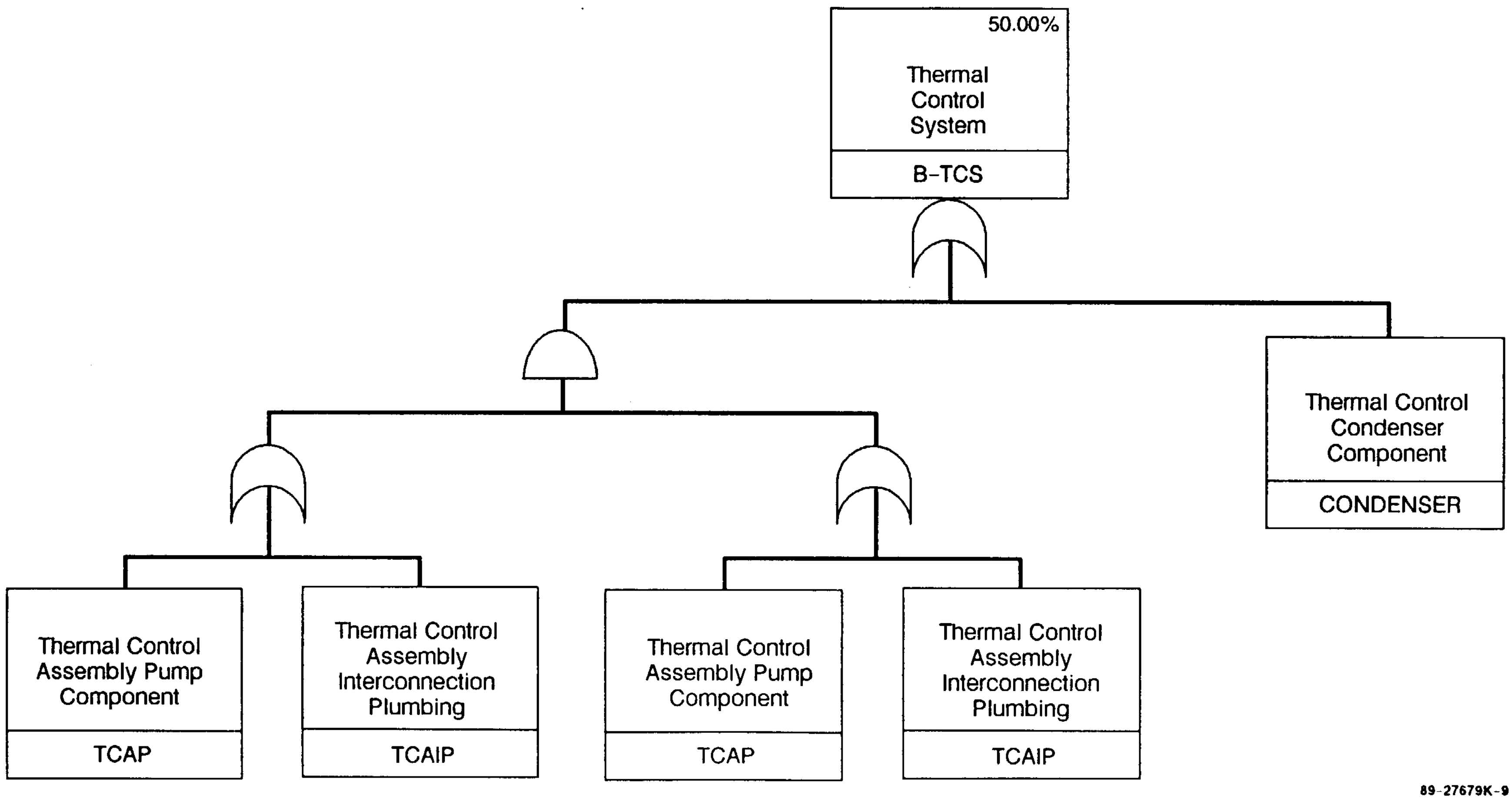


Figure D–5. Thermal Control System Fault Tree

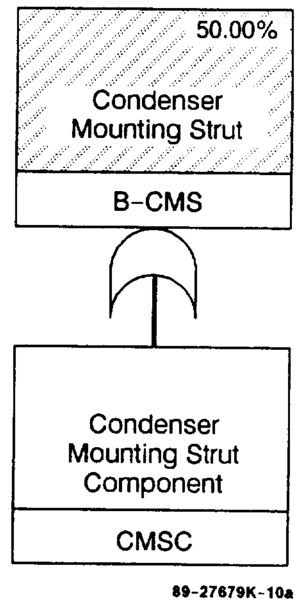
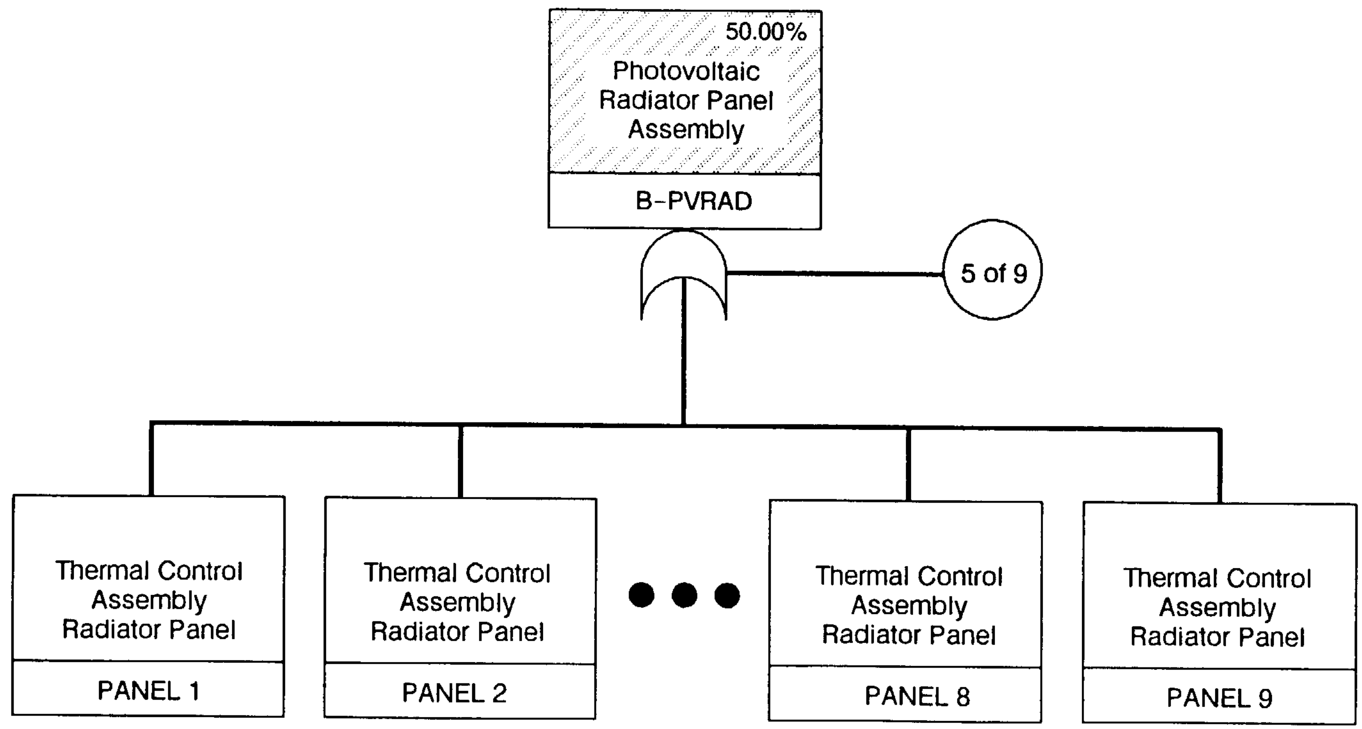


