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Results of the 1984 NASA/JPL Balloon Flight Solar Cell Calibration Program

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ABSTRACT

The 1984 solar cell calibration balloon flight was successfully completed on July 19, meeting all objectives of the program. Thirty-six modules were carried to an altitude of 36.0 kilometers. The calibrated cells can now be used as reference standards in simulator testing of cells and arrays.

ACKNOWLEDGMENT

The authors wish to extend appreciation for the cooperation and support provided by the entire staff of the National Scientific Balloon Facility located in Palestine, Texas. Gratitude is also extended to assisting JPL personnel, especially B.E. Anspaugh, for providing cell spectral response information and data reduction assistance. The cooperation and patience extended by all participating organizations are greatly appreciated.

CONTENTS

I. INTRODUCTION

The primary source of electrical power for unmanned space vehicles is the direct conversion of solar energy through the use of solar cells. As advancing cell technology continues to modify the spectral response of solar cells to utilize more of the sun's spectrum, designers of solar arrays must have information detailing the impact of these modifications on cell conversion efficiency to be able to confidently minimize the active cell area required and, hence, the mass of the array structure.

Since laboratory simulation of extra-atmospheric solar radiation has not been accomplished on a practical scale with sufficient fidelity, high altitude exposure must be taken as the best representation of space itself. While a theoretical prediction (Reference 1) and experimental evidence have suggested that an altitude greater than 30 kilometers is sufficient to give space-equivalent calibration, the final decision as to an adequate altitude must await the results of the space shuttle solar cell calibration experiment flown in August 1984.

To reach and maintain the chosen altitude of 36 kilometers, the calibration program makes use of balloons provided and launched by the National Scientific Balloon Facility of Palestine, Texas.

II. PROCEDURE

To insure electrical and mechanical compatibility with other components of the flight system, the cells are mounted by the participants on JPL-supplied standard modules according to directions in Reference 2, which details materials, techniques, and workmanship standards for assembly. The JPL standard module is a machined copper block 3.7 cm x 4.8 cm x 0.3 cm thick, rimmed by 0.3 cm thick fiberglass, painted a high reflectance white, with insulated solder posts and is permanently provided with a precision (0.1 percent, 20 ppm/°C) load resistor appropriate for scaling the cell output to the telemetry constraints. This load resistor, 0.5 ohm for a 2 cm x 2 cm cell, for example, also loads the cell in its short circuit current condition.

The mounted cells are then subjected to preflight measurements in the JPL X25L solar simulator. These measurements, when compared to postflight measurements under the same conditions, may be used to detect cell damage or instabilities. Prior to shipment to the launch facility, the modules are mounted on the sun tracker bed plate (Figure 1). Upon arrival at the Palestine facility, the tracker and module payload are checked for proper operation, and the data acquisition and Pulse Code Modulation telemetry systems are calibrated. Mounting of the assembly onto the balloon is then accomplished (Figure 2).

At operating altitude the sun tracker bed plate is held pointed at the sun to within ± 1 deg. The response of each module, temperatures of representative modules, sun lock information, and system calibration voltages are sampled twice each second and telemetered to the ground station, where they are presented in teletype form for real-time assessment and are also recorded on magnetic tape

