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Solar Cell Power Systems for Space Vehicles. Proceedings of a Symposium, 3-4 May 1960

INSTITUTE FOR DEFENSE ANALYSES ALEXANDRIA VA

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SYMPOSIUM ON

SOLAR CELL POWER SYSTEMS FOR SPACE VEHICLES

3 - 4 MAY 1960

MEETING NOTES

ADVANCED RESEARCH PROJECTS AGENCY

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1825 Connecticut Avenue
Washington 25, D. C.

ERRATA SHEET

August 12, 1960

Subject: Symposium on Solar Cell Power Systems for Space Vehicles - Meeting Notes dated May 3-4, 1960

The following changes should be incorporated in the subject report:

Page 48, 1st para. Change to read "The resin that is used on the Ranger solar panels is GE's silicon rubber RTV 60 for the bonding agent for solar cells to substrate, and Furane & Plastics 15E resin is used to bond glass slides to the cells."

Page 72, 1st line. Change "18 or 19" to read "16 to 18".

Page 74, 12th line. "The vehicle is designed to operate stabilized only by spinning." should read "The vehicle is spin-stabilized for seven days only."

Page 74, 19th line. Change "recharged" to "Discharged".

Page 75, 1st line. Change "is shown in Fig. 55" to read "is shown on page 169."

Page 75, 2nd para., 3rd line. Change "UV reflective coating" to read "UV absorption coating".

Page 75, 4th para., 2nd line. Change "hold the glass" to read "hold the cells" and "of the cells" to read "of the glass."

Page 76, 1st line. Change "the main battery is nickel cadmium" to read "the recharged batteries are nickel cadmium."

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ERRATA SHEET (Cont'd)

Page 77, 1st para. Change to read as follows:

"a. 144: For this particular satellite, the first of the Courier series of communication satellites, the planned orbit will have a period of 109 minutes, 70 minutes light period and a maximum dark period of 39 minutes at an altitude of 500 miles. A program of interrogations will be conducted to evaluate the performance of the communications system. The peak load is 246 watts and the average or continuous load is 12.2 watts. The design voltage is 28 ± 2 volts. The peak power available from the solar power supply will be in the order of 60 watts minimum. Due to limited space available for the solar cells on the 51" diameter sphere, the power capability of the solar power supply is rather limited.

b. 144: There are a total of 19,152 1x2 cm solar cells in the power supply. They are arranged in 228 modules, each having 84 cells in series, in 7 cell shingles with 12 shingles per module. There is a blocking diode for each module. There are 114 modules, in parallel, for battery A and 114 modules for battery B. (See Fig. 56) The maximum power capability will be in the area of the equator. Battery-solar cell connections are shown in Figure (57).

c. 144: These particular batteries are rated at 12 ampere hours with 22 cells in series (actually two 11 cell t[illegible]) in series. They are similar to the batteries developed [illegible]eed and have a pressure relief valve set at 200 psia. F[illegible] their (Philco) thermal analysis, they don't anticipate b[illegible] temperatures higher than 90°F. Solar cell and battery temperatures, charge and discharge voltages and currents will be monitored."

<u>Page 78, last para., next to last line.</u> Change "and skin to cell" to read "and skin to sphere".

<u>Page 79.</u>

a. Third Paragraph - Comment made by 156, not 144.
b. Fourth Paragraph - Comment made by 157, not 57.

ERRATA SHEET (Cont'd)

Pages 88, 89 and 90. Delete and substitute attached pages.

Page 91, 1st line. Should read "XI. Radiation Damage (data from J. A. Van Allen)".

Page 91, Chart, last line under "Particle Type." Change "180 dev protons" to read "180 kev protons".

Page 92, 2nd line. After "(Per Nature (London) 184" delete "219-224-(1959))"

Page 93, last line. Should read "Excerpts from J.A. Van Allen Mem to N.A.S.A. regarding solar cell protection from NASA payload S-46, which later failed to reach orbit.

Page 131, Figure 54. Change "10 D cells Ag-Zn" to read "10 D cells Ni-Cd."

encls: Revised pages 88, 89
and 90 of subject report.

XI. Discussion of Radiation Damage to Solar Cells -

Dr. W. C. Cooley, NASA, Washington, D. C.

138. I want to outline some of the problems of radiation damage to solar cells as I see them. Basically, they fall into three categories: (1) What do protons and electrons do to a solar cell; (2) what is the flux of protons and electrons in Van Allen belt and (3) what do you do about it? One of these points is covered in data by Rappaport and Lofersky of RCA who found that with protons at 17.6 Mev energy a bare solar cell will degrade to 75% of its output after an integrated flux of $3.5 \times 10^{10} \frac{\text{protons}}{\text{cm}^2}$. This is a very high energy proton and we do know how many protons are above this range in the lower Van Allen belt. The measurements made so far measure only electrons above about 40 Mev. The other data from Rappaport was for 1.7 mev electrons. With a total dose of 5×10^{13} electrons/cm^2, the solar cells will suffer a 25% degradation. Dr. Shelton, in his Huntsville studies, has made an analysis to predict the life of solar cells in the radiation belt, taking into account one set of film pack data on the protons by Freden and White. The reference on the emulsion measurement is Physical Review, Letters to Editor, Vol 3, No. 1, P 9, July 1, 1959. These protons are in the middle of the inner Van Allen belt at an altitude of 1200 kms. In the question of what is up there are two factors; one, what is the flux of protons and electrons; and what is their energy distribution as a function of ~~location~~ (See Fig. 61) Positions of the lower

and outer Van Allen belt are fairly stable, but there is a problem of time variation of the outer belt due to such phenomena as solar flares. The flux of solar-flares sweeps out the outer Van Allen belt and you then have a fairly low density in that belt, but then it builds up again. We have no idea what the low energy proton density is. We think both belts are electrically neutral; i.e., the number of negative and positive charges are equal, but their velocities, and hence their fluxes will be different. Electrons and protons are reflected between the North and South poles, due to the magnetic mirror effect

Regarding protection for cells, you have heard data from GE on the use of glass, and it looks like quartz or cerium glass is a possibility. For a 24-hour satellite no one will make a firm estimate, but possibly 40 70 mils of glass will protect for two years in a 24-hour orbit This is not a firm estimate. The other possible method would be to make use of the annealing phenomenon, if the cells run hot enough. The radiation damage consists of the displacement of silicon atoms in a region near the p-n junction, which degrades the minority carrier lifetime. This results primarily in a loss of current carrying capacity of a cell. Van Allen pointed out that it takes a thickness of glass of 280 milligrams per square cm to stop 780 kev electrons, and that weight corresponds to adding about one half pound square foot to the area.

147. If you put more and more mass on front, it may become the structural member, but you still have to have equal protection fore and aft.

138. We want to get experiments going on cells with or without glass protection at various proton energy levels going down to 200 kev and some further checks of the protons at 10 mev and 20 mev.

147. An additional problem of irradiation in the shadow zone must be considered. In this condition you cannot make use of high temperature annealing. Therefore, when the vehicle reacquires the sun, both a thermal shock and annealing process will have to be carried out simultaneously.