Figure D–6. Condenser Mounting Strut Fault Tree



89-27679K-11b

Figure D-7. Photovoltaic Fault Tree Radiator Panel Assembly

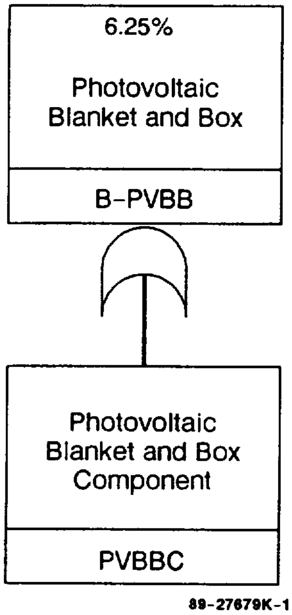


Figure D-8. Photovoltaic Blanket and Box Fault Tree

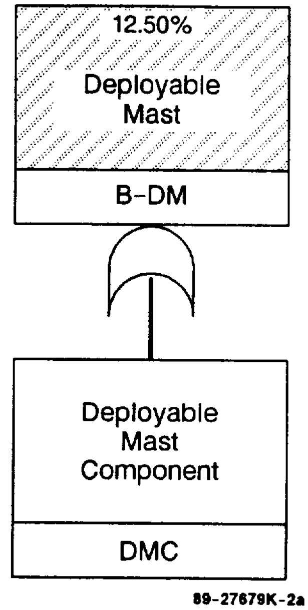


Figure D-9. Deployable Mast Fault Tree

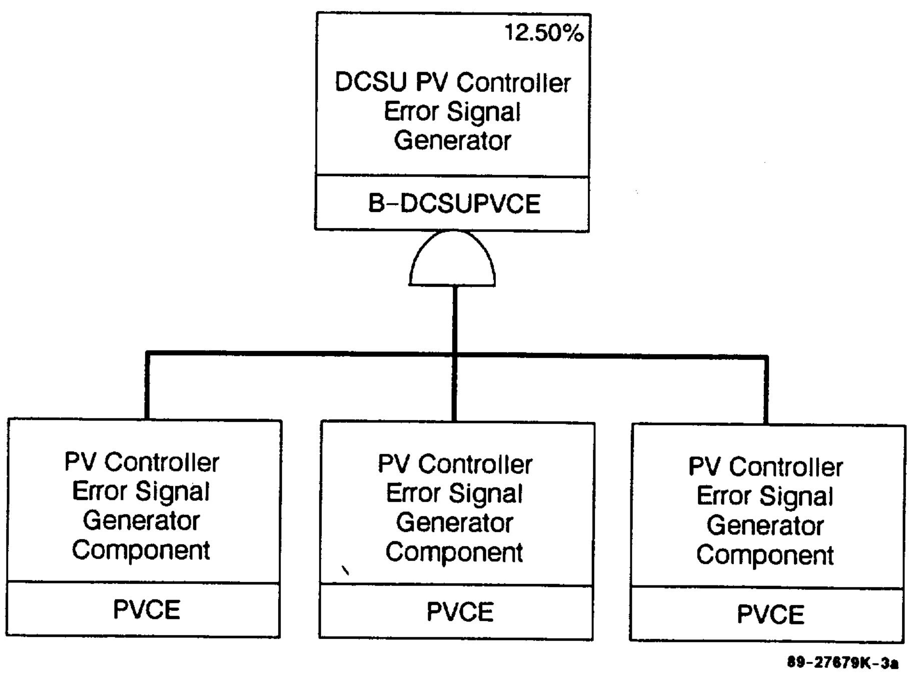


Figure D-10. DCSU PV Controller Error Signal Generator Fault Tree

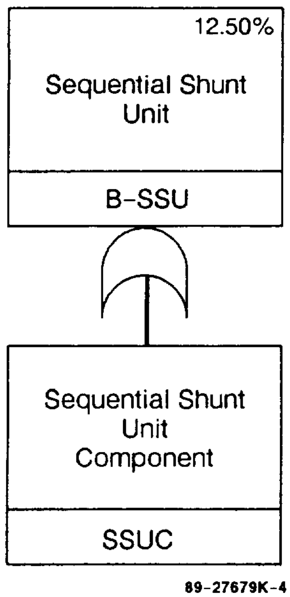


Figure D-11. Sequential Shunt Unit Fault Tree

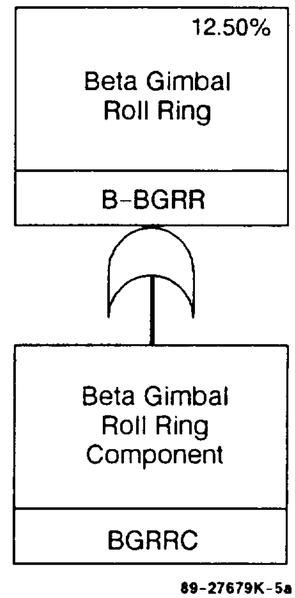


Figure D-12. Beta Gimbal Roll Ring Fault Tree

