ASSESSMENT OF TWO YEAR ALSEP ARRAY E CAPABILITY.

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1.0 INTRODUCTION

Basically, the two year life of ALSEP Array E is achieved by "designing-in" a high degree of redundancy and "designing-out" single point failures in the Central Station (uplink, downlink and power subsystem), by intensive selection and screening of electronic and electro-mechanical parts for Central Station and Experiment hardware, and by assuring the maximum achievable stress de-rating of all electronics and electro-mechanical parts used. In addition, the use of limited life (or cycle sensitive) parts and materials were meticulously avoided by selection of items from BxA ATM-241 (parts) and BxA ATM-242 (materials).

Also, ALSEP Array E development, prototype, qualification and flight hardware testing at all configuration levels was assessed by ALSEP Reliability to assure that adequate de-rating and malfunction corrective action was accomplished throughout the program.

Design control documents in the form of:

.. Parts Application Analysis (de-rating)
.. Failure Mode Effects and Criticality Analysis
.. Reliability Predictions (numerical analyses)
.. EEE Parts Lists (selection of parts)
.. Non-Metallic Materials Lists
.. Reliability Time and Cycle Sensitive Parts Lists
.. Parts Source Control Drawings (screening requirements)

were prepared and issued by ALSEP Reliability concurrent with design disclosure to assure that no hazards to the two year life capability were overlooked for all Central Station and Experiment Hardware.

The ensuing paragraphs consider specific subjects related to two year life expectancy, namely:

.. Reliability Predictions
.. Time/Cycle Sensitive Items
.. Previous ALSEP Lunar Operations
.. Thermal/Power Prediction vs Time
.. Qualification Levels

2.0 RELIABILITY PREDICTIONS

Table 1 shows a summary of Array E Reliability Predictions. It is of notable significance that all new Array E experiments (in conjunction with the Data Subsystem) show better than 90% probability of success for their intended mission.

TABLE 1

ALSEP Array E Reliability Prediction Summary
(Experiments shown in reverse order of ripple-off)

Subsystem or Experiment	Reliability (Prob. of Success)	Prediction Criteria
Data S/S (Incl. Power S/S	.9878	2 years with all functions intact
LSPE (Listening)	.9804	Passive is for 2 years in "Listening Mode" only (LSPE Central Electronics and Geophones)
Listening Mode LSPE X Data S/S	.9684	
LSPE (Active)	.9845	200 hours operation of LSPE Central Electronics, 90 hours on timers, 1 hour for thermal battery and items powered by battery.
Active Mode LSPE X Data S/S	.9843	Is with all functions intact and includes all 8 EPA's (active mode).
LSG	.9122	2 years with all functions intact
LSG X Data S/S	.9011	
HFE	.8080	
HFE X Data S/S	.8040	1 year with all functions intact per earlier array design criteria.
LEAM	.9460	Is for total functioning of east, up, and west sensors for 6 months plus functioning of east, up and west sensors without microphones for an additional 18 months. This does not include HK data. (This is mission success criteria)
LEAM X Data S/S	.9345	
LMS	.9380	2 years with at least all three channels of mass count data as a minimum
LMS X Data S/S	.9266	

Figure 1 is a projection of the Array E experiment Probability of Success (Reliability) for five years. Note that for the established mission success criteria, all new Array E experiments have a probability of success of 79% or better for five years. It is expected, however, that LMS will need commands for switch to the Electron Multiplier Tube "boost" voltage at about the end of two years of operation.

Figure 2 shows a projection of Previous Array Experiment Probability of Success for five years. Note that, in general, the predictions for Array E experiments are greatly improved over those for previous experiments.

Figure 3 shows the Array E Central Station (Data/Power Subsystem) Probability of Success vs Previous Array Data Subsystems. The large degree of improvement for Array E was due primarily to adding complete redundancy and elimination of single point failures. The Array E Central Station probability of success is better than 98%/2 years (95%/5 years). On previous arrays, the central station was better than 85%/2 years (61% for 5 years).