168. We also need the integrated flux through these belts.

147. Are you familiar with the nuclear emulsion recovery package?

138. A little; they will give us some data

147. Its general objective is an exploratory flight to measure low-energy particle density. It is scheduled for flight in less than a year. The other think would be to get some detector that measures protons and electrons that can be mounted on the skin that will measure what happens in the first few milligrams of thickness.

168. Bloom of Livermore has recently given a paper on solid-state scintillation counteres. We have here a broad research area - we want to get going and we need experiments on current flights to get measurements up there and a better idea of how to protect cells without adding one-half pound of glass per square foot to the skin.

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SOLAR CELL
POWER SYSTEMS FOR SPACE VEHICLES

PROCEEDINGS OF A SYMPOSIUM

May 3, 4, 1960

Prepared Under The Direction of

Nathan W. Snyder

MEETING NOTES

Sponsored by

Advanced Research Projects Agency

Advanced Research Projects Division

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PREFACE

The purpose of this symposium was to bring together the engineers responsible for conceiving, developing and constructing the solar cell systems for U. S. space vehicles which have been flown or are to be flown and exchange information on the methods of design and construction, research and development programs and outstanding problems associated with these systems. The symposium more than met my expectations because of the free exchange of information and perseverance of several of the participants.

In order to make the valuable discussions and information available to the participants and many others who are engaged in research and development of components or systems, a tape was made at the meeting. The report was developed with some editing as it came from the tape. Instead of giving the names of discussors, a number is shown which refers to a participant listed on page . The meeting and report was arranged according to specific space vehicles. Certain data and figures shown are not complete and in some cases not highly accurate. In the interest of quickly providing the information obtained, the report was developed as enclosed for immediate use by space vehicle designers as well as for those who are interested in critically evaluating the solar cell-nickel cadmium power systems.

It is requested that those non-participants who have information which was not made available at this symposium should prepare a brief paper with data, graphs and pictures for inclusion in an addendum

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to be sent out in approximately two to three months. Those participants who feel that more complete and accurate material can be furnished than that given at the symposium as found in the present report, should also prepare a brief report with respect to their work. These briefs should be sent directly to (N. W. Snyder) for arrangement in an addendum and distribution. Where possible, copy directly on mats would be preferable.

N. W. Snyder

ACKNOWLEDGEMENTS TO

Richard Karcher	General Electric, MSVD, Manager Electrical Power and Distribution, who performed the monumental task of extracting information from the tape recorder, putting order to this information and the many figures associated with it. Working many days and nights immediately after the symposium to help speed the work, he is a great credit to his firm, General Electric MSVD, Philadelphia.
LTCOL Ray E. Nelson	ARPA, Project Manager on ADVENT and Manager of the symposium, who arranged for and made possible the symposium.
Joachim Kaiser	Institute for Defense Analyses, ARPD, Project Leader on ADVENT (Communications Satellite). For helping arrange the symposium and seeing to it that the conference was taped.
John Huth	Rand Corporation, Astronautics Division, who helped in the editing of the tape
William Peace	Institute for Defense Analyses, ARPD, who arranged many of the details of the meeting, taping and report development
Frances Fennessy) Sandra Rosakranz) Bethel Ross) Carolyn Bennett) Lois Schieck) Connie Kniess) Peggy Lee) June Curtis) **Violet Carrigan**)	Our secretaries who worked day and night to get this report quickly finished - many thanks.
Participants	Who exchanged a great deal of information freely in order to make it possible for the United States to advance more rapidly in the field of space vehicles. This includes not only those from industry but also those from government agencies who have the prime responsibility for the research and development - namely: Air Force, Navy, Army, ARPA and NASA.
William Cooley	Chief of APU's for Space Vehicles, NASA, who saw to it that NASA participated strongly.

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Introduction - Dr. Nathan W. Snyder - ARPA

It is becoming more apparent that the electrical power supply for space vehicles is an important consideration in designs of that vehicle particularly where requirements are several hundred watts and up. Orientation of panels of solar cells is needed, otherwise unwieldy large surface areas must be incorporated in the design. Reliability of orientation systems which have not been operated as yet is still to be established. Furthermore, the nickel-cadmium battery as an electrical energy storage device for use in partly shadowed orbits does not appear to be as reliable as required (one to three years) particularly for low orbits where cycling (charge and discharge) occurs every 90 minutes.

There are space flights which may require a short period of operation only and therefore can use other than solar cell-battery systems. Research and development is proceeding with solar concentrator-heat engine and nuclear power systems as well as research in special fields such as electrochemical, thermoelectric, thermionic, photoemissive, photovoltaic, dynamic engine energy converters in order to provide more efficient, more reliable or more compact and lightweight power systems.

The power system which is primely considered for specific space vehicles is the solar cell-nickel cadmium system. Strong backup is being supplied by the nuclear systems (isotope or fission) particularly in terms of reliability for small or large power or compactness for large power. There are many curves and charts available which show, parametrically, regions where solar cells, nuclear isotopes, nuclear fission, solar-turbomachinery, and other combinations systems apply as a function of KW/LB, KW and duration of operation. The fallacy of relying too much on such plots is that there are many other factors which affect a choice in a power system such as nuclear hazards, launch forces, Van Allen radiation and reliability. (See "Space Power" by N. W. Snyder, Proceed. 13th Annual Power Sources Conf., Sig. Corp, May 1959 for some further discussions.) For example, at 10 watts, the solar cell-nickel cadmium system for a low orbit vehicle appears more feasible than a radioisotope-thermoelectric power source. One factor which appears overriding, though, is that the reliability of the isotope powered system is much greater than that for the solar cell system primarily because of the batteries which have not shown long cycle life time. I'm sure that discussions today and tomorrow will clarify this issue. One must be careful on the choice of a power system based on availability, reliability, and space vehicle system integration. Failure of a space vehicle due to the power source involves a prorated cost of the whole cost of launching, boosters, etc. which may run as high as 10 or 15 million dollars. At the present time, the only power source which has been available is the solar cell-nickel cadmium one but a low powered (5-15 watts) radioisotope-thermoelectric (Snap 3) 6 months to 1 year lifetime system can be furnished also. Fission reactors with thermoelectricity or turbomachinery will not be available for two to four years.

As higher power requirements are specified in the range of say 3 KW to 300 KW, the solar cell systems appear more difficult to handle because of size and difficulty of orientation as well as increased problems with batteries. The nuclear reactor program will provide for such power requirements. The AEC is developing the Snap 10, a fission-thermoelectric system at 300 watts which has no moving parts, the Snap 2, a fission-turbomachinery (using sodium and mercury) at 3 KW to 10KW is now under ground testing. NASA and the AEC are developing the Snap 8 a growth version of Snap 2 but at 30 KW to 60KW output which is now being started. The Air Force will study in detail a 300 KW fission-turboelectric system with several new features (using Lithium and Potassium) for future development possibilities.

This symposium will be restricted to discussing the present "State of Art" of solar cell-nickel cadmium battery systems.