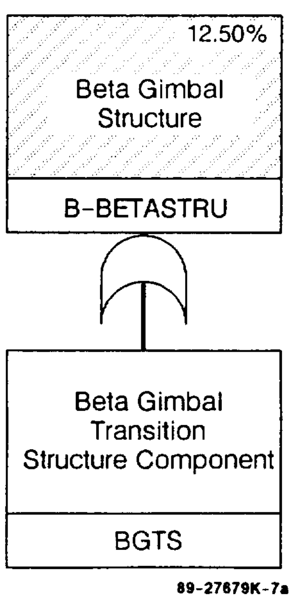


Figure D-13. Beta Gimbal Structure Fault Tree

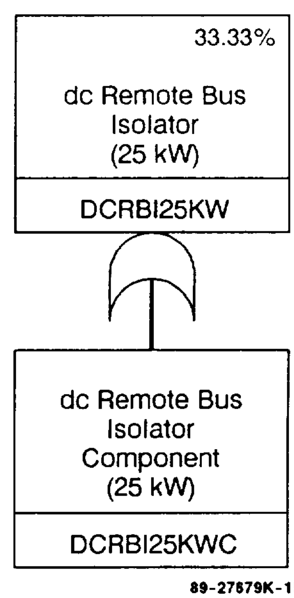


Figure D-14. dc Remote Bus Isolator (25 kW) Fault Tree

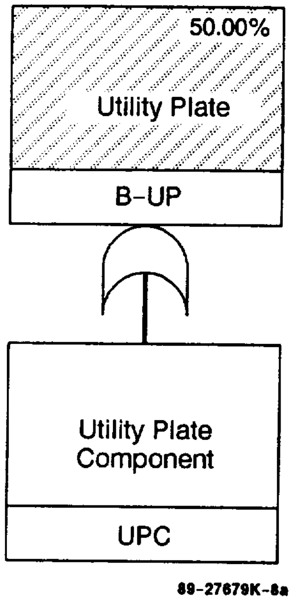


Figure D-15. Utility Plate Fault Tree

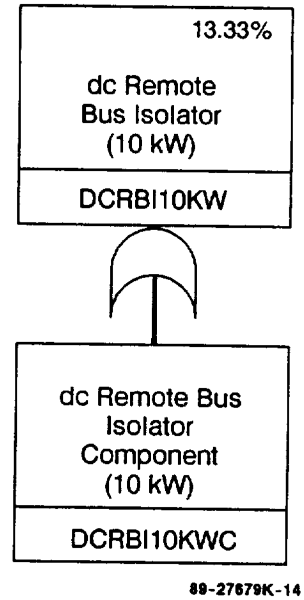


Figure D-16. dc Remote Bus Isolator (10 kW) Fault Tree

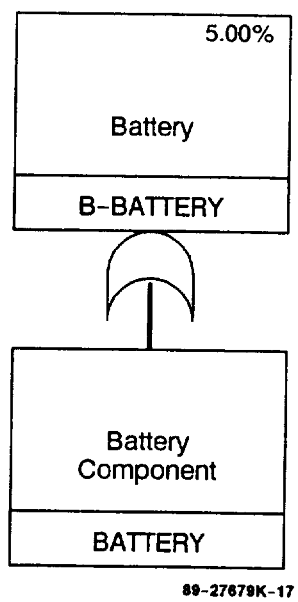


Figure D-17. Battery Fault Tree

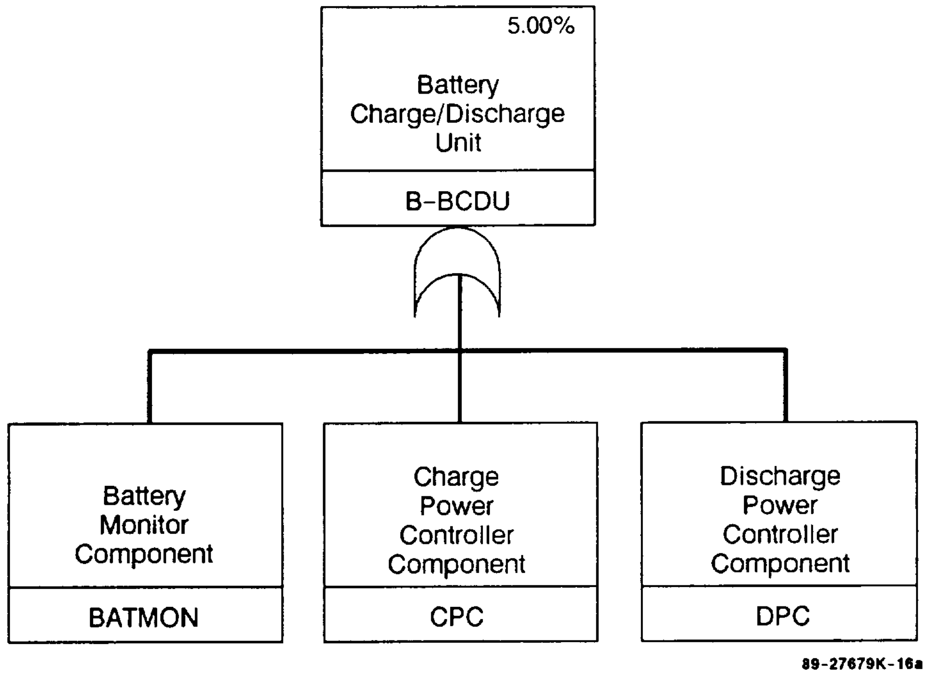


Figure D-18. Battery Charge/Discharge Unit Fault Tree

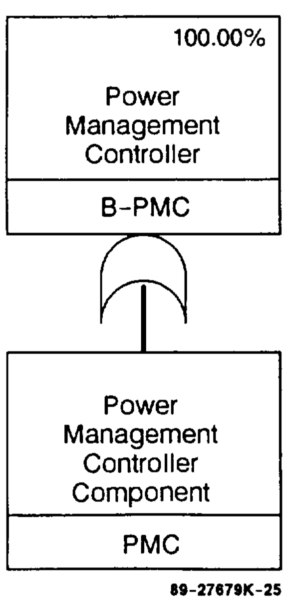


Figure D-19. Power Management Controller Fault Tree

