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ALSEP LONG TERM OPERATIONAL PLANNING

(FINAL)

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1.0 INTRODUCTION

This document provides engineering information relative to the long term operating characteristics of the five ALSEP systems presently active on the lunar surface. The information includes a current summary of the operational status of each of the systems and an assessment of the predicted life from both hardware reliability calculations and RTG power availability. Additionally, recommendations are given for managing each system in terms of power utilization for maximum life. Finally, some suggestions are provided for obtaining useful engineering data at the end of life of the respective systems.

The information presented in this document is intended to provide an engineering baseline which, when evaluated against an overlay of scientific achievements and expectations, will result in an overall plan for maximizing the effectiveness of the ALSEP systems. The scientific assessment, consideration of Flight Operations and requirements for data analysis and archiving will be evaluated separately by NASA and are not a part of this discussion.

0 OPERATIONAL SUMMARY

The assignments, lunar location and date of deployment of each ALSEP are summarized in Figure 1. Figure 2 presents a summary of the current operational status of the ALSEP systems.

The purpose of this report is to discuss the long term utilization of the operating systems. To this end, two ALSEP systems and one experiment, listed in Figure 1, will not be discussed further. These are the ALSEP packages flown on Apollo 11 and 13 and the laser ranging retro reflector package LRRR. The simplified Apollo 11 package, which was powered by solar panels, exceeded its fourteen day design life by fifty seven days and is now non-operational. The Apollo 13 mission was curtailed without an attempted landing. The LRRR package is a passive unit of fuzed quartz corner reflectors used as a reference point for measuring precise ranges between the array and points on earth, using the technique of short pulse laser ranging.

The following subsections amplify on the Figure 2 summary to provide the current status and note significant operational changes that have occurred during mission life of the five operating stations.

Apollo Lunar Surface Experiments Package (ALSEP)

Mission Assignments

LUNAR SURFACE EXPERIMENTS	APOLLO / DATE ON MOON / Lunar Location - Long. - Lat.	11 July 20, 1969 Tranquillity Base 23.4°E 0.7°N	12 Nov 19, 1969 Oceanus Procellarum 23.5°W 3.0°S	13 - -	14 February 5, 1971 Fra Mauro 17.5°W 3.7°S	15 July 31, 1971 Hadley Rille 3.7°E 26.1°N	16 April 21 1972 Descartes 15.5°E 9.0°S	17 Dec 10, 197 Taurus Littrow 30.8 E 20.2°N
SEISMIC								
• Passive		▬	▬	▬	▬	▬	▬	
• Active		-	-	-	▬	-	▬	
• Seismic Profiling		-	-	-	-	-	-	▬
MAGNETIC								
• 3-Axis Magnetic Field		-	▬	-	-	▬	▬	
PARTICLE								
• Solar Wind Spectrum		-	▬	-	-	▬	-	
• Ionosphere Detection		-	▬	-	▬	▬	-	
• Atmosphere Detection		-	▬	▬	▬	▬	-	
• Charged Particle Detection		-	-	▬	▬	-	-	
• Mass Spectrum		-	-	-	-	-	-	▬
• Ejecta and Micrometeoroids		-	-	-	-	-	-	▬
SPECIAL								
• Heat Flow		-	-	▬	-	▬	▬	▬
• Laser Ranging								
- 100 Reflectors		▬	-	-	▬	-	-	
- 300 Reflectors		-	-	-	-	▬	-	
• Gravity		-	-	-	-	-	-	▬

APOLLO STATION / SEP SUBSYSTEM	11 7/20/69	12 11/19/69	14 2/5/71	15 7/31/71	16 4/	17 12
CENTRAL STATION	Mission Complete Uplink Operated 1 mo. Dnlink Operated 5mo.	All Systems Oper. Except Timer 39 Months Oper. >19,000 cmds.	All Systems Oper. Except Timer 36 Months Oper. >11,000 cmds.	All Systems Oper. 30 Months Oper. >20,000 cmds.	All Systems Oper. Except Xmtr A(3/73) 21 Months Oper. >9,800 cmds.	All Systems Oper. 14 Months Oper. >12,500 cmds.
POWER (Initial) (Current)	(Solar Power)	73.6 W 65.1 W	72.5 W 68.0 W	74.7 W 70.4 W	70.9 W 68.9 W	75.4 W 74.9 W
LRRR	Operational	------	Operational	Operational	------	------
PSE	Mission Complete	LP X&Y Sensors OK LPZ Intermittent 1/74 SPZ Malfunctioned at Mission Start No Tidal Data	SP Z&LPX&Y OK LPZ Malfunction No Tidal Data	SPZ&LPX&Y OK LPZ Cal Abnormal 1/74 No Tidal Data	All Sensors Operational No Tidal Data	------
ASE	------	------	Hi Bit Rate Oper OK Geophone 2 Noisy Geophone 3 Failed Mortars Not Fired	------	Hi Bit Rate Oper OK All Passive Systems Operational	------
SIDE/CCGE	------	Hi & Low Energy Detectors OK< 55°C Eng Data OK CCGE Malfunction From Mission Start	Hi & Low Energy Detectors OK Night Only Pos ADC Malfunct. CCGE OK - Night Only	Hi & Low Energy Detectors OK < 85°C < 85°C Eng Data OK CCGE Noisy - Cal Raster Incorrect	------	------
CPLEE	------	------	Analyzer A Partial Analyzer B Malfunct.	------	------	------
SWS	------	Operational	------	Non Operational (Operated for 15 Months)	------	------
LSM	------	Non-Operational (Operated for 30 Months)	------	Non-Operational (Operated for 28 Months)	Operational Exhibited Intermittent Function	------
HFE	------	------	------	Fully Operational Probes < Full Depth	Non-Operational Cable Broken	Fully Operational
LEAM	------	------	------	------	------	Fully Operational Under Limited Temps.
LMS	------	------	------	------	------	Non-Operational Operated for 10 Months
LSG	------	------	------	------	------	Fully Operational Limited Science
LSP	------	------	------	------	------	Fully Operational For Passive Listening

2.1 Apollo 12 ALSEP

Central Station - Fully operational with exception of the timer. Although presently operating in transmitter B and Data Processor Y modes, all redundant capability is still fully usable.