The choice between solar cell systems, solar concentrator systems, nuclear power systems is not easy, but must be surely done in the final analysis by the design engineers connected with space vehicles. Space vehicle systems engineers should enter early into all discussions. This has been well done by AFBMD with regard to the snap program.

I would like to introduce Major George Austin of AFBMD who has cognizance of the space power work needed by the Air Force in its programs.

II. Discussion of Power Sources - Solar Cells and some Aspects of Nuclear Power - Major G. Austin - AFBMD

Military vehicle power for systems in the next ten years fall into two categories; one, several hundred watts, and another group of several kilowatts. To be sure, one can go on higher and conceive of systems that use even larger amounts of power up into the megawatt range (i.e. electrical propulsion and/or manned vehicles). But I think for the next ten years, most of our military non-propulsive auxiliary power requirements will be fulfilled by systems on the order of several hundred watts and several kilowatts. Now, in the several hundred watt area the solar-powered system is, perhaps, the leading contender But there are things about it that worry us. First of all, even in the power range which should be manageable for a solar system, one is forced to moving (oriented) arrays; a static system seems out of the question, if simply only because of cost. One then does have to have an array which moves, and moves in a complicated continuous and discontinuous fashion. We are also concerned with solar cell degradation about which I am sure you will hear much today; degradation due to protons, meteorites, etc. We are also concerned with the compatability between large moving arrays ~~plus~~ and the vehicle itself. The drag which these larger rays introduce at low altitudes may be a serious problem. Low altitudes, incidentally, are, in the opinion of many people in the field, the most militarily significant.

Then, I think, most importantly, we are just generally concerned about the question of reliability for one year. As Nate Snyder pointed out, the secondary battery itself may be the limiting component of the power system. We have confidence that solar power - systems will be developed. We, at the same time, feel that it is necessary to proceed vigorously with a back-up of an entirely different approach and the entirely different approach is an obvious one, the nuclear system. Hence, Snap ten, which is the completely static nuclear system. (A reactor-thermocouple system, with a self-regulating negative-temperature coefficient.) The degree to which we pursue this is dependent quite a bit upon the progress which you people make in the solar-powered system. In one sense, Snap ten is competitive with a solar-cell system.

In another sense, they are really not competitive when you take a broader look at the future. We feel there will be a place for both types of systems. There will be missions which one or the other gives such an outstanding advantage that they really aren't competitive at all.

We do not expect to have the first flyable Snap ten units until September of 1962. Whether or not we could at this point accelerate the program and get in flight test earlier is something of a question, but at least the question we will get some insight on today is whether or not we ought to even try.

154: Is there any information available on the cross over point between solar and nuclear power systems as far as weight is concerned?

Maj. Austin: I think that in every survey that I am aware of, solar-powered systems dominate below 15 or even 30 kilowatts. However, weight may be secondary to reliability.

162: Major Austin, I'd like to ask this question. Is there any reason right now to believe that, specifically, the Snap ten unit could be more reliable than the presently conceived solar cell unit?

130: That's a good question. The answer to that is we certainly don't know and I think we can say we are fairly ignorant in both areas. It's because of this ignorance that we are pursuing both. However, what we do know about the Snap ten system, as far as reliability is concerned, is somewhat encouraging. In the first place, one of the questions which we've had all along is the possibility of the radiation damage to the thermo-electric elements. It has now been determined by tests at Westinghouse that any radiation damage to the thermal electric elements is annealed out completely at 350° F which is far below the temperatures at which these units do operate. The radiation damage no longer bothers us with this type of device, and the people working closely with it feel that now, the main problem of systems involving thermo-electric materials is their brittleness; i.e. their ability to withstand the conditions of launch. These seem to be the two problems which people are most concerned about. If they turn out to be overcome, other problems are presumed to be straight-forward.

168: It has been pointed out that we have turbo machinery, particularly in the big power plants, that can run for two or three years at a crack without any servicing at all under full power; however not at 60,000 RPM.

III. Discussion of ADVENT and STEER - R. Karcher - G. E.-M. S. V.D., Philadelphia, Pennsylvania

147. We are concerned with the ADVENT and STEER programs which will require higher powered systems than those to be discussed. This system will use solar cells for the energy conversion and nickel cadmium batteries for energy storage. I would like to outline the system approach being used in its entirety and then we may go back and examine the details. The STEER vehicle is to be a communications satellite in a 6 hour orbit and will require approximately 350 watts peak power. The average power demand will be approximately 200 watts. The maximum dark period for this orbit will be 45 minutes. The ADVENT program will require 500 watts continuous for its 24 hour cycle. The maximum dark period will be 71 minutes. The vehicles resulting from both of these programs are to be designed for a 3 year life. (See fig. 1a & 1b for load-time curve and schematic)

The solar converters will be mounted on deployable arrays which will be continuously oriented to the sun. The design approach has been to analyze the state-of-the-art and make performance prediction and then by laboratory tests verify these predictions. We selected this approach to economize on manpower requirements. The predictions will be made in the form of a graphical curve. The tests will be selected so as to verify a few points on this curve. Therefore, the entire curve need not be created by testing - assuming tests results show verification of the prediction. Lack of verification will point out areas requiring additional evaluation. One of the tools which we are using in this program is an electrical system analog. This analog is being created in three phases: simple, intermediate, complex. To give you an idea of the simple analog - we are making assumptions that (1) the conversion array is a large single silicon cell and (2) the battery characteristics are a series of linear functions. You must appreciate that these are not the ultimate conclusions but do indicate the problem areas as well as indicating the secondary consideration that do not warrant maximum effort. This analog will take into account the optical consideration, the thermal aspects, the cell physics, the energy storage, the system regulation, and the effects of paddle orientation.

In addition to the system analog we are examining the circuit consideration of solar cell connection. In order to minimize the degradation of system performance as solar cells fail we are looking at the relations which exist. Failures due to meteorite impact, electron radiation, and unreliable soldered connections are those which cause this analysis. We are all aware that a given number of cells must be connected in series to provide the system voltage; and that a given number of cells will be required in a parallel arrangement to provide the necessary current. This study will examine the choices available to have the highest reliability. One extreme case would be to have the necessary numbers of cells connected in series strings to establish voltage and then to parallel the required number of such strings (this paralleling would be done only to the power buss). Any cell failure in this arrangement would cause the loss of the remaining cells in its string. The other extreme is to parallel every shingle with the same shingle in an adjacent string. In this configuration a shorted cell would cause the loss of all cells paralleled with it. Currently we have taken the characteristic curves of 50 typical cells and use these as the basis for the analysis. Approximately ten circuits which appear to have merit have been selected for the computation. The expected results of this program will be a series of V-I curves showing the effects of probable modes of failures.

The testing to date has been concentrated on an evaluation of electron radiation effects. For this work we have established an equivalent flux rate and total exposure which will be the equivalent of that in a 6 hour orbit. Silicon cells, covered glasses, bonding materials, and structural materials are being evaluated. (See photographs in the appendix B-1)

Our simple analog will be finished by the end of May. Initial radiation testing has been accomplished showing the degradation of the silicon cell and the discoloring of many cover glass materials. The battery tests are under way. The major effort is devoted to nickel cadmium batteries, however, testing of sealed silver-zinc and sealed silver-cadmium batteries are also in process. The initial testing utilizes constant current charging and will shortly be modified to charge with the characteristics and regulation of a typical solar array. All of the battery tests will be conducted on the same time cycle so that for once comparable data will be available. The series-parallel analysis has been programmed on a digital computer and initial results are expected in June.