FIGURE 1 - ARRAY E EXPERIMENT RELIABILITY

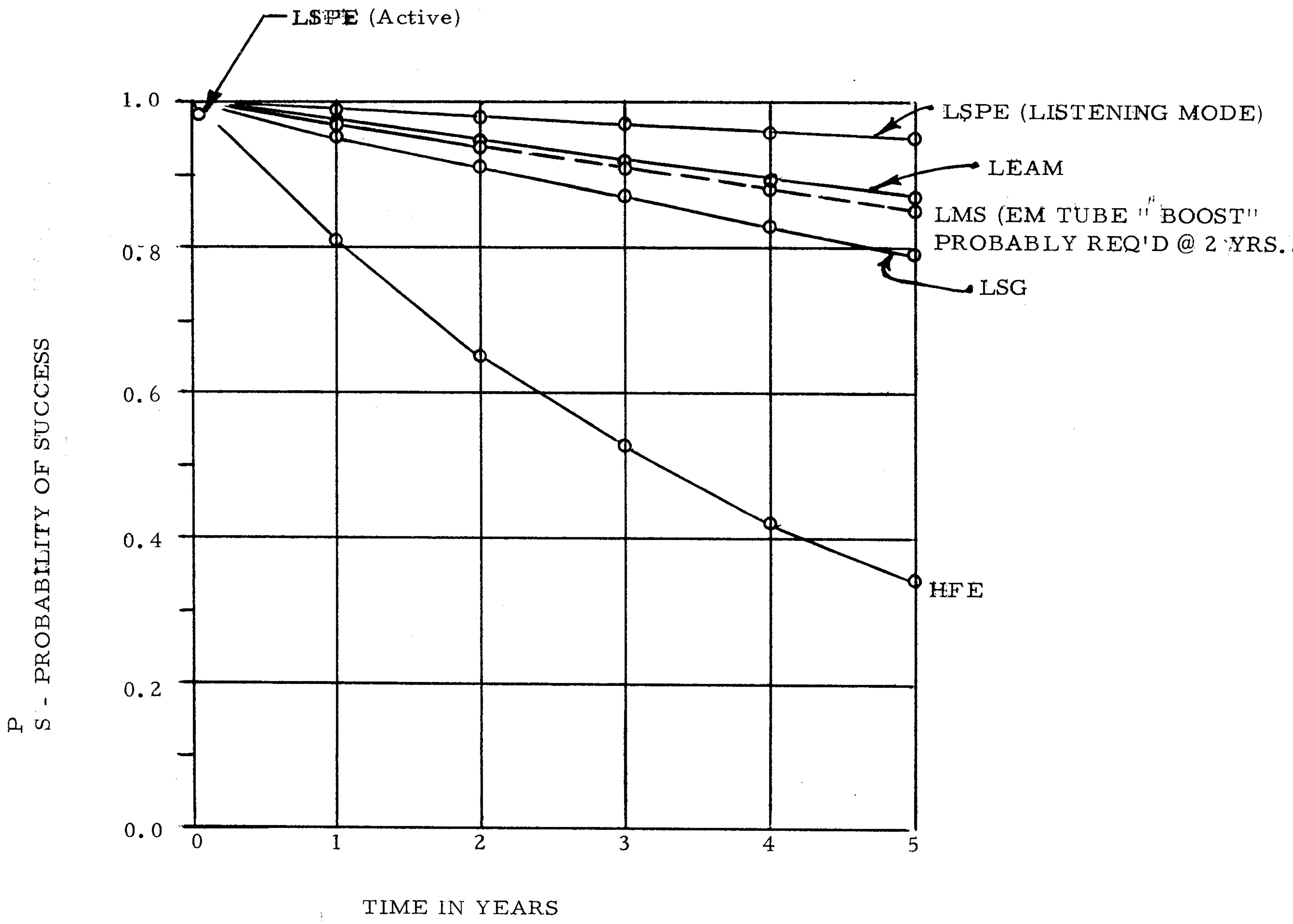