Passive Seismic Experiment - Long period X and Y axis seismic operation continues satisfactory and the experiment engineering data as well as its response to commands is fully operational. The data from the short period vertical sensor system has not been acceptable since the beginning of the mission. Additionally, use of the feedback filter results in an oscillitory condition which negates tidal data. An intermittent condition in the LPZ data was noted during January 1974 wherein the instrument failed to respond properly to calibration and the science data output went to a quiescent condition. This anomaly initially lasted for 2 days, then data appeared proper for about 20 days. As of the end of January 1974 the anomaly had recurred and data is presently quiescent for the LPZ sensor.

SIDE/CCGE - All SIDE sensors and associated circuits continue to operate satisfactorily and engineering data and command response is functional. A minor limitation in performance has been observed above temperatures of 55°C, however operational procedures have been instituted to maintain acceptable thermal conditions. The CCGE malfunctioned from the start of the mission and has not produced acceptable data since.

Solar Wind - Continues to operate satisfactorily except for intermittent modulation loss in proton energy levels 13 and 14.

Lunar Surface Magnetometer - Inoperative since June 1972. Both engineering and science data outputs are static.

2 Apollo 14 ALSEP

Central Station - Fully operational with exception of the timer. All redundant components are fully usable.

PSE - Fully operational except long period vertical sensor and feedback filter. Tidal information is nonexistent as a result.

Active Seismic Experiment - Passive listening mode is operational but is limited in that the geophone #2 circuit is not functioning and geophone #3 data is erratic. The weekly high bit rate operation has been discontinued as a result of an assessment of the scientific usefulness. The mortar experiment was never actuated due to deployment location and questionable stability. Any further exercise of this portion of the experiment is presumed to be of engineering interest only in view of the current operational condition of the geophones and would only be considered as a last resort before final termination of the total system.

Charged Particle Experiment (CPLEE) - Limited operation on Analyzer A continues. Analyzer B failed after two months of lunar operation. The instrument continues to output engineering data and is fully responsive to commands.

SIDE/CCGE - SIDE is presently operational during the lower temperature phases only, due to apparent arcing in the High Voltage supply at elevated temperatures. In addition, an anomaly in the positive section of the A/D Converter precludes processing of any positive value inputs. This condition complicates the evaluation of scientific data in that certain engineering parameters are required for proper interpretation of science output. Operating power modes for the Apollo 14 SIDE experiment are now limited to OPERATE and OFF. The STANDBY mode must be avoided at lunar night due to an apparent open circuit in the standby power supply line. The cause of this anomaly is presumed to be a blown fuse in the PDU control circuits.

The CCGE is still functional but operational modes are limited due to the SIDE electronics anomalies described above.

3 Apollo 15 ALSEP

Central Station - Fully operational on primary components.

PSE - Fully operational for all functions except that an abnormal response to LPZ calibration has been observed in January 1974. Attention is required in operational profile for degraded thermal performance and routine leveling.

SIDE/CCGE - Fully operational for all functions except during high temperature condition. Standby mode is selected when the temperature approaches 85°C to preclude internal high voltage arcing. CCGE continues to output useful data but tends to exhibit erratic and noisy information at low temperatures.

Solar Wind - Non-operational since June 1972. Experiment is maintained in STANDBY and periodically switched to OPERATE to assess any change in performance.

Magnetometer - Engineering and science data static since December 1973.

Heat Flow Experiment - Fully operational.

2.4 Apollo 16 ALSEP

Central Station - All functions continue in a nominal condition with Transmitter B in use. The prime downlink transmitter exhibited anomalous performance after a year's operation. Investigation of the anomaly indicated that power output had fallen off approximately six db and resulted in intermittent ground station signal reception. The system is operating as a consequence, with the backup transmitter. All other components are available for use should the prime fail or degrade. In the event of failure of Transmitter B, it is expected that transmitter A could still be used in a degraded mode of operation, e.g., low bit rate, to extend mission life to the maximum.

PSE - Fully operational except for tidal data operation, but with minor thermal control problem during lunar day. Higher temperatures at lunar noon cause minor operational anoyances such as increased leveling activity.

ASE - Fully operational for passive listening however, this operation has been discontinued due to an assessment of scientific usefulness.

Heat Flow Experiment - Non-operational due to broken cable.

Magnetometer - The instrument has been fully operational for the past six months. Prior to August 1973, the instrument exhibited intermittent performance in science data output and flip calibration operation.

2.5 Apollo 17 ALSEP

Central Station - Fully operational. All redundant components remain available for contingent utilization.

Heat Flow Experiment - Fully operational.

Lunar Ejecta and Meteorites Experiment - Fully operational under limited temperature conditions. The instrument has continually exhibited excessive temperatures as the lunar noon condition approaches. Operations have been curtailed as temperatures approach 196 °F as a conservative measure to maximize reliability and extend life relative to idealized science return during the lunar noon condition. Reassessment of the LEAM reliability in terms of stress at elevated temperatures has been performed. Results of this analysis indicate that the instrument would not be degraded at temperatures as high as 212°F. Continuous monitoring of the temperature performance indicates that the instrument thermal balance may be dependent on slight variation of the sun angle due to summer/winter solstice. Current temperatures are repetitive of those measured approximately a year ago indicating a possible cyclic profile. The present temperatures are lower than the maximums measured at equivalent sun angles during previous lunations. Full operation through the lunar noon condition may be possible as a result during this lower temperature period.

Lunar Siesmic Profiling Experiment (LSPE) -
The LSPE remains fully operational for the passive seismic listening mode. High bit rate data is satisfactory and the instrument engineering data as well as command response continues to function properly.

Lunar Mass Spectrometer - The LMS operated satisfactorily for approximately 10 months. An initial failure of the number one filament was followed by an apparent high voltage power supply breakdown in October 1973. The instrument is maintained in the standby power mode and is periodically switched to operate to a ascertain any performance change.

Lunar Surface Gravimeter - The LSG instrument continues to perform nominally in its engineering functions and is producing limited scientific data. Exercise of the instrument is performed at intervals in an attempt to overcome deficiencies in the beam centering capability.