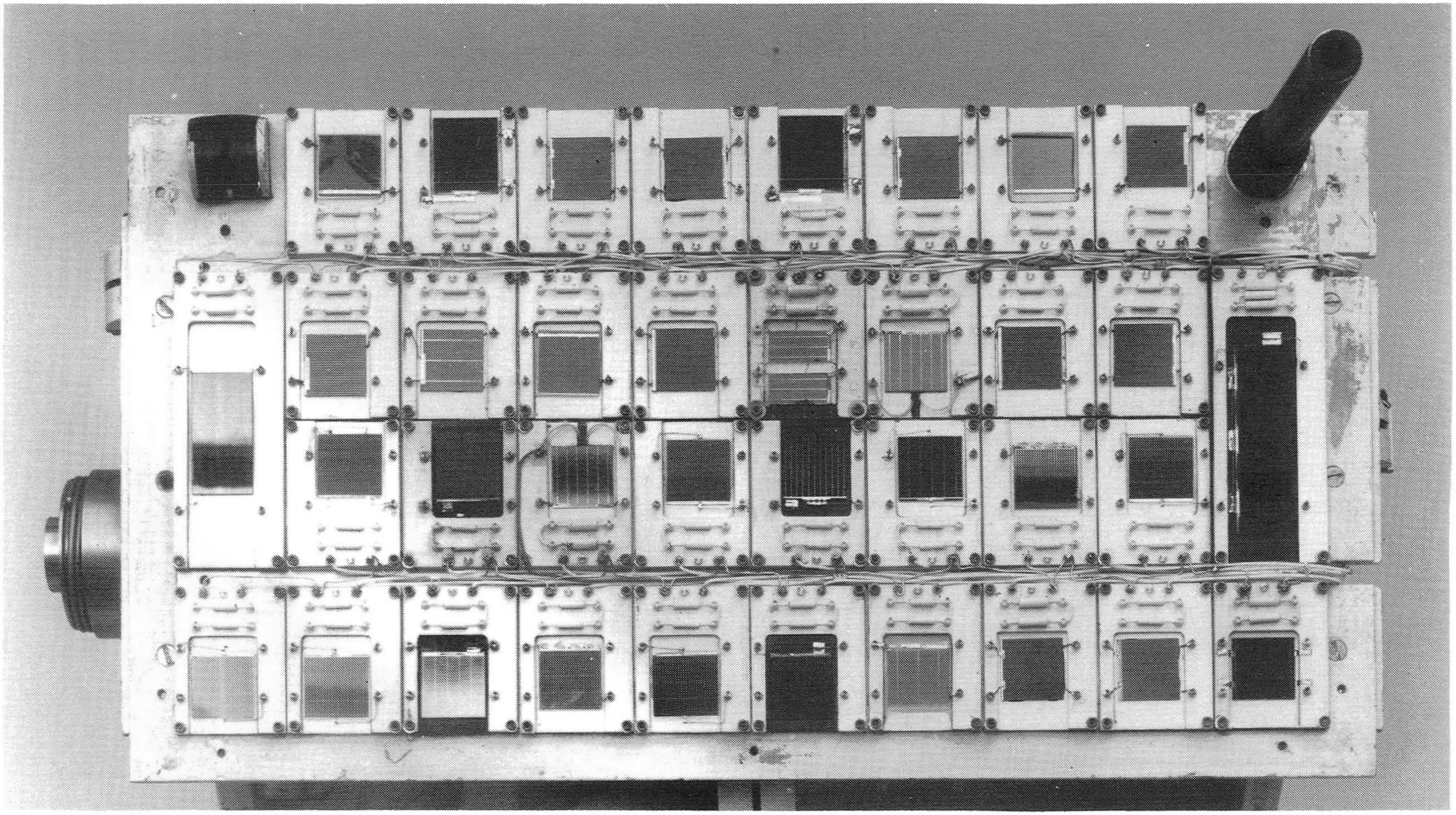

Figure 1. 1984 solar module payload

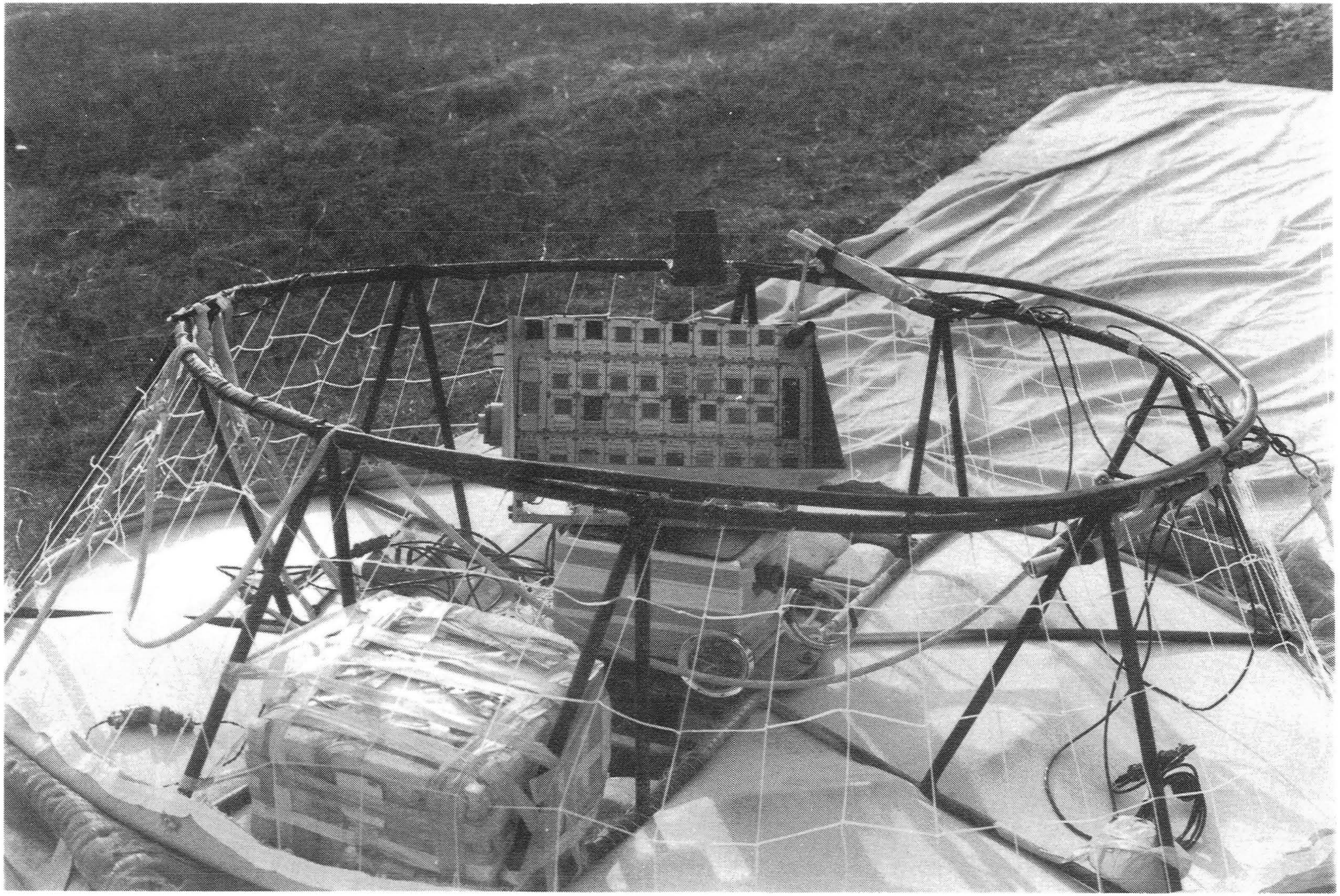

Figure 2. Balloon mount

for later processing. Float altitude information is obtained from data supplied by the balloon facility. A plot of altitude in kilometers versus Central Daylight Time for the 1984 flight is shown in Figure 3.

III. SYSTEM DESCRIPTION

A solar tracker mounted in a frame on top of the balloon carries the module payload, while the transmitter of the data link is located in the lower gondola along with batteries for power and ballast for balloon control. At completion of the experiment, the upper payload and lower gondola are returned by parachutes and recovered. A more complete description of the system, including the sun tracker, can be found in Reference 3.