FIGURE 2 - PREVIOUS
ALSEP EXPERIMENT RELIABILITY

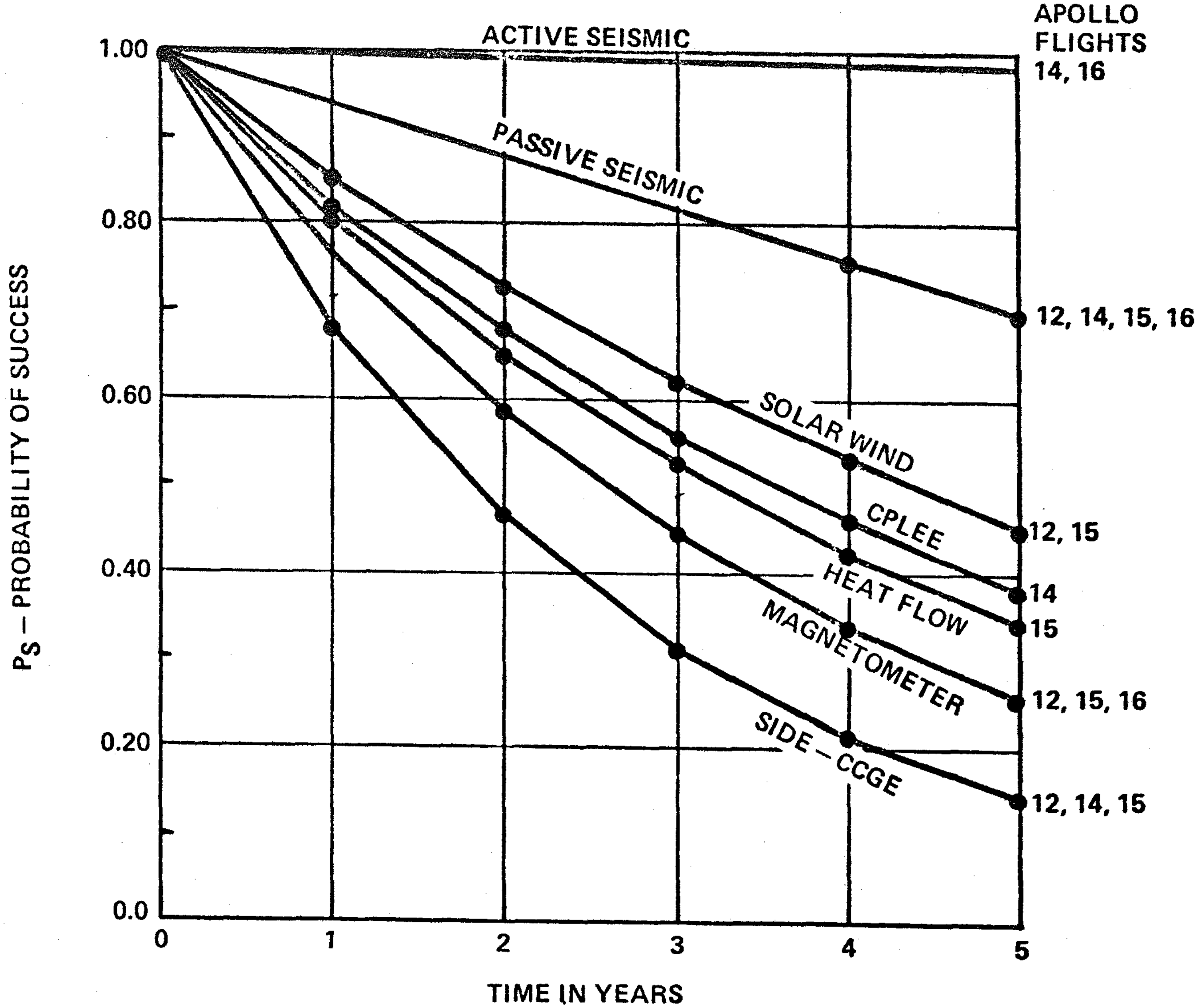
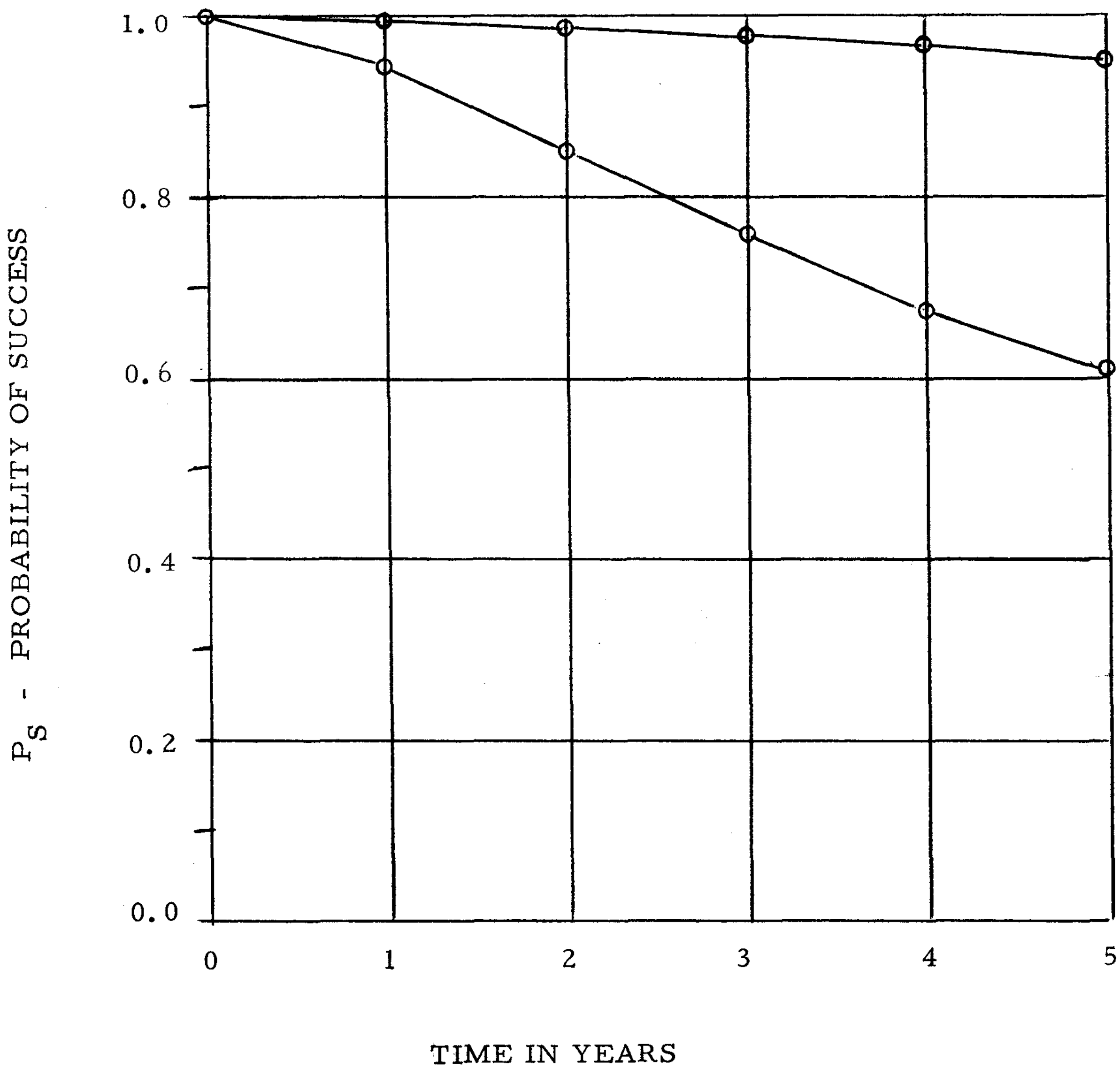