The results of our preliminary design indicate that the STEER vehicle with a 350 watt maximum requirement can be satisfied with a 44 square foot array; the ADVENT vehicle with a 500 watt continuous requirement will dictate an 80 square foot array. We are using a factor of 7.4 watts per square foot to determine the areas required. The batteries are sized on the basis of a 35% overcharge and a depth of discharge of 35% for the 6 hour orbit. The depth of discharge for the 24 hour orbit will be higher - probably 60 to 70%.

130. You mentioned that the ADVENT vehicle requires 500 watts. Could you break this up in terms of peak and average?

147. Currently we are sizing ADVENT on a 500 watt continuous basis.

154. Have you concluded any particular arrangement of series-parallel connections for your array?

147. We had made an initial study to examine this consideration. (See figure 2). From the figure we concede the series and parallel connections previously mentioned. From the preliminary analysis we determine that the maximum reliability or the minimum power loss would occur with 3 strings paralleled to make a block and each block paralleled to give the power capacity. (See figure 3) The shape of this curve can be seen in figure 4.

150. This covers the probability for opens and shorts due to meteorites, bad solder connection, or any other cause. We ran the probability of failure from 10% open circuit - 90% short circuit down to a 50-50 rate. The results of the analysis show that the percentage failure is not critical when you have an optimum number of shingles paralleled. From this we conclude that the number and the basis of failure is of small consequence. The sharp break point of this curve was at 3 shingles per block for a 28 volt system. This may vary with other system voltages. The basis for this analysis was a 5 cell shingle. It would probably be better system design to use 4 or 5 strings in parallel so that failures would bring the system nearer to an optimum point. The initial losses due to this increased paralleling are slight and the gain resulting from a failure would be significant. This is a simplified study and does not deal with a shift in characteristics. The digital computer program will go into much more detail in this area.

154. You defined shorts here - are this shorts to ground or shorts to another cell?

150. Both. We also took into consideration the location of these shorts.

144. Can you give us some indication of the results of your radiation damage study?

147. (See figure 58-d) We are finding that as we go to the higher dose levels we encounter a thermal problem. The effect of the thermal problem is such that the radiation rate must be held to a low level to avoid heating the cell and thereby masking the damage by annealing. This brings to mind one of the most important areas of radiation testing and that is the low temperature area. It is certain that the array will be degraded during the dark portion of the cycle as well as during the light portion and the effects will be much more severe because of the lower temperature. We are now making the necessary fixtures for this low temperature irradiation.

152. With the higher altitude vehicle also your responsibility do you plan to run tests at the lower dose levels?

147. With the advent of ADVENT we are planning to run lower dose rate tests. The particle energy levels will remain the same but we will evaluate total exposure from 10^{12} on up to 10^{16} electrons/sq. cm.

162. I have two questions on glass. First, are the results you mentioned those using quartz? Second, how do you plan to install these on the array?

147. The covers used for the radiation testing were quartz. We are getting samples of other cover materials and are now in the process of testing these. We are running spectral response curves before and after testing to evaluate the damage with differing exposures.

160. Are there any isolating diodes on this array?

147. There will be isolating diodes on this array.

173. You didn't answer the question about the means used to attach the cells to the arrays. I have another question - how long did you take to irradiate the cells to an exposure of 6×10^{14}?

147. The 6 x 10^{14} exposure required roughly a 30 minute period. Thirty hours was required for the 6 x 10^{16} dosage.

173. In your tests did you attach these or just set them on top of the cells?

147. The glass was just laid on top of the cells and a clamp was used to hold it in position. The glass was not bonded to the cells.

173. What do you propose to do to bond the glass plates to the cells?

147. We are looking at two configurations. The first configuration is the standard technique of shingled cells with each cell individually covered. This assembly would in turn be bonded to an aluminum honeycomb substrait. The second approach is what we are calling a planar approach in which the cells are mounted on a flat surface immediately adjacent to each other. The second approach appears to offer advantages of a structural nature in as much as the glass may be extended over many cells and because of its thickness will have quite high strength. The shingled construction has a serious limitation from the assembly point of view in that the very thin solder areas are the only joint between the heavy glass slides. (See fig. 6&7

162. Wouldn't it seem desirable to test the adhesive as part of the cell cover glass system? Otherwise wouldn't you have to go back and repeat all this testing if you flunked the adhesive?

147. In the flat plate approach the cell bond to a substrait can be a metallic bond (solder) and the cover glass can be held in position mechanically. This could be accomplished by rolling the edges of a frame over onto the glass to lock it in position. This has an added advantage because the chemical filler between the cell and the glass must have only optical and thermal properties with no requirement to be an adhesive.

170. What is the average efficiency of the silicon solar cell you are using?

Can you describe how you define the watts per square foot figure?

147. We are planning to use solar cells centering around the 9% point. We are faced with the technical-economic decision of picking a number for the basis of calculation but not forgetting that it was an assumption. Here again I might point out the versatility of the electrical analog. With this as a design tool compensation for later changes can easily be made. The 7.4 watts per square foot was based upon a shingled assembly where considerable design information is obtainable.

173. What are the assumptions in your 7.4 figure?

(See appendix B-1)

151. You mentioned 15% degradation factor of glass slides. What is this specifically attributed to?

147. This covers degradation of the transmission of glass under irradiation and surface erosion.

160. Over what period of time?

147. 15% yearly.

173. What about the possibility of proton damage in your degradation calculation?

148. Let me get back to that 15% for a minute. This is based on the understanding that you cannot induce more than 15% loss of transmission due to micrometeorite damage. We have no plans to run proton damage tests at this time. We understand that the dose is much smaller than that from electrons and expect its effect to be less. This is an opinion that we have received covering the 24 hour situation.

138. What is your best estimate of the thickness required for the 6 hour and the 24 hour designs?

147. In the 6 hour orbit we feel that 70 mils will be required; 40 mils is our best thinking for the 24 hour orbit.

130. What is the ambient radiation you are assuming when you come up with those numbers - whose data - and what specific fluxes?

148. We are working on the basis of 10^6 electrons/sq. cm./second. For a three year period this would be on the order of 10^{14} electrons/sq. cm. total dosage. For the STEER environment the number would be 10^8 electrons/sq. cm./second. These figures are for electron above 600 kev. The threshold of damage for silicon cells is 145 kev.

144. The 145 kev was established by Rappaport and Lofersky of RCA.

170. Have you any data to justify the use of a 50 to 60% depth of discharge for the ADVENT program?

165. Considering one of the limiting factors of available recharge time we feel that this is a reasonable discharge level. Upton Thomas of Bell Labs has an equation which he uses to calculate depth of discharge.

$$\frac{C}{I_L} = \frac{1}{\alpha}\left[f(1+\beta)(1+\delta)+\delta\right]$$

Where:

α = rate of charge in hours
f = ratio of dark to light periods
β = overcharge
δ = selected constant for system
C = nominal battery capacity
I_L = load current

For my purposes I remove all expressions with the δ in it.