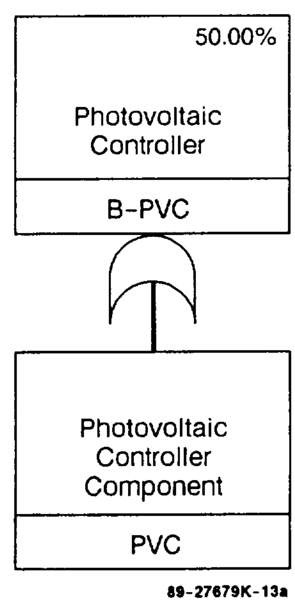


Figure D-20. Photovoltaic Controller Fault Tree

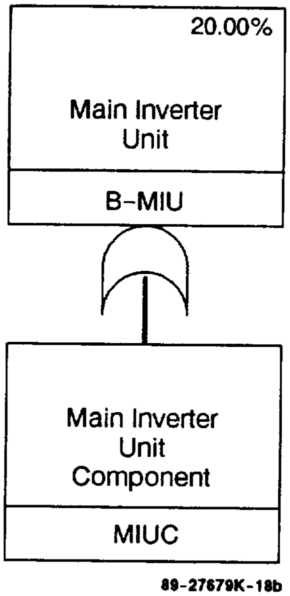


Figure D-21. Main Inverter Unit Fault Tree

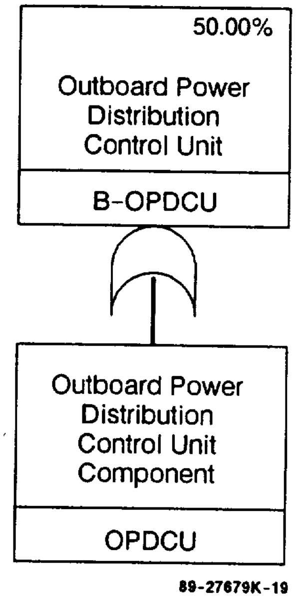


Figure D-22. Outboard Power Distribution Control Unit Fault Tree

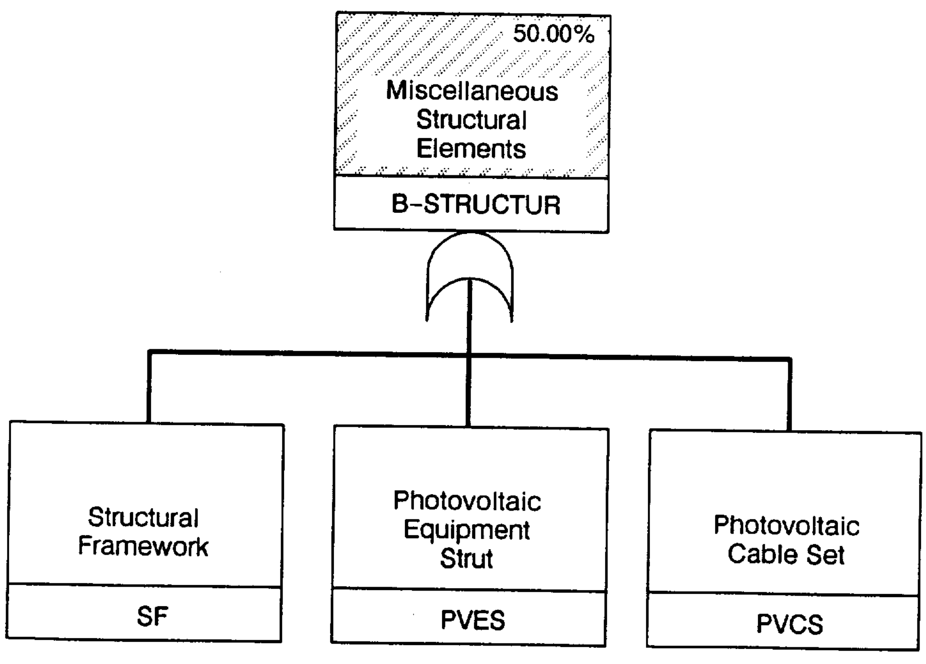


Figure D-23. Miscellaneous Structural Elements Fault Tree

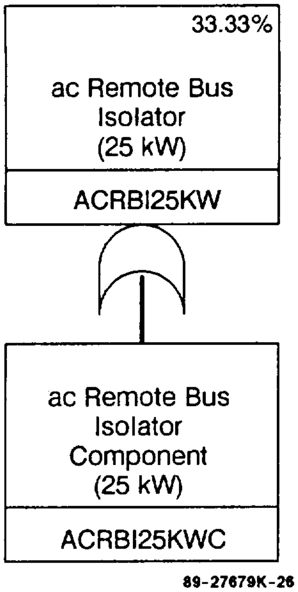


Figure D-24. ac Remote Bus Isolator (25 kW) Fault Tree

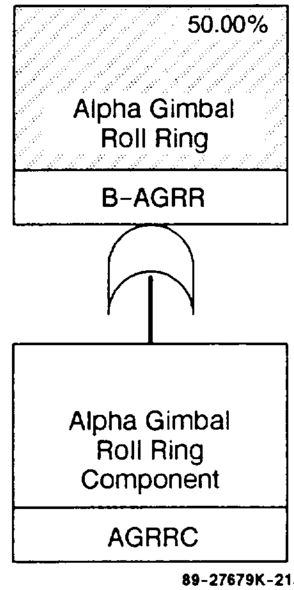


Figure D-25. Alpha Gimbal Roll Ring Fault Tree