3.0 OPERATING LIFE

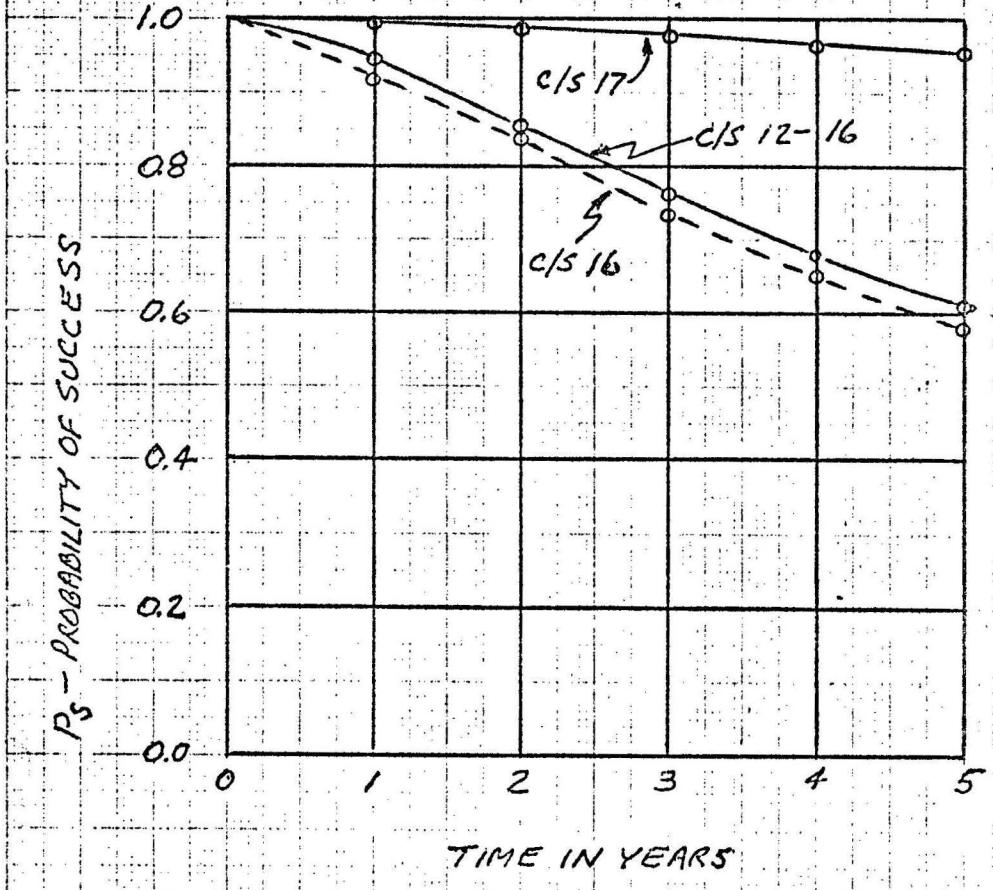
The prediction of the operating life of the ALSEP systems is a function of a reliability assessment of the individual subsystems and the availability of RTG power to maintain thermal control as well as functional requirements. The reliability assessment results in a probability of success relative to life time, and is based on cumulative failure rate calculations of the parts and materials used in each subsystem or component. This probability calculation is relatively fixed and is only dependent primarily on maintenance of the operating thermal environment within pre-established limits. Initial selection, screening and burn-in of parts and materials precludes consideration of wear-out in this assessment since typical life characteristics of individual parts are in the order of 20-30 years minimum.

Availability of RTG power is, on the other hand, a real limitation on the life of the ALSEP systems. Judicious management of system power is required to maximize the total operating life of the ALSEP systems. This management is dependent on continued real time assessment of each system and is based on science priorities as well as engineering performance of each experiment and the central stations.

3.1 Reliability Predictions

The probability of success for each deployed ALSEP central station and experiment is graphically shown in Figures 3 through 5. Although each of the subsystems was theoretically designed to meet 1 or 2 year life requirements, there are significant probabilities that individually and collectively, the systems will continue to provide useful science data for the next several years. Given that an individual subsystem is operating today, the prediction may be taken at 0 time, and viewed over the next several years.