FIGURE 3 - ALSEP CENTRAL STATION DATA AND POWER SUBSYSTEM RELIABILITY



TIME Years	P_S C/S 12-16 Data/Pwr	P_S C/S 17 All Func.
1 yr.	.9468	.9951
2 yr.	.8546	.9878
3 yr.	.7608	.9786
4 yr.	.6790	.9675
5 yr.	.6121	.9548

3.0 TIME/CYCLE SENSITIVE ITEMS

Table 2 lists the Array E time and cycle sensitive items and also shows the considerations for allowing their use.

The only two items of consequence are the Ion Source Filaments and the Electron Multiplier Tubes on the LMS experiment. The filaments have been tested for a cycle life that exceeds the two year requirement by a factor of 250. In addition, the filaments are redundant. The Electron Multiplier Tube power supplies are equipped with a commandable "boost" voltage to maintain tube gain beyond two years as explained in Table 2.

TABLE 2

ALSEP Array E Time/Cycle Sensitive Items Consideration

Subsystem or Equipment	T/C Sensitive Item(s)	Remarks/Considerations
Data S/S (Incl. Power S/S)	(1) Johanson tunable RF capacitors in command receiver and TTC transmitter	(1) Any wearout is a function of tuning only. Not time dependent once tuned. Number of tuning adjustments controlled during assy/tuning operations to be less than 10% of manufacturer's wearout of tuning threads.
LSPE	(1) Johanson tunable RF capacitors in 40 MHz transmitter (2) Battery timer in EPA (3) S/A timer in EPA	(1) Same comments as above. Capacitors are not time dependent once tuned. (2) and (3) are approximately 90 hrs. time-out devices (inherent in design).
LSG	None	None
HFE	None	None
LEAM	None	None
LMS	(4) Ion source filaments (2 redundant per system)	(4) Hardest stress on Tungsten-Rhenium filaments is ON/Off cycling since mechanical stress occurs as filament heats on cools. Also, at snap-on there is a momentary current surge since "cold" resistance is much lower than "hot" resistance. Life cycle tests on ten (10) flight type samples showed that filaments did not burn out or degrade after 50,000 ON/OFF cycles. Approximately 200 ON/OFF cycles are expected for test and two year lunar operations. (This is about .04% of tested cycle life).

TABLE 2 (cont'd)

ALSEP Array E Time/Cycle Sensitive Items Consideration

Subsystem or Equipment	T/C Sensitive Item(s)	Remarks/Considerations
LMS (cont'd)	(5) Electron multiplier tubes (3 per system). High-mass sensor and mid-mass sensor data is partially overlapping).	(5) These E. M. tubes have no filaments or usual wear-out phenomenon. However, since the dynodes work on an electron bombardment with secondary emission principle, they will eventually degrade in gain. For this reason the tubes are operated at 2400 to 2600 volts at start of Lunar operations and the LMS is capable of switching to a "boost" voltage of 2800 to 3000 volts near the end of two years operation to compensate for possible gain degradation.

4.0 PREVIOUS ALSEP LUNAR OPERATIONS

Table 3 shows a combined ALSEP Lunar operating time of nearly six (6) years for previous ALSEP systems. For a single system (Apollo 12 ALSEP) the Lunar operating time is in excess of 2.5 years and this system was designed for only 1.0 year of operation.

The significance of the information in Table 3 is that:

a) It demonstrates an ALSEP system capability in excess of 2 years.

b) It indicates that the Reliability prediction techniques used by Bendix are conservative.

c) Although there is only one common experiment between Array E and previous ALSEP Arrays (HFE), the tremendous improvement in predicted Reliability for Array E and demonstrated operating life for previous ALSEP arrays leads to the conclusion that Array E should far exceed previous arrays in operating life (i.e. Array E should considerably exceed its 2 year operating requirements).

TABLE 3

Two Years of ALSEP Operation

	APOLLO 11	APOLLO 12	APOLLO 14	APOLLO 15	APOLLO 16	APOLLO 17
Deployment	July '69	Nov. '69	Feb. '71	July '71	April '72	Dec. '72 (Pend.)
Presently Operating	No	Yes	Yes	Yes	Yes	(Pending)
Design Life (Mo.)	0.5	12	12	12	12	24
Operating Time (Mo.)*	2.4	33	18	13	4	(Pending)
Experiments:						
PSE	X	X	X	X	X	
ASE			X		X	
SIDE		X	X	X		
CCGE		X	X	X		
SWS		X		X		
CPLEE			X			
LSM		X		X	X	
HFE				X	X	X
LRRR	X		X	X		
LSPE						X
LSG						X
LEAM						X
LMS						X

*At end of August 1972

5.0 THERMAL/POWER PREDICTION VS TIME

Known degradation modes of the ALSEP Central Station are the radioactive life decay of the RTG core and a slight increase in the contact resistance of the thermoelectric elements of the RTG. As shown in Table 4 these changes are seen as a decrease of RTG output power of approximately 1.5 watts per year, which in turn reduces the Central Station base plate temperatures and reserve power. These (Table 4) predictions are based on extrapolated flight data and on information derived from analytical models.

Of importance is any possible Reliability degradation due to long term central station thermal performance. In particular the concern is with low temperatures since both lunar noon and night average thermal plate temperatures gradually decrease due to decay in the RTG output power. (Lower temperatures enhance part reliability but may cause circuit detuning, etc.)