The removal of the δ expressions does not affect the battery design in as much as it deals only with the solar array. One of the most important factors is α which is the rate of charge that a battery can accept. At the present I personally feel that 8 is a limiting figure. You just don't charge these things at a greater rate. Using the figure of 8 on a 6 hour orbit there is a depth of discharge no greater than 35%. That also involves a trade off study on the ascent power requirements of the system. We decided to use one battery rather than using a primary battery during ascent and a secondary battery during the cycling period. On a 24 hour period this equation no longer establishes the criterion. With approximately 23 hours to recharge the battery the α figure becomes meaningless. The considerations of depth of discharge for the ADVENT orbit (24 hours) become somewhat meaningless based on the nature of the annual cycle. For the first 22 days the dark portion of the orbit is continually decreasing in time and about the 22nd day it is nonexistent. This is followed by a period of approximately 136 days when there is no shadow time. (See Figure 8) When we talk about depth of discharge actually we are speaking of a maximum depth of discharge which only occurs during the longest shadow periods. With the orbit time being constant and assuming a steady load your overcharge gets greater and greater. In our particular program we are going to test to an approximation of this cycle using a step function approach. When I say we have a 75% depth of discharge on a 24 hour period it is the initial depth. Eventually it will get down to a 0% depth of discharge and 100% overcharge. In this program we are starting out with a 25% overcharge on the first step.

138. In a typical orbit of a 24 hour period what fraction of the orbit would have any discharge?

165. The maximum dark period is approximately 72 minutes.

138. But if your orbit is in the equatorial plane you are in the sunlight most of the time, aren't you?

165. There are about 40 days out of each 180 days during which some shadow will occur. The biggest worry from the battery point of view is the long continuous overcharge not the discharge periods.

138. What is the longest period that these batteries have been tested on continuous overcharge?

132. About 97 days ago we started testing at 131 deg. F and we have been running since that time at approximately the 9 hour rate. In a second test we have achieved 3 years of continual overcharge at the 16 hour rate. This second test is being run at room temperature.

154. What is the charge current when you refer to 100% charge? your ambient payload temperature? and the battery temperature at the end of the long overcharge period?

165. We will have an active temperature control and attempt to keep the temperature around 75 Deg. F. I do not know what the payload temperature will be.

162. Is there any difference in the permissible charge rate between the sealed cell and the batteries previously used?

132. We find that the glass-to-metal seal permits somewhat higher rates of charge. We recommend an 8 hour rate for the sealed cell and continue to recommend the 16 hour rate for the nylon gasketed cell. Figures given before concerning the 3 year test refer to several cells of the nylon gasketed type. At the present time tests are still in progress (and have been running for more than 4 months) at the 8 hour rate on the hermetically sealed cell. These cells

seem to be working very well.

165. I might add that the particular cellsthat we are testing are the 20 ampere power cells used by Lockheed. They have a teflon pressure seal and have been running at an 8 hour rate of continuous overcharge for a period of a few weeks. They have performed well and still deliver capacity. This test was run using forced convection cooling which kept the cells around 80 to 90 deg F. We also plan to test gas leakage rates on dummy cells at 200 psi. using helium and an appropriate leak detector.

130. I would like to ask Mr. Belove to explain the apparent inconsistency between the tests which were just quoted at 131 deg F and the recommendation of operation at 105 deg F.

132. I purposely eliminated one factor here. I thought we might defer a discussion until the battery became the main topic. However, it looks as though we had better clarify the situation now. Within the last 3 months we have begun to observe a limitation which results from a thermal problem. We have discovered that the amount of overcharge - the rate of charge - depends primarily on the temperature that is maintained in the cell. That is, the higher the ambient temperature or the cell temperature the greater the degradation effect upon the cell. We have found that if you operate these cells around 100 deg F they will continue for long periods of overcharge. The figure of 131 deg F is based upon performance of a new separator that we have used. We have introduced a teflon separator and are trying to establish the upper temperature limit for these new cells. We had made initial comparisons between the cellulosic and the teflon separator by running two cells at 24 hour continuous charge at 212 deg F. Cellulosic separator had shorted out in this period

while the teflon cell lost 80% of its capacity - there was no sign of degradation. The same cell on a subsequent room temperature cycle gave us full capacity. We have found one problem which has resulted from use of the teflon separator. As a cell is centrifuged the electrolyte moves out of the separator region. This effect does not take place over short periods of time but is very noticeable at the end of a long test.

165. Our preliminary analysis of the battery design for the 24 hour orbit shows a very low charging rate which may be a problem. If you assume a constant current charge and design for a 50% depth of discharge with a 25% overcharge you will find that the equivalent charging will be done at a 40 to 50 hour rate. From our experience the battery does not perform as well at these low charge rates as it does at the 8 or 16 hour rates. I have figures which show as much as a 20% capacity loss when going from an 8 hour rate to a 16 hour rate.

133. What happens within these electro-chemical cells in a zero G environment? Is there any limitation imposed by the gases and liquids of the system?

156. As far as we know on PIONEER IV, V, and VI, TIROS, and TRANSIT have encountered these environments and have apparently worked satisfactorily.

133. The examples you mentioned were all low altitude flights where you have an appreciable gravitational field.

151. The above vehicles were spin stabilized but other than this spinning would not have any acceleration forces on the vehicle.

173. Quite a few months ago we proposed a power supply to GE in which we recommended a 60% discharge. We had quite a disagreement on the subject of discharge depths. Since GE is now proposing 60 to 70% depth of discharge I would like to have more information on their decision.

165. When RCA made this proposal we were both considering the STEER program. The requirements of this program are such that an equivalent charging period of 4 hours is all that is available for the batteries. This results from the standby loads and things of that nature. If there is to be any overcharge at all then a 60% depth of discharge would require charging at a 6 hour rate. This is contrary to the recommended practice previously discussed.

173. The question really is concerning your testing. What have you been doing or what is in progress to give you confidence in life vs. discharge?

165. Our cycling program just recently started and as yet we do not have any results. However, under a Lockheed program as many as 1400 cycles were accomplished with a 50% depth of discharge and charging at about 2½ hour rate. The results were a bit marginal but the battery did not degrade. In fact, those same cells were later taken and "rejuvenated" and performed exactly as they did when they were new. I hope that answers the question.

134. I would like to join Mr. Schulman in saying that the 60% depth of discharge is perfectly all right.

156. I guess it is generally understood that the limitation on overcharge is a thermal limitation since the battery is a very efficient converter to heat in the overcharge region. The thing that puzzles me is that there has been no effort made to place a limitation on charging.

165. Recently I investigated pulse charge methods and regardless of whether the pulse charge is due to a thermal cut-off or a voltage cut-off, voltage fading still occurred. There did not seem to be any advantage over a straight constant current charge.