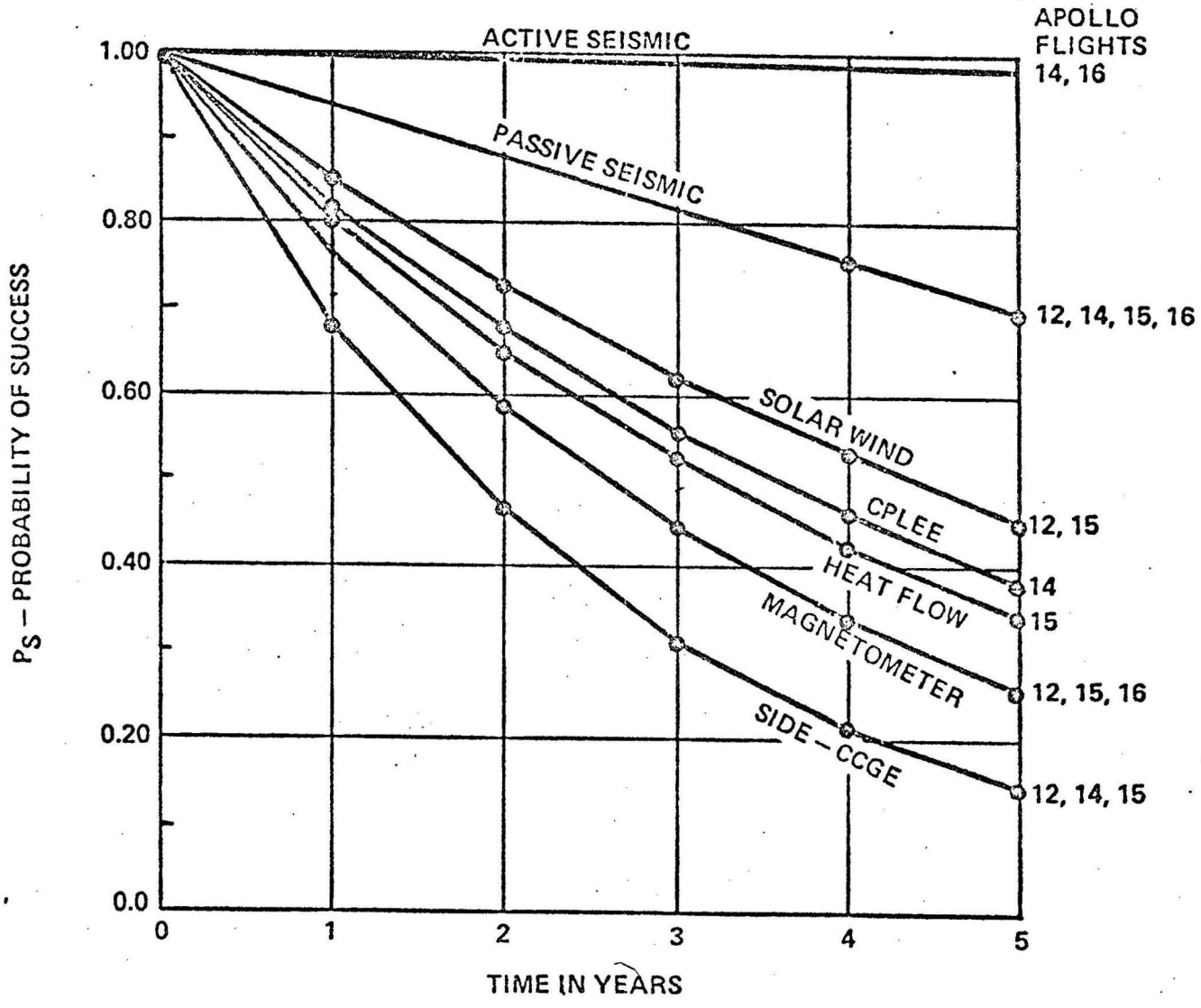
FIGURE 3 ALSEP CENTRAL STATION RELIABILITY



TIME YEARS	P_S C/S 12-16	P_S C/S 16	P_S C/S 17
1	.9468	.9173	.9951
2	.8546	.8361	.9878
3	.7608	.7362	.9786
4	.6790	.6499	.9675
5	.6121	.5795	.9548

Figure

ALSEP EXPERIMENT RELIABILITY



F 5 - ARRAY E EXPERIMENT LIABILITY

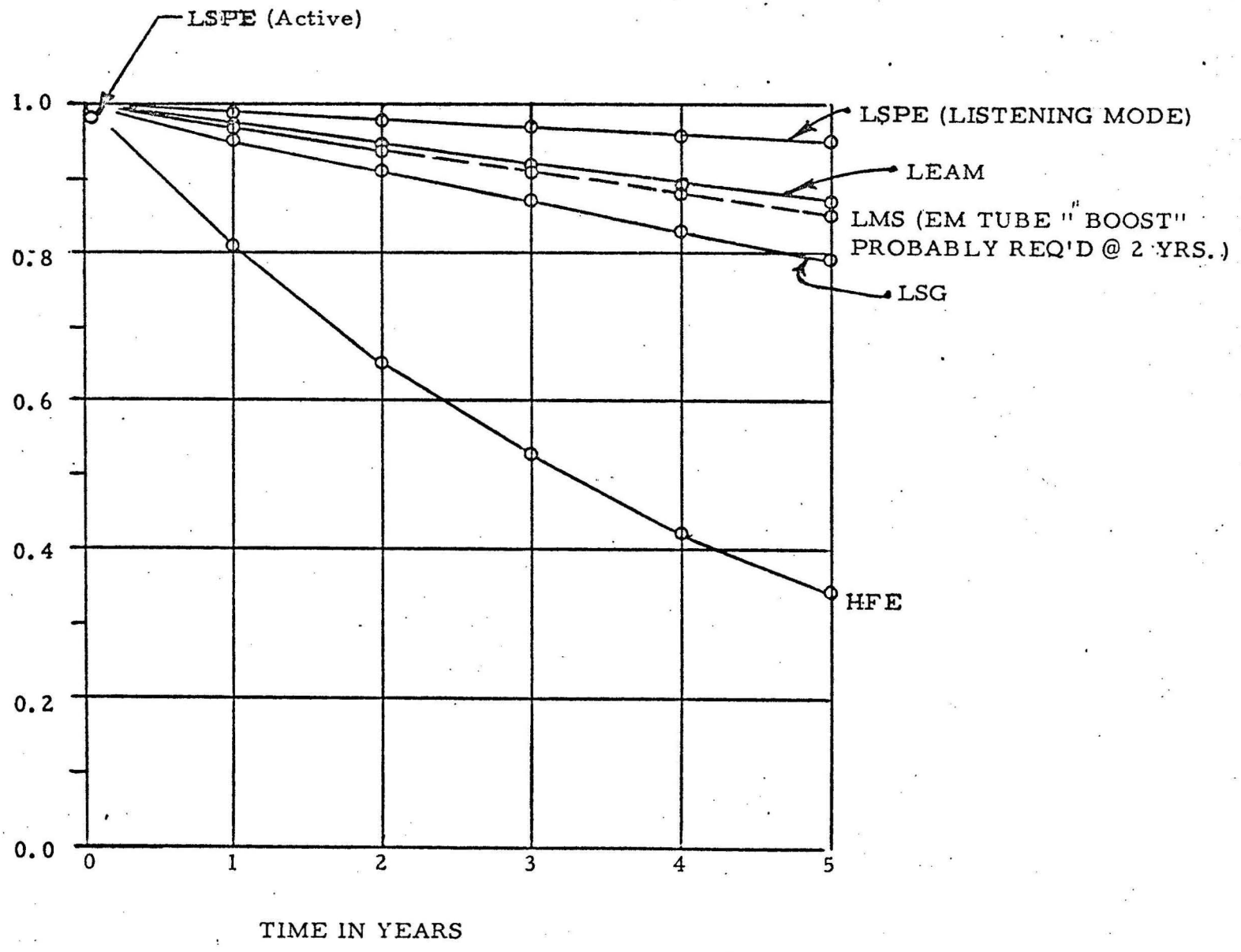


Figure 3, Central Station Reliability shows a separate dotted curve for C/S 16. This curve should be used as the current prediction of probability of success based on an apparent failure of one of the redundant transmitters. The equivalent degradation can be seen from comparison of the solid (original predictions) and broken curves.