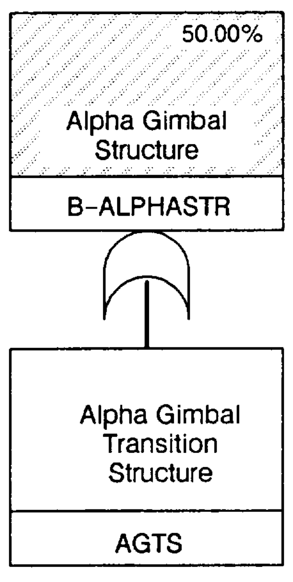


Figure D-26. Alpha Gimbal Structure Fault Tree

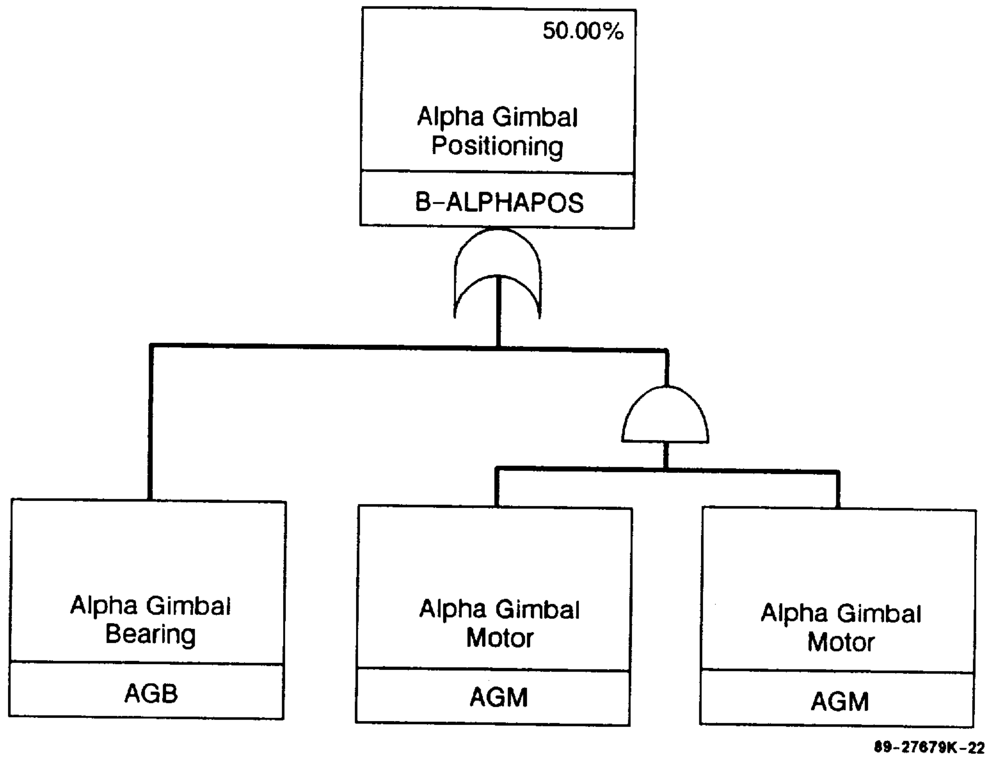


Figure D-27. Alpha Gimbal Positioning Fault Tree

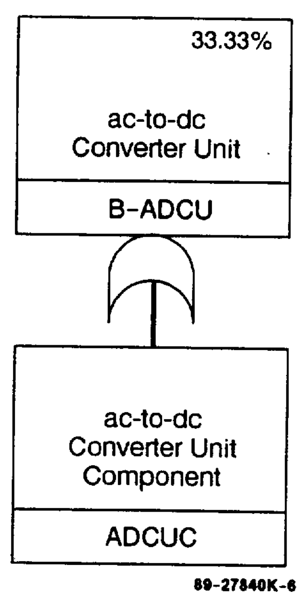


Figure D-28. ac-to-dc Converter Unit Fault Tree

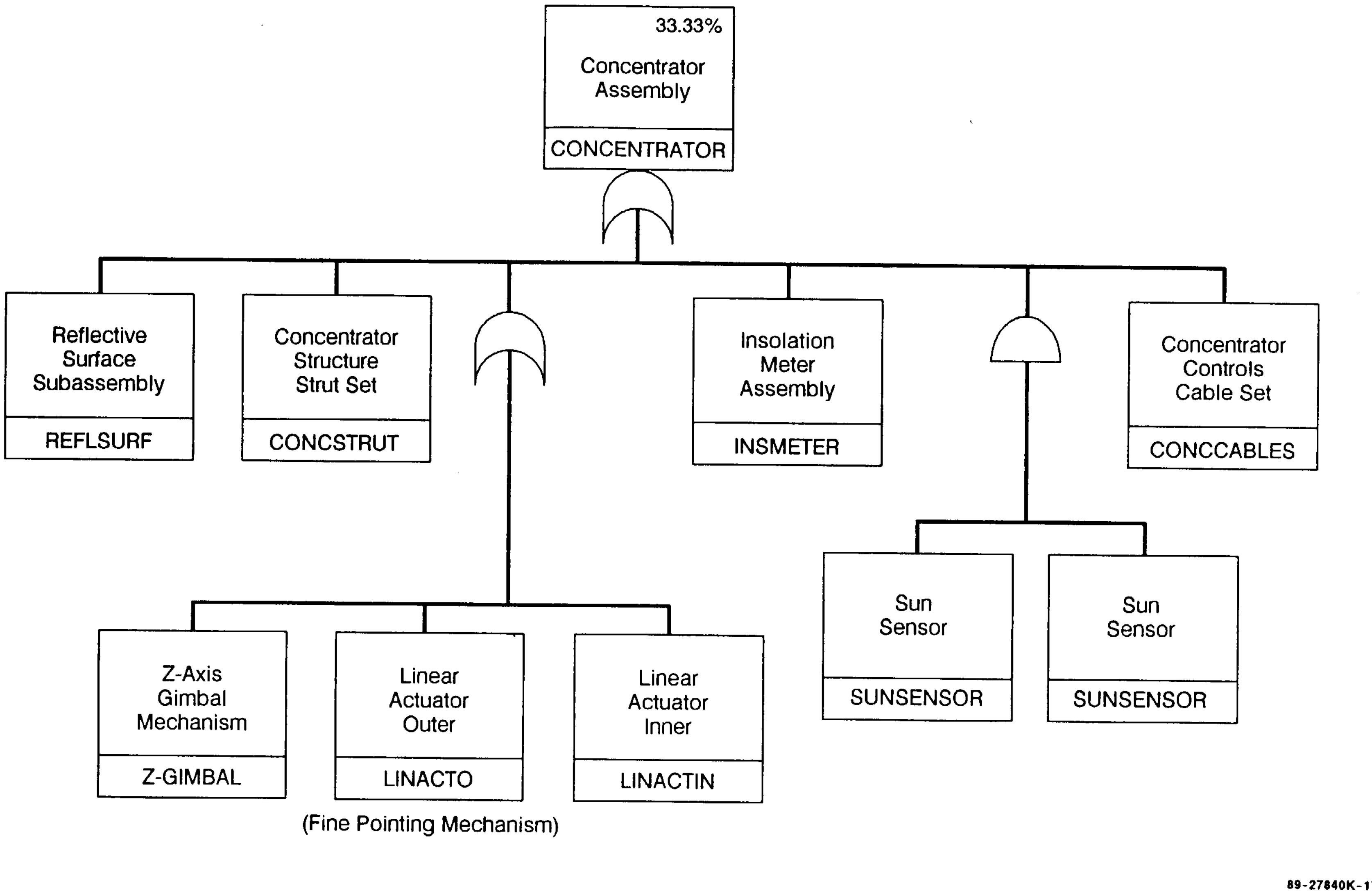


Figure D–29. Concentrator Assembly Fault Tree

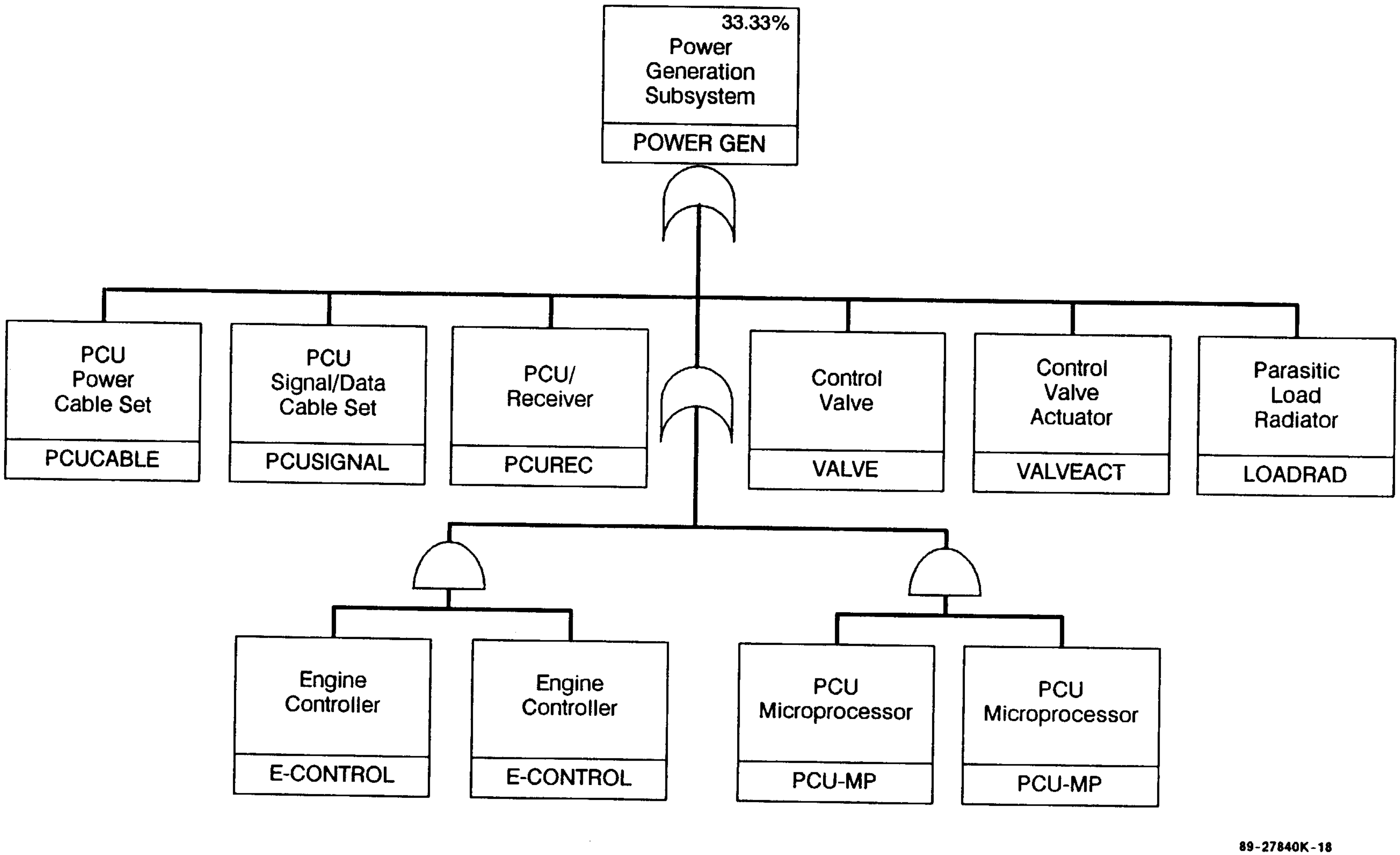


Figure D–30. Solar-Dynamic Power Generation Subsystem Fault Tree

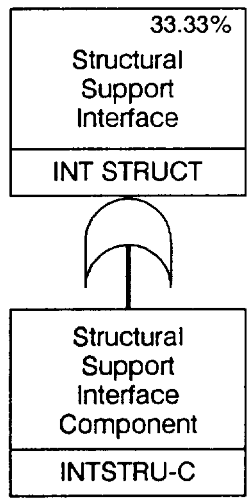


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Figure 31. Structural Support Interface Fault Tree