173. A similar system is being used on the TIROS satellite and will be discussed later.

161. We have been looking at a way of limiting the current on the end of charge. Of course, we are working on the 60/40 cycle. We have been putting Zener diodes in a circuit to limit the voltage at the end of charge. Because the lowest voltage diode that we can get to give a reliable cut-off is 6 volts we are using a diode to limit 4 cells in series. This system works fairly well to cut off current but it does not solve the temperature problem. The diode characteristics shift with temperature and allow higher voltage charge at higher temperature. We understand that a negative temperature coefficient has been developed and might solve this problem. We are currently testing at room temperature but do plan to test at 120 deg F ambient. Right now we are taking out about 25% of the capacity on this 40 minute discharge and we find that if you stay within this 20% voltage limit (from end of charge to end of discharge) that we have to put back only 12 to 20% overcharge. This is based on a limited number of cycle so far.

137. You quoted a 20% loss in capacity in going from an 8 hour to a 16 hour charge. What was your cycle depth? and what was your overcharge rate? What was the percentage of overcharge?

165. This was not on a cycling basis at all. A group of 20 ampere -hour cells were charged at 3½ amps for 8 hours and 1.75 amps for 16 hours. In both cases you would receive about a 40% overcharge.

132. Mr. Thomas at Bell Labs reports that he has been able to use a 10% overcharge where he's taking out 25% of the capacity. He finds that in going below 10% he cannot maintain his voltage level.

161. We had planned to put in a 25% overcharge but using the diodes we find that we are only putting in between 12 and 20%. Again this is based on a limited number of cycles but there is no evidence of fading. We do have a

serious problem of voltage distribution between the 4 series cells. We have found individual cell voltages range from 1.40 to 1.60 volts.

168. Perhaps we can get back to a couple of points on the power system. One of the things would be a clarification of some of the numbers of sizes of the solar array and the method of orientation to be used.

147. The photograph (appendix B-1) will indicate the relative arrangements of the payload and the solar array. This photograph is a conception of the STEER vehicle and is probably indicative of the ADVENT configuration. As previously mentioned STEER array will consist of 2 paddles with a total area of 44 square feet. Our area factor is 7.4 watts per square foot. (A tabulation of the design calculations is included in appendix B-1.)

154. How much of the supporting structure is included in the 7.4 watts per square foot figure?

148. This includes the cell, the glass, and a weight of 2.0 to 2.2 pounds per square foot; including the supporting structure, but not the orientation shaft.

168. I understand that these paddles move with respect to the vehicle and are always oriented toward the sun. How are you going about maintaining this paddle orientation? What is your design approach for the bearings and drive motors?

147. With regard to the orientation we are evaluating the number of sensors. One of the more attractive of these is the same silicon cell used in the power system. Other engineers in Philadelphia are investigating plastic ball bearings and various plated metallic and plastic sleeve bearings. The drive motors will probably be of the stepper type.

162. Why are you orienting the paddles independently of the vehicle?

147. The program requirements are such that a highly directed antenna must be oriented to the earth.

160. Is the orientation system of the paddles independent of the rest of the vehicle or is it all tied together? Is part of this system needed to keep the rest of the vehicle in operation?

147. Of course, we have to orient the power system to supply the vehicle with power. The rotation of the paddles about the axis of the shaft through the vehicle is done strictly for the power system alone. (Refer to vehicle photograph in appendix section B-1) The rotation of the vehicle about the antenna axis is done for the power system. The positioning of the antenna axis to the earth's vertical is done only for the communication requirements. Obviously, the two are very definitely related.

136. What portion of the power being generated is required for orientation and what portion for communication?

148. Approximately 50 watts is required for the orientation system. The balance is available for other purposes such as communication and energy storage.

130. What is the temperature which you are designing to be the steady state condition of the array?

148. We are designing to operate at 100 deg F.

151. You can operate around 100 deg F just with the coatings which have been available up to now.

173. Have you determined this experimentally in vacuum chambers?

151. I think we are beyond the point now where we have to depend on experimental data. We do determine the optical properties by experiment but beyond that there is the data of satellites that have already flown. These can verify that the calculations are correct. On an oriented array where we are drawing out about 10% of the power the cell operation does not contribute to heating as it does on your TIROS satellite. With improved coatings the array can be run at temperatures below 100 deg F.

152. I don't think 100 deg F is optimistic now even with present coatings. We hope in the future to be able to drop that down considerably.

Comment. The sun paddle orientation is definitely important to your attitude control and even more so to your orbit control because it is the third axis which gives you the yaw axis control. Presently they're planning to compute from downstairs the attitude of the vehicle in order to give us the proper orientation in the orbit. The paddle orientation system is an integral part of the vehicle orientation system and if the paddle orientation system fails it will deopardize the orbit control system.

151. The control requirements on the paddle are quite wide in comparison to the requirements on the body orientation.

146. The paddle influences what you do with your orbit control and is in the loop of the orbit and attitude control system. So you can't ignore it, it's very important.

162. We feel fairly confident of our numbers and I'll tell you where the areas of uncertainty are. We have made temperature calculations on a flat plate oriented collector and the stabilized temperature in space is 39 deg C. This is about 108 deg F. And also as a matter of interest we are talking about 9.5 watts per square foot. The only uncertainty attached to this number are these: The uncertainty attached to the degradation due to the solar constant (not being able to use 140 mw./cm^2), some small degradation due to the ultra-violet degradation on the glass and cell. These are the only two areas where we feel we are really uncertain. The a/e ratio has been tied down and the thermal design through honeycomb has been tied down experimentally.

147. There are two main contributors to regulation, one is the non linear charatteristics of the silicon cell, the other is characteristics of the

battery as it is imposed on the cells. Therefore, you can go through a trade off and add pounds of weight of regulation equipment to give any desired regulation accuracy. We have determined that the unregulated system deviation would be plus or minus 16%. This deviation is due solely to the characteristics of the two major contributors.

(A comment was interjected regarding the orientation drives pointing out the desire to avoid high speed rotating machinery for orientation control.)

On the ADVENT program the philosophy has been to use a stepping drive rather than a rotational control. One factor that this stimulated in my mind is that this will not be a 360 deg of revolution, but rather less than one full turn. And once each season the vehicle will be flipped so that we do not have to use slip rings for power take off, but rather can use a simpler approach.

(Another comment was interjected regarding the trade off of complexity of continuous rotation and slip rings vs. flipping the vehicle each year.)

Q. When do you intend running complete system tests of this sort in a vacuum chamber and under environments?

A. Literally we are picking them up piece meal in component tests covering battery leakage, wire wrapping, bearings in vacuum, and measurements of comparing torques under vacuum conditions.

133. (Brought up the subject of voltage regulation again.) Asked if there were any possibilities to reduce the wide regulation limits by a "small electronic package". The necessary weight increase in the communication equipment due to the wide regulation was pointed out as in incentive to tighten the voltage limits.