IV. DATA REDUCTION

The raw data as taken from the magnetic tape is corrected for temperature and sun-earth distance according to the formula (Reference 4):

$$V_{28,1} = V_{T,R}(R^2) - \alpha(T-28)$$

where

$V_{T,R}$ = measured module output voltage at temperature T and distance R.

R = sun-earth distance in astronomical units.

α = module output temperature coefficient (supplied by participants).

T = module temperature in °C.

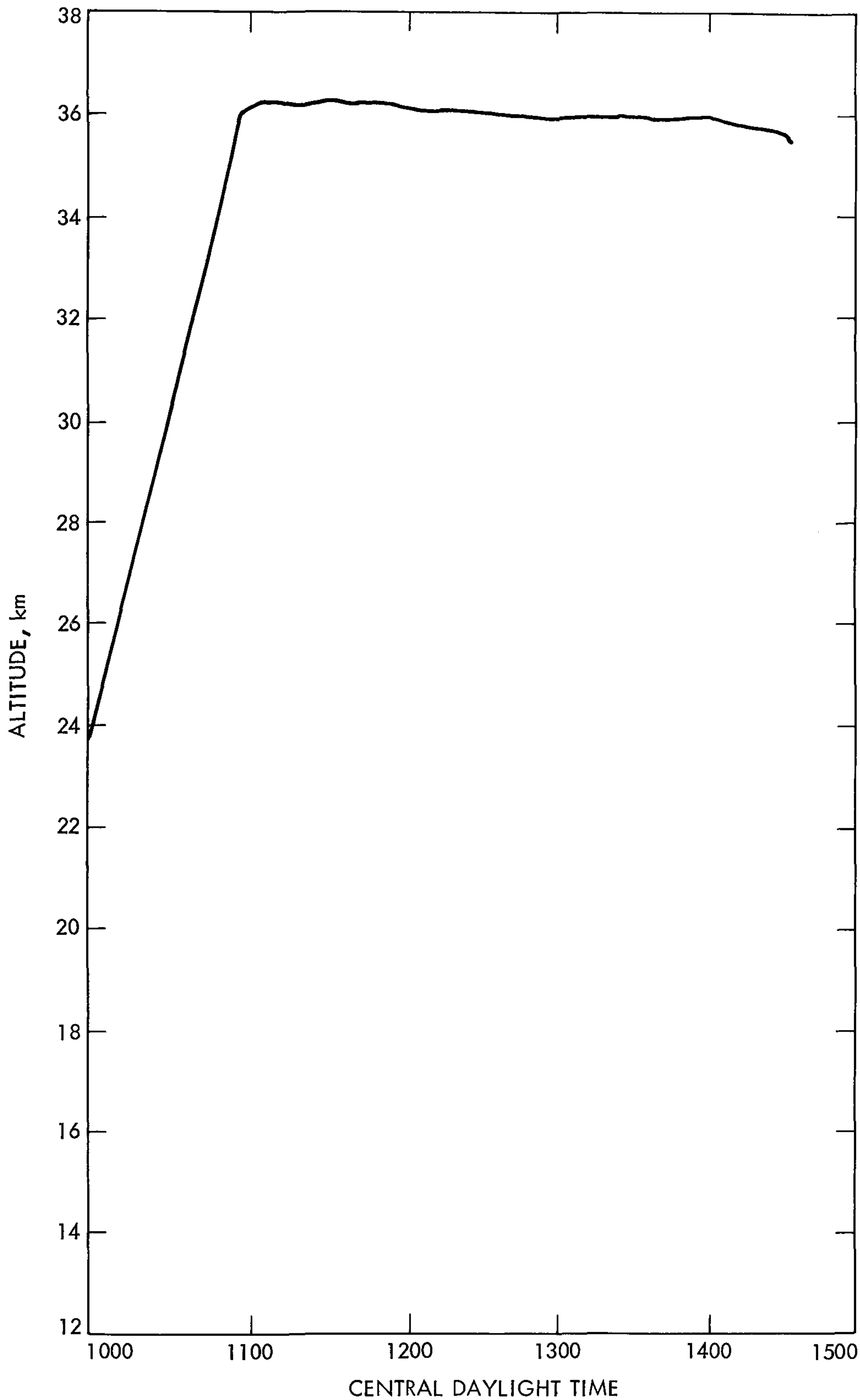

Figure 3. Flight 1984 altitude versus time

The calibration value is taken to be the average of 200 data points taken around the time of solar noon after indicated temperature stability.