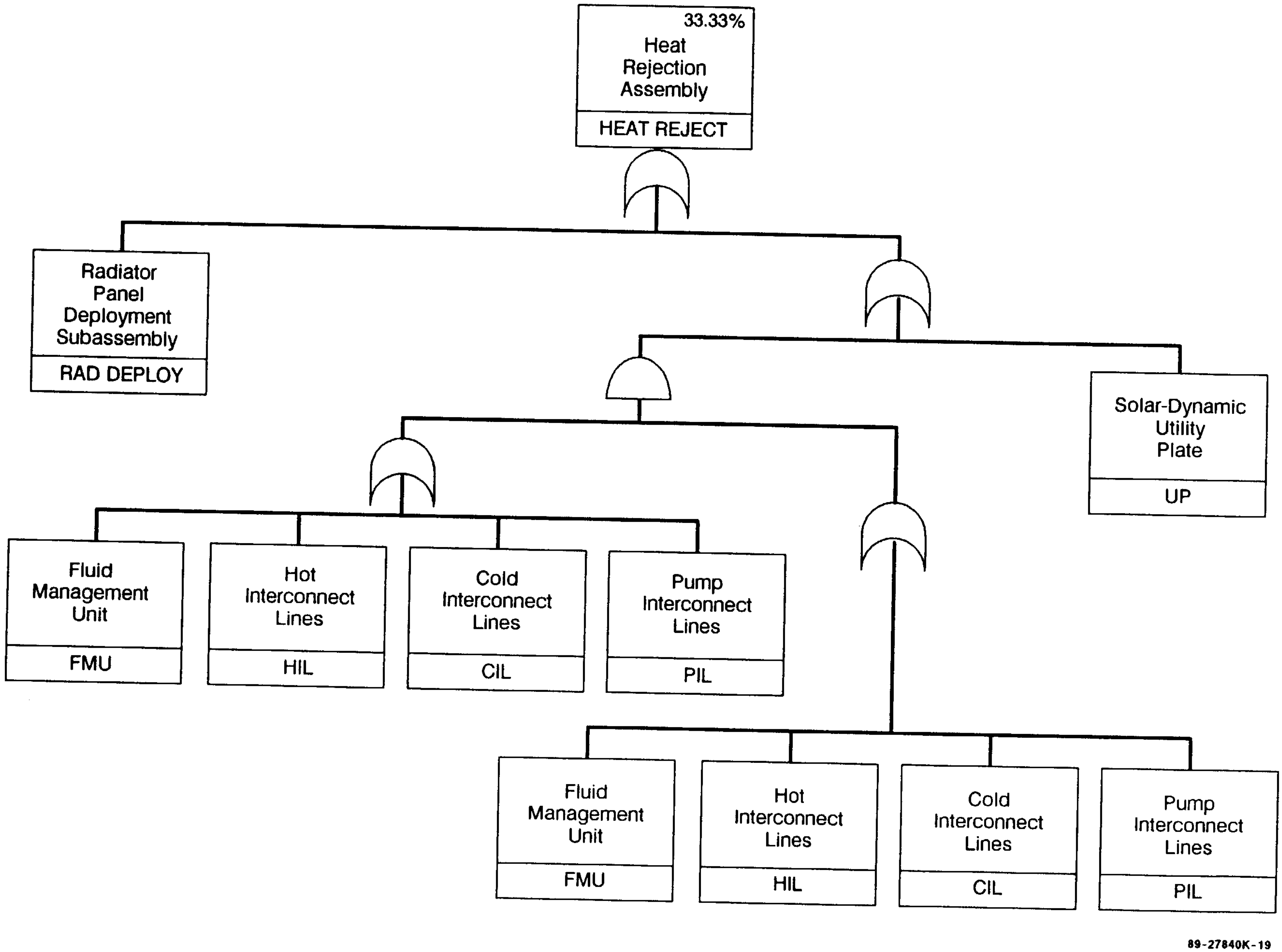


Figure D–32. Heat Rejection Assembly Fault Tree