A. The decision will have to be the result of an engineering compromise. By selecting a favorable operation point on the curve of the array, one can make a favorable gain in regulation: However, a weight increase of the array will be the result. So that in the final analysis weight becomes the determining facotr. There are many considerations in this regulation prime of which is the battery. From the standpoint of the battery the regulation is determined by considering depth of discharge, cycle life, and ultimately, reliability. At this time with a 28 volt system and 22 cells per battery, I feel that going to plus or minus 16% is reasonable. When you get involved in depths of discharges as high as 50 to 70%, I don't believe that you can depend on a plus or minus 10% figure.

Q. You indicate that the high depths of discharge occur only during the maximum shadow periods, but during the shadowless periods the battery sees continuous overcharge. Isn't this a very stable condition?

A. Yes, but the regulation figures are the extreme over the entire orbit period and therefore must include both charge and discharge cycles. The charging will be done at 1.47 volts per cell, but the discharge voltage will be down to about 1.08 volts per cell.

Q. Now when the vehicle is in full sunlight for two or three months at a stretch and the batteries are at full over charge, can we get regulation limits as wide as this plus or minus 16%?

A. If one is willing to consider a "seasonal regulation" the new limit will be very narrow. However, later during the period of the yean the battery will have to supply power and therefore operate in the discharge region.

Q. Doesn't the battery see discharge duing the whole year?

A. (Chorus) No. During the daylight period the battery is merely floating across the buss. So that for forty days the battery goes through a charge - discharge cycle and for approximately 100 days is not discharged at all.

Q. From the standpoint of the designer of the electronic equipment within this vehicle what figure of regulation does he work towards?

A. Plus or minus 16% for the full year.

150. I think there is some confusion over what the orbit is and why we have light and dark periods. It's a polar orbit for the STEER program. For the 24 hour orbit you also have light and dark periods but not of the same ratio as the 6 hour orbit.

Q. Isn't the 24 hour orbit practically all sunlight?

A. (Chorus) No. The numbers are approximately as shown on the board. There are 40 days of dark periods with a maximum dark period of 71 minutes. This is followed by approximately 100 days where there are no shadows. And this again is followed by the same shadow period.

Comment: It just happens that in the 24 hour orbit there are periods of no eclipses which are just about as long as the 6 hour orbit. You are so far away from the earth that even though you are on the equator and because the equator is tipped 23 degrees to the ecliptic it turns out that you get about the same period. The maximum eclipses are a little bit longer like 80 minutes, and the periods of eclipse time are about the same and the same length of time when you get no eclipses.

Q. For the 24 hour orbit will the variation voltage be as much as plus or minus 16%?

A. Those are the figures we are using at the present time.

If our laboratory tests show a decided decrease in those figures we will be most pleased. That's the only information that I can give you at this time.

144. If I can go back to the radiation question at this time, have any considerations been given to the stopping power of the materials in the back of the cells?

147. Radiation protection works out to be a function of the density of the materials. Because of the structural materials required to support the cells, sufficient protection will always be present on the back of the cells.

130. I don't know what your structural design is, but in the Lockheed configuration their backside is essentially open. In your physical arrangement, what do you have on the backside? Going from back to front we have an aluminum honeycomb, bonding materials, solder of the cell, and finally N-type material of the cell.

151. Even if you have nothing on the backside of the cells you still have 0.020 inches of silicon as a barrier because it is the top layer of the cell which is damaged by radiation.

Comment: The physics of the cell is such that you don't want to destroy the very thin layer on top and it doesn't matter if you do a little bombarding of the material on the bottom.

138. Has anyone looked into the question of secondary radiation if you are hit from the back by a high energy proton or electron? Is this secondary radiation something to worry about or is it a secondary factor?

152. The test that GE ran at the General Engineering Laboratory in Schenectady indicated that the bremsstrahlung as far as the glass on the top is concerned, is negligible compared to the beta damage at the energy levels of the 24 hour orbit. But when you get down to the inner Van Allen belt it's another story.

173. If the presumptions on the possibility of proton fluxes are true then the protection of 0.010 to 0.070 inches of glass or quartz will not do very much against the protons. At least centimeter thicknesses will be required to stop these particles, however, the thing that we wound up with - and the thing which came from Van Allen's recent flux information - is that if you will tolerate a statistic degradation due to the protons and you protect against the electrons, you can get your out-put for one year's life by an increase of 20% in the total area. The decrease in out-put for each following year will be logarithmic.

168. By having the ADVENT people here, we serve to bring in a lot of other problems. I think we've got a good picture of what's going on in this program and the problems as they see it. This ties in with some of the problems of other programs and we will get the specific details as these programs are discussed. And now I thought we'd have the oldest experienced group up here to discuss the SAMOS/MIDAS program. They have been working on this program since before ARPA.

This looks like an ideal time to adjourn for lunch and we will resume the program with Chuck Burrell.

IV. Discussion of SAMOS & MIDAS - C. Burrell - LMSD, Sunnyvale, California

134: I hope you fella's are more gentle with me than you were with GE. Lockheed's SAMOS and MIDAS programs are done under the cognizance of AF/BMD and uses the Lockheed AGENA-B as the basic vehicle for these two systems. The MIDAS program uses a vehicle on a 2000 mile orbit (polar) and carries an IR detection system as an early warning device for the detection of rockets, ICBM's and so forth. The SAMOS vehicle is of the same type operating 400 mile orbit and is primarily a reconnaissance vehicle. (Photo) App. B-2. The SAMOS vehicle will carry a 4200 lb payload; the MIDAS approximately 2000 lbs. Of this weight approximately ten to fifteen per cent is allocated for the auxiliary power. In electrical load the MIDAS vehicle infrared system operational version will use a 180 watt average power solar photovoltaic system. The peak power requirement will be on the order of 1.5 kw. The development vehicle that we are proceeding with at the present time carries a suitable amount of instrumentation. It operates at an average power of 320 watts. The peak power requirement is still 1500 watts. The SAMOS operational version is 275 watts and the development version 400 watts average and also a peak of 1500 watts; the system in size is probably very close to that discussed by GE. During the development period of these programs we have considered the fixed array systems, the cylindrical arrays around the outside of a vehicle and finally ended up deciding -- as GE has indicated their decision has been -- that the only practical approach is one in which you would use an orientation control system.

As the vehicle sits on the booster we have an adapter section that sits on top of the booster with the tank section of the vehicle as shown in figure 9. Payload is up top and forward of the booster. We package the array on the aft equipment beam-between the fuel tanks and the booster-for ascent. There is a section on each side where the plates can be folded up. The rest of the space in the back is taken up by pressure spheres for the engine and the various pieces of equipment for the propulsion system. Operating in orbit the vehicle is arranged and stabilized nose down, the adapter stays on the booster vehicle. (See figure 10 for the launch configurations and the direction of deployment.) We have arranged it so that the array will open up on kind of a lazy-tongs affair and move out as shown in the previous referenced figure. The vehicle is in a polar orbit and is designed for a years' life. It is arranged to track the sun about the array axis. (See figure 11 for sketches of the earth, sun, paddle alignments.)