The flight data were thus reduced, and modules with their data and calibration values were returned to the participants. This information is collected in Table 1. The placement of modules on the field of the tracker bed for the 1984 flight is shown in Figure 4.

A detailed discussion of data reduction and an analysis of system error may be found in Reference 3. The error in the calibration values due to radiation absorption and scattering by the residual atmosphere at float altitude is estimated to be less than 0.2 percent (Reference 1).

V. MONITOR CELLS

Several standard modules have been flown repeatedly over the 22-year period of calibration flights. The record of the one with the longest history, BFS-17A, appears in Table 2. This data shows a standard deviation of 0.23 percent and a maximum deviation of 0.58 percent from the mean.

In addition, the uniformity of the solar irradiance (i.e., no spurious reflections, shadowing) over the field of the modules has been demonstrated since the location of this module was changed in that field from flight to flight.

Table 1. Cell Calibration Data

CHANNEL NUMBER	MODULE NUMBER	ORGANIZATION CODE	TEMP. INTENSITY AVERAGE	STANDARD DEVIATION	AMO, SOLAR SIM. 1 AU, 28 DEG.C		COMPARISON, SOLAR SIMULATOR & FLT		TEMP. COEFF. (MV/°C)	COMMENTS
					PRE-FLT	POS-FLT	PRE-FLT VS. POS-FLT (PERCENT)	FLIGHT VS. PRE-FLT (PERCENT)		
1	84-170	SOLAVOLT	67.70	.06573	68.60	67.10	-2.19	-1.31	.071	
2	84-116	COMSAT	71.80	.08293	71.30	71.00	-.42	.70	.031	K7
3	84-102	ASEC	60.63	.08308	60.90	60.40	-.82	-.44	.050	GA-AS
4	84-002	JPL	59.61	.06414	59.60	59.70	.17	.02	.038	GA-AS
5	84-117	COMSAT	71.59	.07372	71.10	69.60	-2.11	.68	.033	K7
6	84-103	ASEC	61.29	.06663	60.90	60.90	.00	.65	.041	GA-AS
7	84-172	SOLAVOLT	77.23	.05969	76.60	76.30	-.39	.82	.039	
8	84-160	TRW	86.55	.08185	85.80	85.40	-.47	.87	.033	
9	84-110	ASEC	61.09	.06441	61.00	60.80	-.33	.15	.036	GA-AS
10	84-161	TRW	86.65	.06466	85.80	85.50	-.35	.99	.036	
11	84-106	ASEC	85.17	.07306	85.10	84.80	-.35	.08	.061	
12	84-175	SOLAVOLT	67.23	.07874	66.00	65.80	-.30	1.86	.122	
13	84-109	ASEC	80.29	.06747	80.00	78.40	-2.00	.36	.043	
14	BFS-17A	JPL	59.84	.07064	60.10	60.60	.83	-.43	.036	REF STD
15	73-182	JPL	67.62	.05880	68.00	68.50	.74	-.55	.055	TEMP MONITOR
16	84-120	ASEC	80.02	.07308	80.00	79.70	-.38	.02	.061	
17	84-104	GE	58.63	.05918	58.90	58.90	.00	-.46	.040	GA-AS
18	84-138	HUGHES	76.94	.05855	76.00	75.80	-.26	1.24	.020	
19	84-182	SPECTROLAB	92.04	.04885	90.20	89.70	-.55	2.03	.036	XSAT
20	78-110	HUGHES	95.59	.06606	93.40	93.40	.00	2.35	.039	K7
21	73-183	JPL	66.71	.07159	67.30	67.80	.74	-.88	.055	TEMP MONITOR
22	84-122	GE	85.13	.06610	84.50	84.40	-.12	.75	.042	DSCS
23	83-120	HUGHES	91.95	.05926	90.00	90.40	.44	2.17	.028	K7I6
24	84-183	SPECTROLAB	97.47	.07244	95.90	95.50	-.42	1.64	.038	I6
25	84-141	NASA	57.87	.06321	58.00	58.20	.34	-.22	.037	GA-AS
26	84-184	SPECTROLAB	85.04	.08068	84.40	84.00	-.47	.76	.041	DSCS
27	84-124	GE	85.59	.07720	84.80	84.50	-.35	.93	.044	DSCS
28	84-187	SPECTROLAB	88.20	.06523	87.60	86.60	-1.14	.68	.042	K6
29	83-130	HUGHES	83.72	.06544	83.20	83.30	.12	.63	.035	K6.75
30	84-142	NASA	83.92	.05280	82.30	82.60	.36	1.97	.034	
31	84-188	SPECTROLAB	89.94	.08558	90.00	89.50	-.56	-.06	.066	K7
32	84-131	HUGHES	87.14	.07351	86.10	85.90	-.23	1.21	.038	K5
33	84-150	SOLAREX	72.89	.06302	73.50	72.90	-.82	-.83	.044	
34	84-001	JPL	59.99	.07372	59.90	59.80	-.17	.15	.038	GA-AS
35	84-003	JPL	77.36	.05845	77.60	77.30	-.39	-.31	.033	K6.75
36	74-205	JPL	89.26	.07768	87.20	87.00	-.23	2.36	.044	TEX
39	100-MV		99.88	.04415	.00	.00	.00	.00	.000	
40	80-MV		79.93	.08139	.00	.00	.00	.00	.000	
41	50-MV		50.06	.05658	.00	.00	.00	.00	.000	
42	0-MV		.00	.0000	.00	.00	.00	.00	.000	