3.2 RTG Power Availability

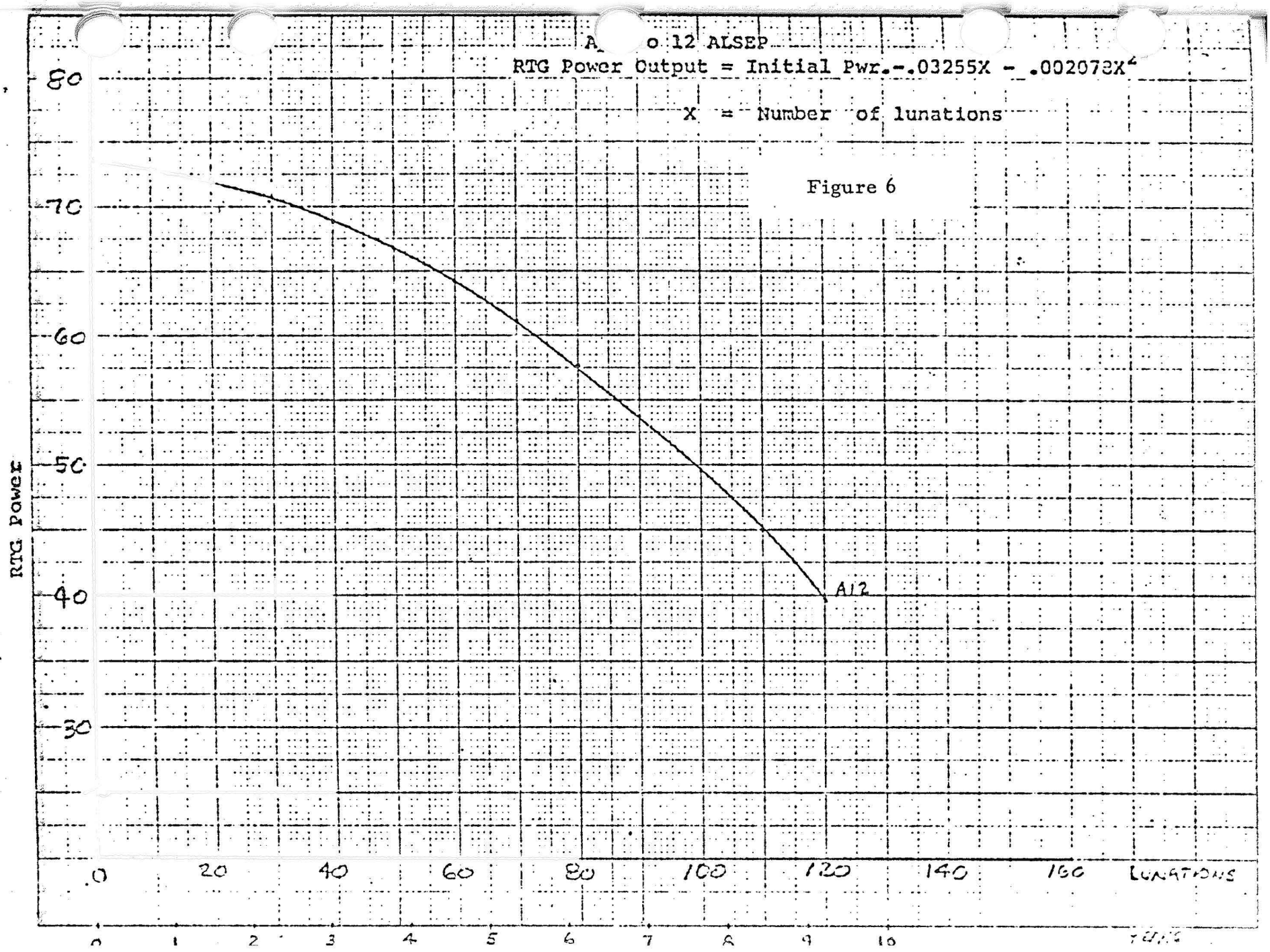
The RTG power output decreases with time as the fuel element is depleted, the thermal coatings degrade, the inert gas pressure decreases and the thermopile efficiency degrades. A graph showing typical degradation rates using data accumulated to date and curve fitting extrapolation techniques is shown in Figure 6. In each system, as the RTG power decays, load adjustments will be required to maintain Central Station Thermal plate temperatures above -10°F during lunar night operation and to avoid activation of the ripple off circuits. A tradeoff analysis was performed and was documented in ASTIRTM44-2 to determine the operating configuration of the experiments and Central Station heaters that results in optimum usage of the remaining power. The recommendations for power management as the available power decays are given in the following section.

4.0 RECOMMENDATIONS

4.1 Power Management

The optimum long term profiles which give the maximum scientific return from each array can be obtained through the selection of one of several operating load configurations.

The recommended turn-off sequences are based on maintaining the minimum temperature of the Central Station thermal plate above -10°F, considering the Passive Seismic Experiment (PSE) as the highest priority experiment. This means that PSE will normally be the last experiment to be turned off, unless it experiences a failure. Where possible experiments are initially set to standby ON, for survival during lunar night, so that operation may be commanded during lunar day. The experiments will probably not survive if left off at night.


A 12 ALSEP
RTG Power Output = Initial Pwr. -.03255X - .002078X²
X = Number of lunations
Figure 6
RTG Power
80
70
60
50
40
30
A12
0
20
40
60
80
100
120
140
160
LUNATIONS
0
1
2
3
4
5
6
7
8
9
10

4.1.1 Apollo 12, ALSEP Turn Off Sequence

Figure 7 indicates the prime options available for turning off experiments and the power levels at which decisions must be made. The option which is selected will depend upon operational status when the decision is made and the relative merits of the scientific data being received.