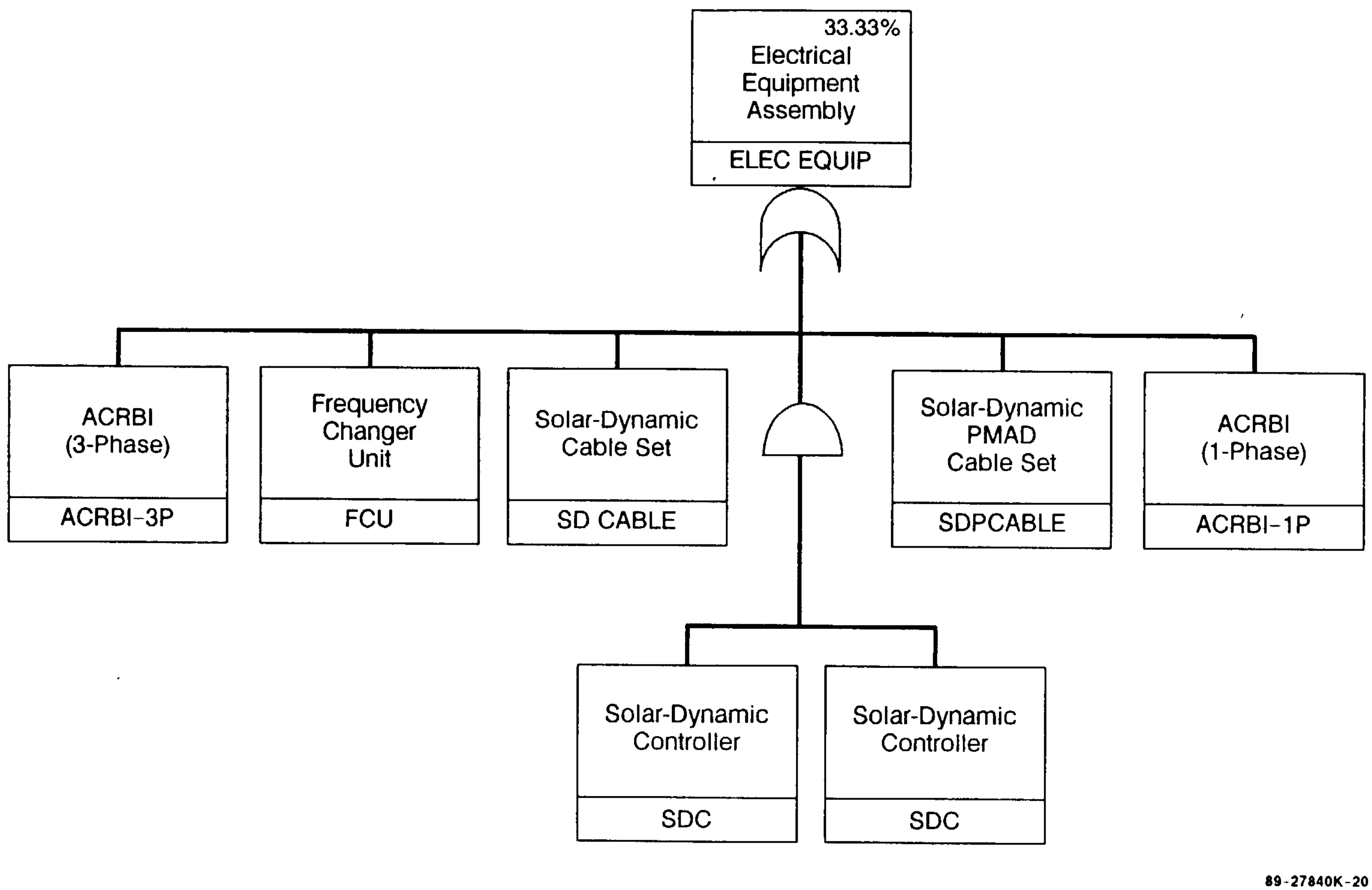
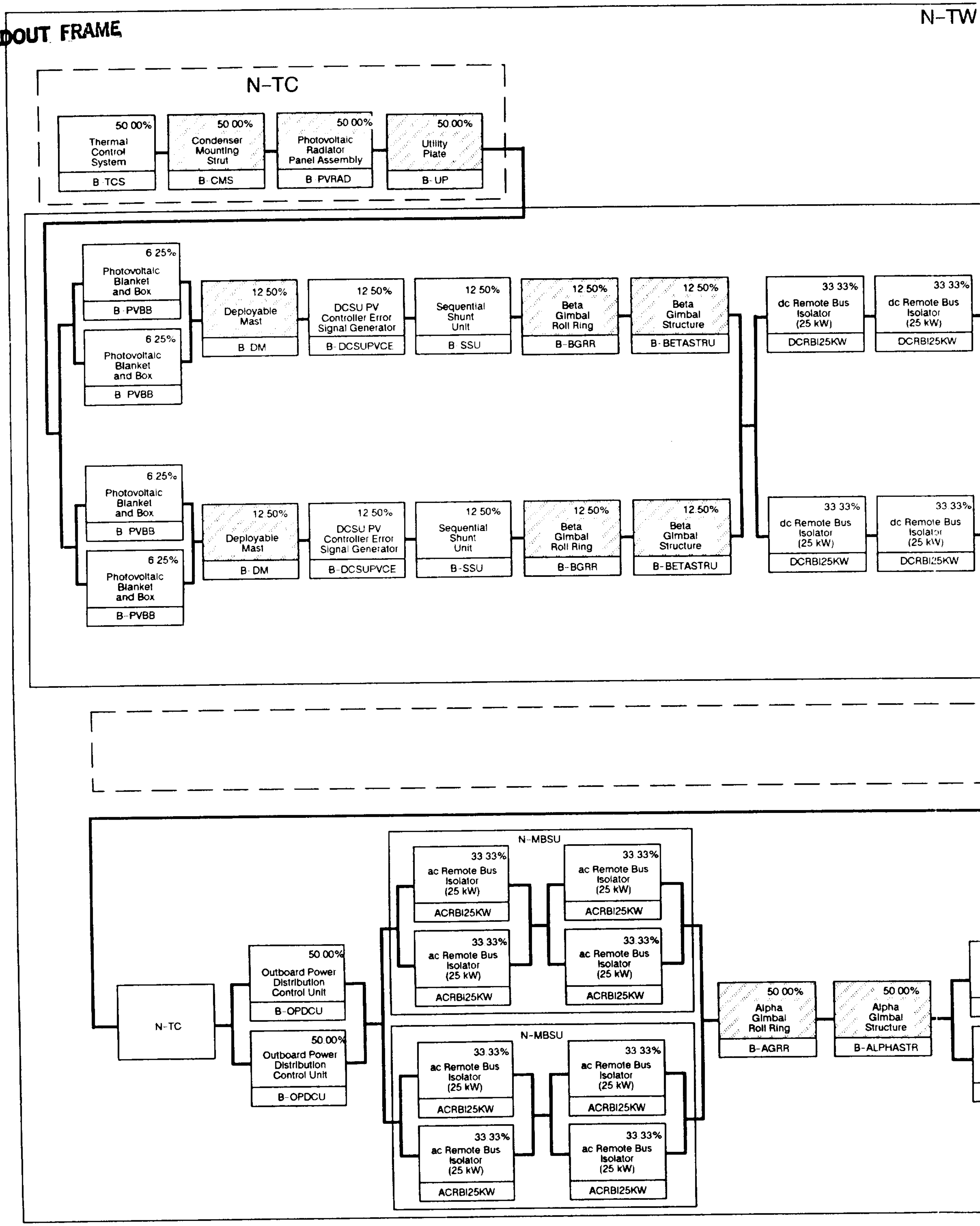