Table 2. Repeatability of Standard Solar Cell BFS-17A (36 flights over a 22-year period)

Flight Date	Output, mW	Flight Date	Output, mW
9/5/63	60.07	4/5/74	60.37
8/3/64	60.43	4/23/74	60.37
8/8/64	60.17	5/8/74	60.36
7/28/65	59.90	10/12/74	60.80
8/9/65	59.90	10/24/74	60.56
8/13/65	59.93	6/6/75	60.20
7/29/65	60.67	6/27/75	60.21
8/4/66	60.25	6/10/77	60.35
8/12/66	60.15	8/11/77	60.46
8/26/66	60.02	7/20/78	60.49
7/14/67	60.06	8/8/79	60.14
7/25/67	60.02	7/24/80	60.05
8/4/67	59.83	7/25/81	60.07
8/10/67	60.02	7/21/82	59.86
7/19/68	60.31	7/12/83	60.10
7/29/68	60.20	7/19/84	59.84
8/26/69	60.37		
9/8/69	60.17	Mean	60.21
7/28/70	60.42	Std. Deviation	0.24
8/5/70	60.32	Maximum Deviation	0.59

Each data point is an average of 20 to 30 points per flight for period 9/5/63 to 8/5/70.

For flights on 4/5/74 through 7/1/75 each data point is an average of 100 or more flight data points.

For flights starting in September 1975, each data point is an average of 200 data points.