4.1.2 Apollo 14, ALSEP Turn Off Sequence

The functional options available are indicated in Figure 8 together with the power levels at which decisions should be made. The Suprathermal Ion Detector (S.I.D.E.) has blown the fuze in the standby line and so it may only be turned off. The Active Seismic experiment is in standby, except during listening periods, and should be maintained in this status unless a decision is made to abandon any attempt to fire the mortars.

4.1.3 Apollo 15, ALSEP Turn Off Sequence

The available options and power level decision points are shown in Figure 9. The Solar Wind Spectrometer (SWS) has been in standby since June 1972 because of high current drain and scrambled data and since it shows no signs of correcting itself it is the prime candidate to be turned off first. No options are shown for PSE as it is considered the highest priority experiment and as such the last to be turned off.

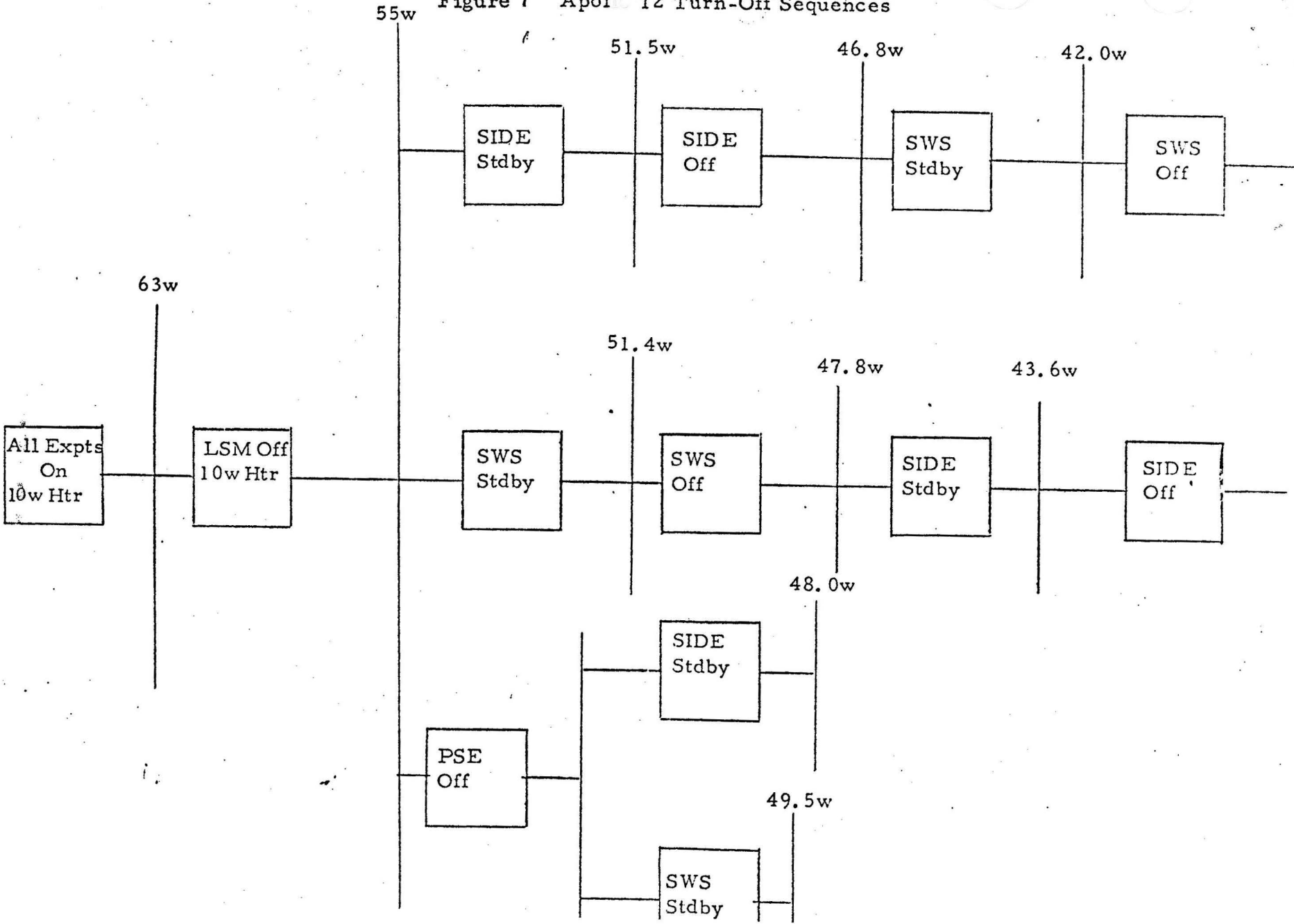
4.1.4 Apollo 16, ALSEP Turn Off Sequence

The two options and power level decision points are shown in Figure 10. The Heat Flow experiment is inoperative and Active Seismic experiment is normally Off except for listening periods, leaving only two possible options, which include turning PSE to standby.

4.1.5 Apollo 17, ALSEP Turn Off Sequence

The power subsystem design provides for automatic management of available reserve power; therefore the Apollo 17 experiments