Figure D–33. Electrical Equipment Assembly Fault Tree

FOLDOUT FRAME



D PV MODULES

FOLDOUT FRAME 2

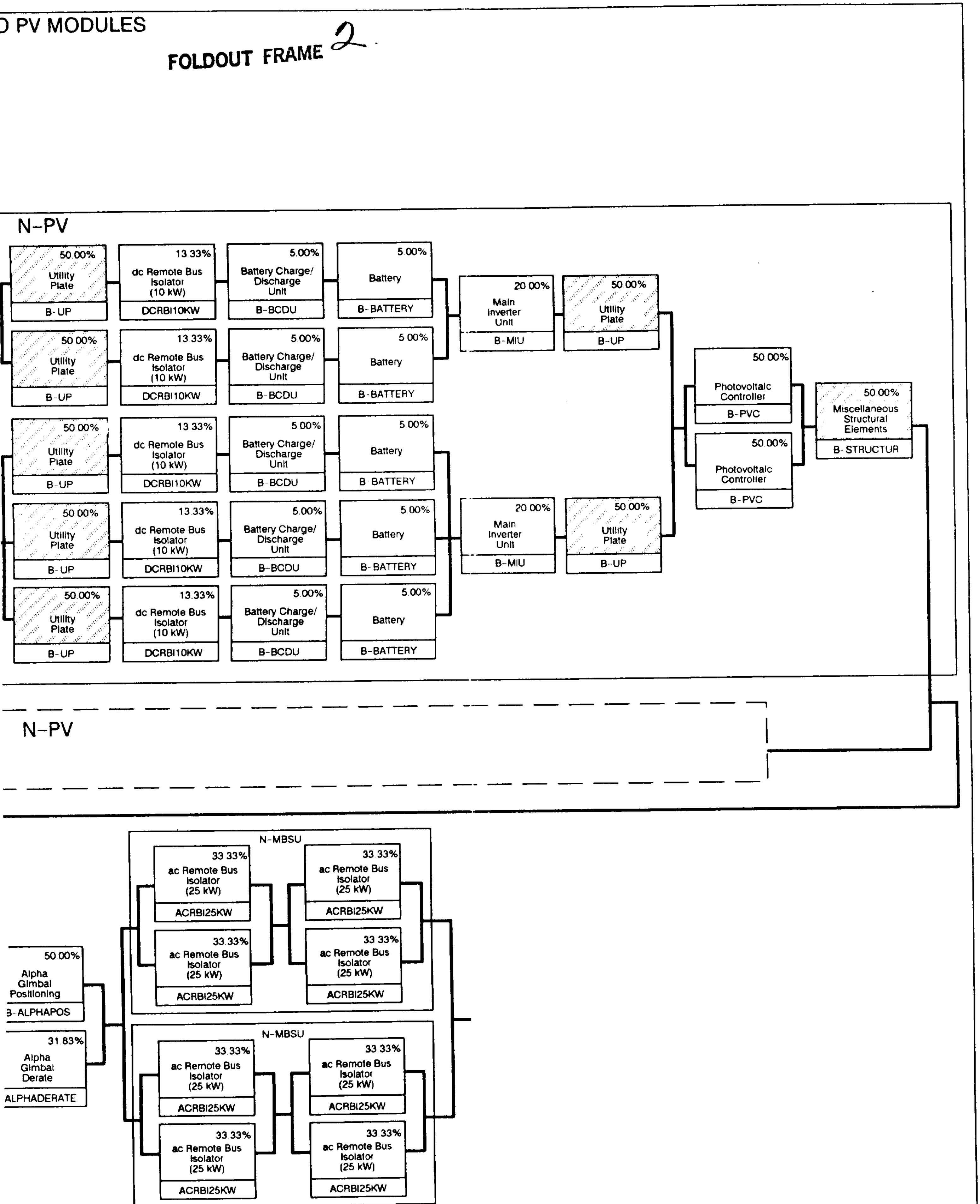


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Figure 2–2. One-Half EPS Power Generation Block Diagram

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Report Documentation Page

1. Report No. NASA CR-185181	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle Space Station Freedom Electric Power System Availability Study		5. Report Date February 1990
		6. Performing Organization Code
7. Author(s) Scott R. Turnquist		8. Performing Organization Report No. ARINC Research Publication 4247-01-01-5032
		10. Work Unit No. 474-12-10
9. Performing Organization Name and Address Analex Corporation NASA Lewis Research Center Cleveland, Ohio 44135		11. Contract or Grant No. NAS3-24564
		13. Type of Report and Period Covered Contractor Report Final
12. Sponsoring Agency Name and Address National Aeronautics and Space Administration Lewis Research Center Cleveland, Ohio 44135-3191		14. Sponsoring Agency Code

15. Supplementary Notes

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16. Abstract

This report details the results of follow-on availability analyses performed on the Space Station Freedom electric power system (EPS). The scope of this study includes analyses of several EPS design variations, these are: the 4-photovoltaic (PV) module baseline EPS design, a 6-PV module EPS design, and a 3-solar dynamic module EPS design which included a 10 kW PV module. The analyses performed included: determining the discrete power levels that the EPS will operate at upon various component failures and the availability of each of these operating states; ranking EPS components by the relative contribution each component type gives to the power availability of the EPS; determining the availability impacts of including structural and long-life EPS components in the availability models used in the analyses; determining optimum sparing strategies, for storing space EPS components on-orbit, to maintain high average-power-capability with low lift-mass requirements; and analyses to determine the sensitivity of EPS-availability to uncertainties in the component reliability and maintainability data used in the study.

17. Key Words (Suggested by Author(s)) Availability, Reliability, Maintainability, Space Station	18. Distribution Statement Unclassified – Unlimited Subject Category 18

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of pages	22. Price*
Unclassified	Unclassified	136	A07

NASA FORM 1626 OCT 86

*For sale by the National Technical Information Service, Springfield, Virginia 22161