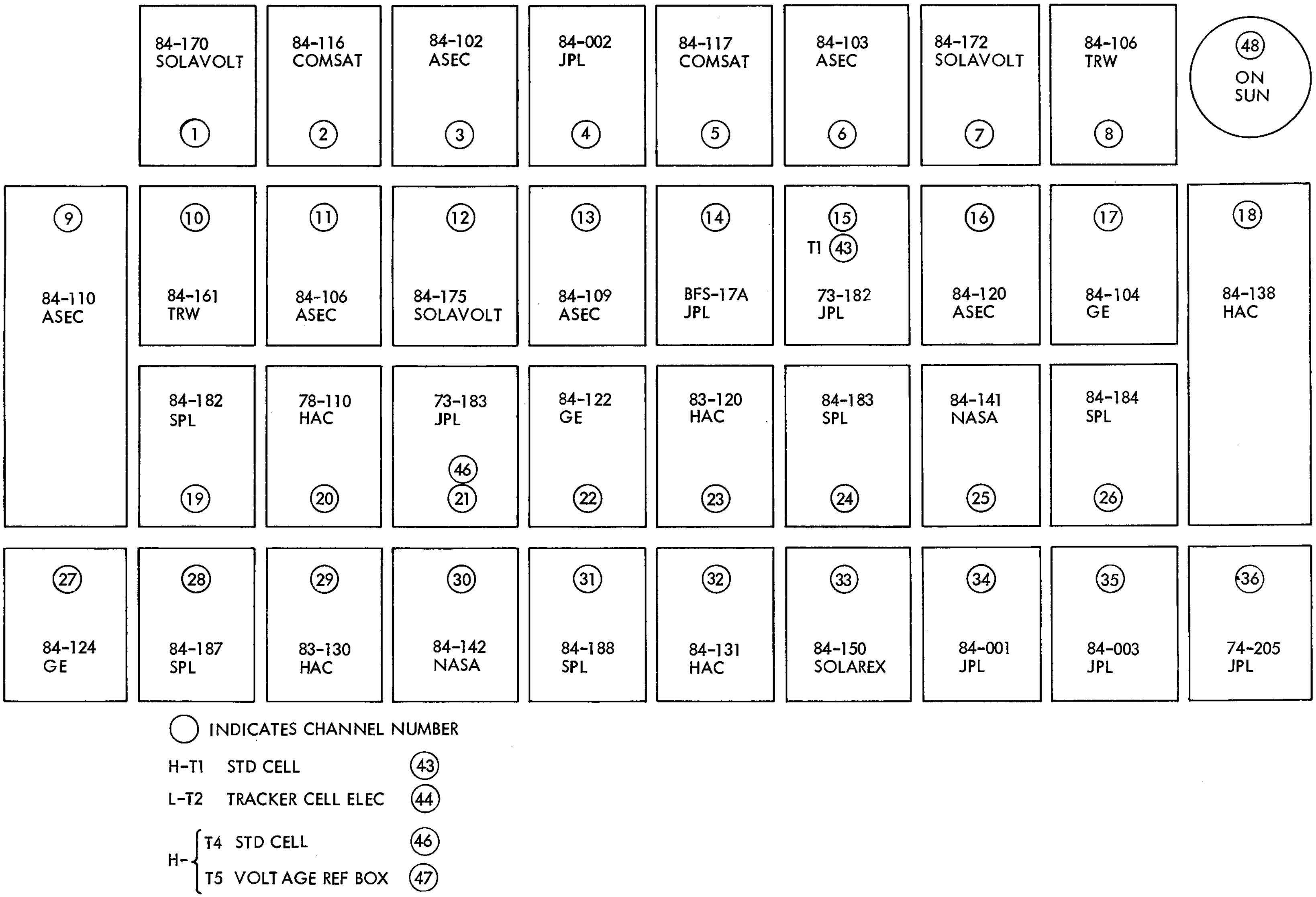

Figure 4. 1984 module location chart

VI. CONCLUSIONS

As emphasized by the history of repeatability of cell BFS-17A, viz, ± 1% (see Table 2), silicon cells, when properly cared for, are stable for long periods of time and may be used as standards with confidence.

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