Figure 7 Apol 12 Turn-Off Sequences



Figure

Apollo ALSEP Tur ff Sequen

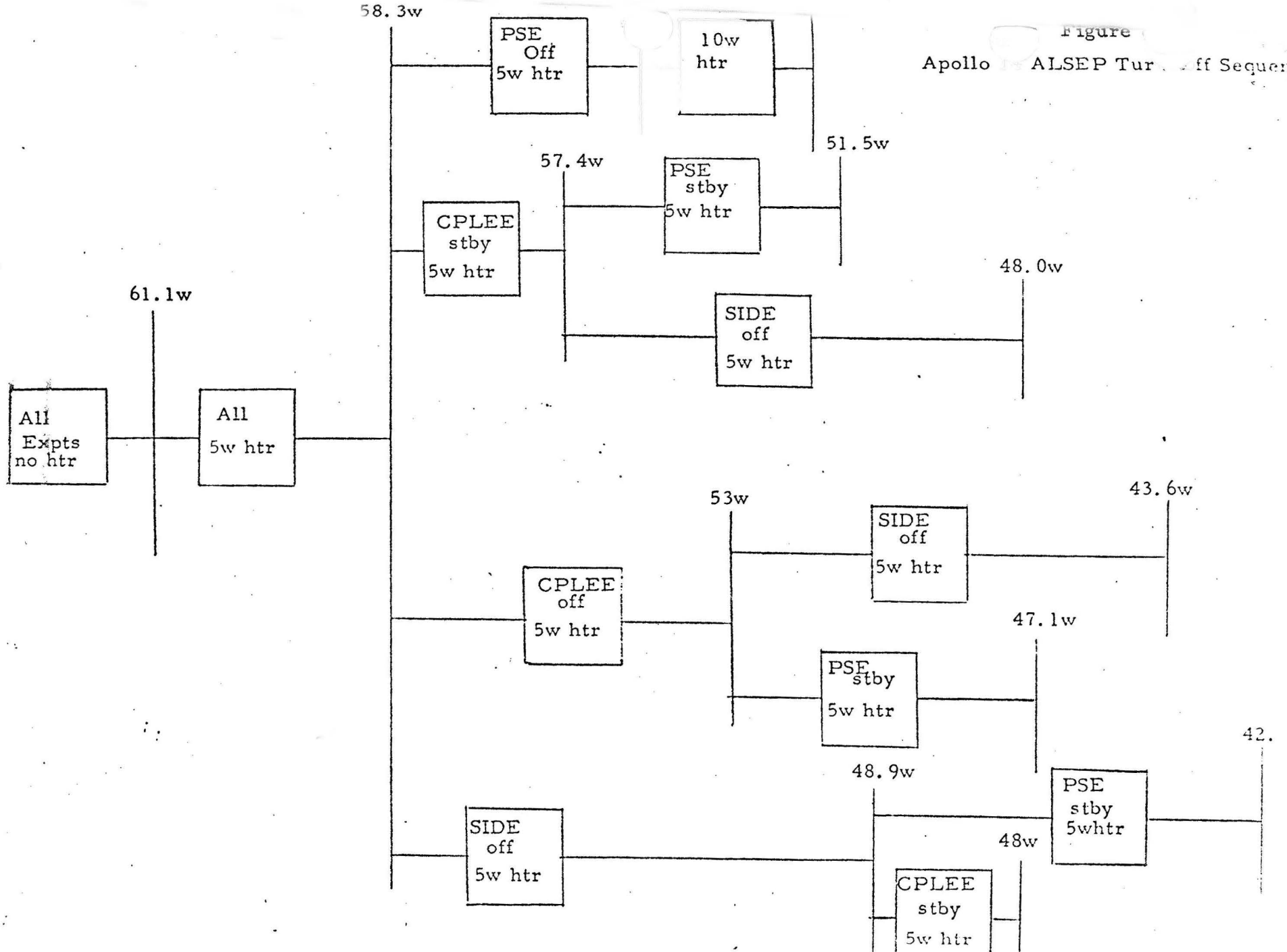


Figure 7

Ap[redacted]15 - Exper[redacted]nt Termination Sequences

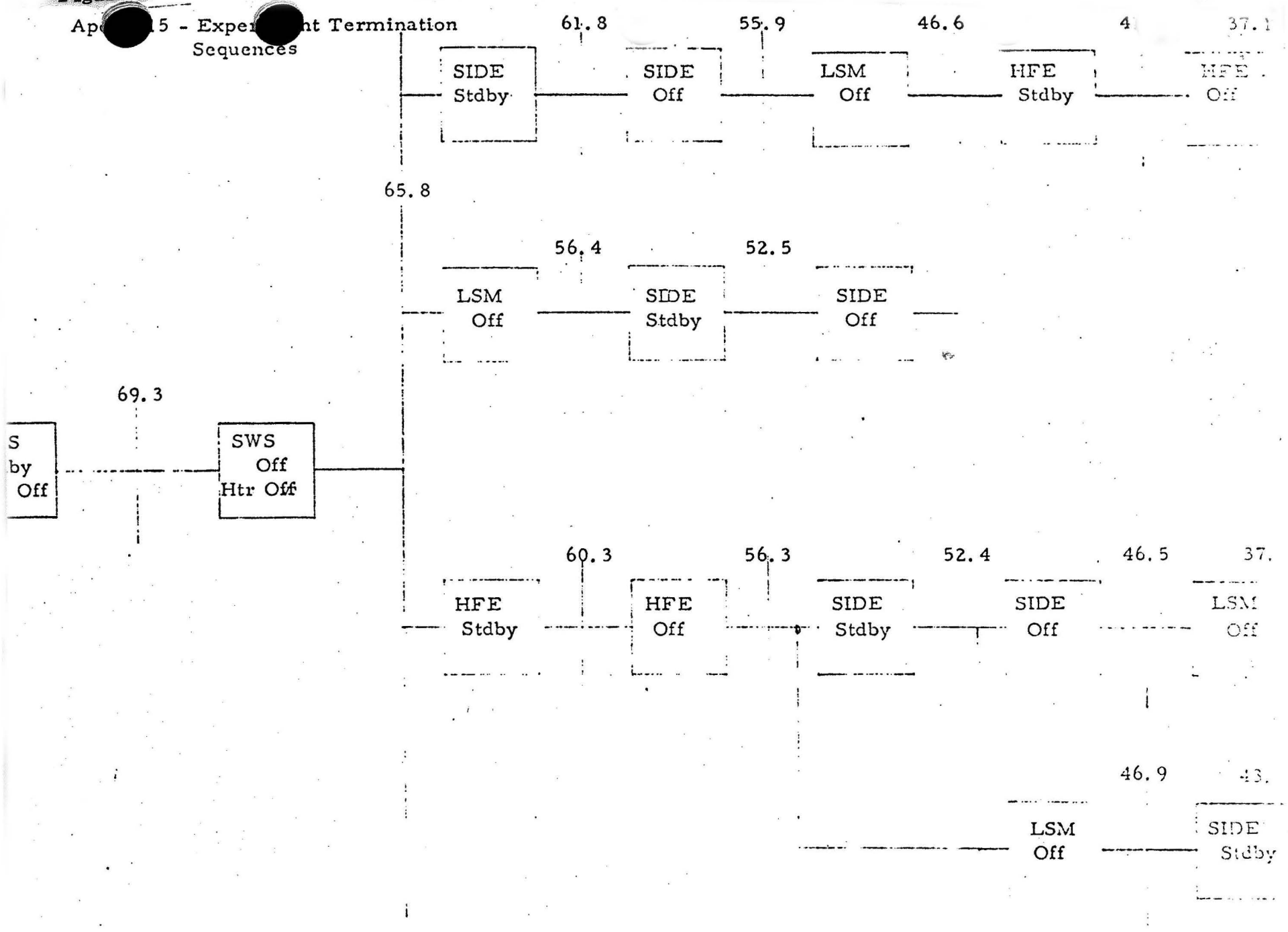
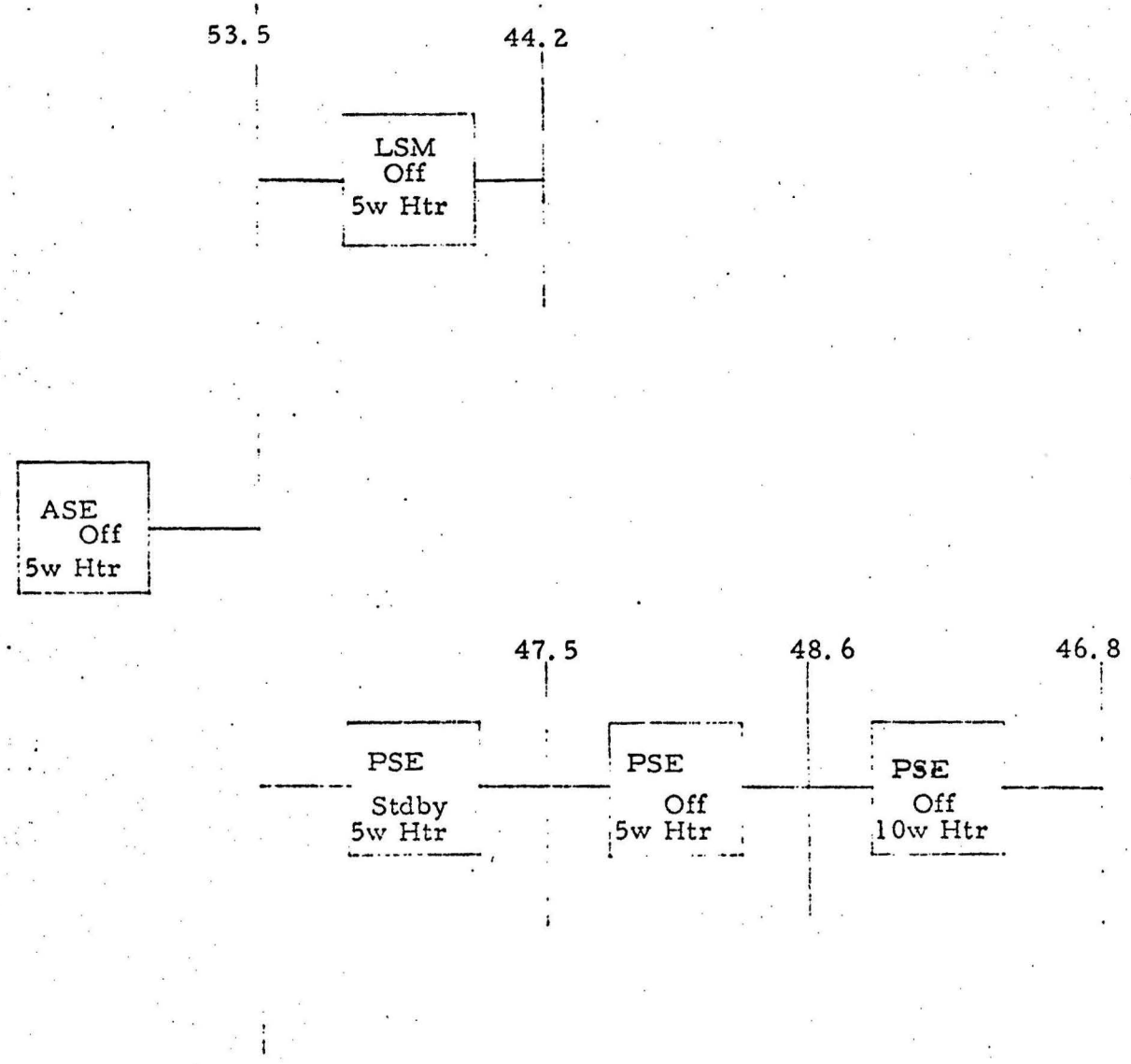


Figure 10

Apollo 16 - Experiment Termination Sequences



may be turned off in any preferred sequence which may be dictated by scientific requirements or functional status. The excess power is automatically controlled by dissipating it either into the heaters on the thermal plate or into the external load resistor as required by the thermostat which senses thermal plate temperature.

The power at which action must be taken to turn an experiment to standby or off is 64 watts for a fully operating system, operating down to -10°F, or 60.5 watts for a fully operating system, operating to -22°F. The temperatures are average thermal plate temperatures.

The minimum RTG power required to maintain -10°F as the average thermal plate temperature is given by,

RTG power = 33.5 + sum of all experiment powers

or

RTG power = 30 + sum of all experiment power, for -22°F.

Thus the required power levels can be determined for any combination of experiments. The experiment load should be calculated from the telemetered values of RTG power, reserve power, etc.

4.2 Engineering Test Recommendations

The primary objective of the ALSEP mission is to obtain the maximum amount of a scientific data possible from each of the operational instruments. While it is recognized that this objective must not be compromised, it is also important to note that valuable data of an engineering sense is continuously available from these operating systems. When a final decision is made (hopefully several years hence) that the scientific usefulness of the ALSEP systems is at an end, a plan should be available for conduct of engineering tests prior to final station shutdown.

Each of the central stations contains component redundancy which may not have been exercised during the course of the mission. It is important that these components be tested — valuable "shelf life" data may result. Additionally, it is recommended that all

systems be operated as long as power is available from the RTG. Continued carefully planned tests with monitoring on an intermittent (rather than full time) basis would result in a cost effective but valuable engineering test program for the ALSEP hardware.