ALSEP Reliability predictions were based upon having thermal control between -4°F to +140°F (-20°C to +60°C). For accurate reliability predictions, the thermal plate temperature should be between these limits.

The conclusions drawn from Table 4 are:

a) Array E is not limited in reserve power at end of 6 years.

b) The Array E lower temperature limit of -4°F is not exceeded even at the end of 6 years.

c) Reliability predictions using failure rates based upon a -4°F to +140°F environment are considered very conservative since thermal plate temperatures are expected to be +3°F to +81.5°F (for night and day) at end of 6 years. (Reliability for parts is slightly better at slightly lower temperatures.)

d) Earlier Apollo flights have measured temperature data that is close to the prediction per Table 4.

TABLE 4

LONG TERM ALSEP CENTRAL STATION THERMAL PERFORMANCE

FLIGHT	D/N	Deployment RTG (W)	RP (W)	Tp (°F)	April '72 Flight Data RTG (W)	RP (W)	Tp (°F)	2 Years RTG (W)	RP (W)	Tp (°F)	4 Years RTG (W)	RP (W)	TP (°F)	6 Years RTG (W)	RP (W)	TP (°F)
Apollo 15 (Flight A-2)	D	74.1	30	116	8th 73.5	24	118	71.1	28	112	68.1	26	107	65.1	24	103
	N	74.1	2	-1	7th 72.9	9	-5	71.1	6	-10	68.1	3	-19	65.1	9*	-1
Apollo 14 (Flight 4)	D	72.5	38	125	14th 71.0	40	117	69.5	38	115	66.5	35	111	63.5	32	107
	N	72.4	18	42	13th 71.4	20	37	69.5	18	35	66.5	15	24	63.4	12	15
Apollo 12 (Flight 1)	D	73.6	35	97	29th 70.6	33	94	70.7	33	95	67.7	30	91	64.7	27	87
	N	74.0	17	24	28th 70.9	14	18	71.0	14	19	68.0	11	10	65.0	8	1
Apollo 17 (Array E)	D	74.0	30	95	N/A			71.0	27	90.5	68.0	24	86	65.0	21	81.5
	N	74.0	20	30				71.0	17	21	68.0	14	12	65.0	11	3

*SIDE is turned off during lunar night after six years of flight A-2 operation.

Tp (°F) = Thermal plate temperature in °F

RP (W) = Reserve Power in watts

RTG (W) = RTG power in watts

6.0 QUALIFICATION LEVELS

An additional item of importance is the fact that the Array E system was qualified by similarity between flight and qual systems. The qual system environmental test levels (design limit levels) in every case exceeded those required for flight in order to establish a design margin. In addition, purchased components (transmitter, receiver) were separately qualified at levels exceeding even the system qual levels.

The qual levels with respect to flight are:

a) Qual vibration was 1.3 times flight level.

b) Qual lunar noon thermal-vacuum simulated solar input was 25% higher than flight level and qual simulated lunar surfaces were about 30°F higher than flight level.

c) Component/Instrument Thermal test range for qual was 36°F wider (18°F higher and lower) than for flight.

7.0 CONCLUSIONS

The ALSEP Array E is considered to be able to meet and exceed its two (2) year lunar operating requirement for all experiments. Also, Array E has a high degree of probability of operating with 4 out of 5 experiments for five (5) years or more.

This assessment is based upon the information given in this ATM, namely:

a) Reliability predictions for Array E are significantly higher than for previous arrays.

b) Previous array predictions are shown to be conservative is that total lunar operations time is almost six years to date (with 2.5 years on one previous system).

c) Limited life items (e.g. LMS filaments) and RTG power for thermal control are capable of exceeding 2 years of operation (5 years with practically no degradation).

d) Design margin has been demonstrated by qualification on an Array E system whose test levels exceed the flight requirements.

e) The inherent system reliability of ALSEP has been enhanced through the inclusion of the following factors.

.. Redundancy used wherever possible within the weight, power, and volume constraints.

.. Hi-Rel piece-part screening to eliminate defective parts.

.. Conservative piece-part derating to reduce stress and increase reliability.

.. Thorough pre-flight testing to assure complete mission capability.

.. Narrow-range thermal control to reduce stresses induced by changing temperatures.

.. Only proven technology and space qualified elements were used in ALSEP design.