The layout of cells is conservative from a system design. I might go through the layout of cells, etc. We employ a basic collector element that is 14½ inches wide x 18 inches long. This collector element carries 740 cells. The electrical inner connection is such that 10 cells are soldered on to a basic strip (Kovar). This then gives us a single basic module in which 10 cells are connected in parallel. The 74 ten cell modules are then connected in series to give each panel a 28 volt output. The design is intended to facilitate the maximum thermal energy transfer through the system to keep the cells running as cool as possible. We are also limited by space for packaging the 150 square feet of array. Therefore we have come up with a design that incorporates the magnesium sheet with cut-outs behind the cells. Fig. 12 The cells are then cemented over these windows. Therefore, there is no barrier between the back of the cell and space. This is an early version; later versions will be made of nickel sheets with holes punched in it to give a further weight reduction and increase the thermal radiation. Fig. 13 From a reliability point of view we considered the use of a shingled construction and felt that with a shingled system the losses by open circuit of one cell would cost us 10% of the power out-put of the package. By using the paralleled groups of 10 cells, the loss of one cell is hardly noticeable. This assumes that we will not get any broken wires. Obviously any broken wires would knock out the whole module. On the vehicle structure each frame is composed of six of these panels. On the MIDAS vehicle there are 84 individual panels. You can see that this system is rather severely over-designed because of the uncertainties in the orbit operating conditions. The specification for the power output of these panels is 10.7 watts or about 6.2 watts/ sq. ft. This corresponds to an average solar cell efficiency of 8.2% and realizes an area efficiency around 85%. We use a variety of glass slides at the present time mainly for temperature control and some protection from the Van Allen radiation. The cells at the present time use 0.006 inch glass with spectrolabs coating Solacoat A. Other slides in the same array have Solacoat B and still others are uncoated. We intend to instrument a good number of the panels to get information on the performance as a function of glass th'ckness, glass coating, back emissivity, the paint films which have been applied to the backs of some cells. The general idea of the first few shots is to instrument very thoroughly and determine the performance under the above conditions.

42: With regard to your orbit I would like to mention that there is one orbit where the progression of the nodes is equal to the motion of the earth around the sun.

134: I should have mentioned that on the SAMOS flight that is meant primarily for photo reconnaissance, we deliberately established that orbit. It is an 84 degree orbit, I believe. This will give us one degree/day retrogression and we will maintain a noon orbit. The orbit is also quite low - 247 miles. The drag of the system (solar array) affects the vehicle attitude. (See figure 13). The vehicle line of flight is along the X-axis as indicated and the array oriented along the Y-axis. The drag on the wings is so great that the attitude is off. Therefore, it has been necessary on those particular flights to change the array system to a new condition. (See figure 14). Since we have established a retrograde orbit we will maintain the noon orbit plus or minus 2 hours. There will never be any reason for the array to track.

42: As far as I know you can find such a retrograde orbit for all kinds of altitudes.

134: But the flight objectives change so that you can't do that. For example, the MIDAS vehicle end intent is to have 16 vehicles in 16 different orbits so that complete coverage is achieved.

138: What is the direction of the earth in this case?

134: The Z-axis is down and you are in a noon orbit so that the paddles do not have to be turned around either axis (they are static). (See figure 14). This is an 84 degree retrograde orbit and the vehicle is always in the same plane and the array is flat out.

138: Then you accept the penalty.

134: Yes. Because there is nothing else we can do. If we change the axis of the paddles and orient the paddles, then the drag is so high that the attitude is thrown off. The requirements for attitude control are 1.5 degrees. We cannot get this with the increased drag conditions.

145: How do you get these tong things to move out?

134: (See figure 15.) There is a set of small springs between each leaf - so to speak - so that the springs furnish the motive power. Back on the last rods (in the vehicle) we have a lead screw and a small DC motor to furnish the controlling power of deployment. Each wing is 18 feet long and 54 inches wide.

154: When these move out is it just a two plane effect?

134: Yes, it is just a flat panel.

154: What is the weight of each paddle?

134: 14' inch x 18 inch or 2.1 lbs a piece. With the holes in the new mounting panels we expect to achieve 1.7 lbs. Since the panel is 1.8 sq. ft. we are slightly under 1 lb/square foot.

138: If the array is 150 square feet, the weight of this must be about 150 lbs. What is the weight of the total power system?

134: The weight of the total system is 280 lbs. This includes batteries, array, and other miscellaneous equipment.

On the selection of the number of cells you can draw a set of curves of millawatts vs cell voltage (See figure 16 .) and get a set of curves which show the shift of operating point with temperature. With the various slide covers and the thermal studies that we have made we have come pretty close to the design point that GE has calculated their operating temperature to be. We say it will run at 108 degrees F. From this curve we find that at 100° we will be operating at .39 volts per cell for the maximum power transfer point.

145: Why is 28 volts always picked as the operating point?

134: I guess this is a carry-on from the available hardware equipment designed to operate at that voltage.

145: Is this the minimum weight point of the system?

134: If you go to a higher voltage your wires get smaller and you run into a strength limitation. If you go to a lower voltage the power conversion efficiency becomes less favorable. The majority of the available transistor equipment available at the start of this program worked better at the lower voltage of 28 and formed the basis for continuing to operate at this point. The voltage regulation on the unregulated part of the auxiliary power system is 22 to 29.25 volts. These were established in the beginning by a comparative analysis of the charge-discharge limits of a NI-CD battery in the solar array system plus the tolerance of a silver-peroxide-zinc battery on discharge for use on the program. This is based on the desire to use as much of the DISCOVER equipment as possible for the SAMOS/MIDAS programs.

154: What is the depth of discharge for the particular voltage regulation?

134: About 10%. Depth of discharge does not enter our problem because we have a battery in the second stage vehicle which we can also use as this space vehicle system. Therefore the second stage battery can be used during the ascent phase to furnish power. This gives us a pretty good sized battery for orbit use. The ascent load is on the order of 1.5 kw and the trip lasts for about an hour and a half. So the load is pretty high. This puts us in orbit in a near discharge condition so that if the array fails we have life for about three passes.

145: Does folding these things out upset the vehicle at all?

134: At the time the main orientation is accomplished the vehicle is under control of a gas jet system. (See figure 17.) It is operating through gyros and an IR system so that we do have control and make an attempt to run them out at the same rate. However, the two paddles are not tied together but rather are run by separate drive motors. I'd like to talk about the redundancy of the system. (See figure 17.) Each wing has its own orientation control system and is completely separate from the other. Therefore if one fails the other will still come out and work. From the standpoint of the electrical control each wing is divided into two units. (See figure 17.) From an electrical point of view then we have four individual sources - any of which could fail and still permit full system operation. This gives us a 25% safety margin. If one failed to track but came out, and the other came out and did track we would be o.k. there also. From that point of view we have a dual redundant system by tracking and by the additional electrical panel. (See figure 18) From the array we go to a small black box which is a regulator to the battery through a diode to the buss. This is repeated four times. The main reason for the voltage control is the temperature control of the battery as we discussed it this morning. It also permits system voltage control. As we progress from a noon orbit to a twilight orbit, as the seasons change we will get to an overchange condition. It is desirable that the charge be shut off or reduced at the time we hit our 29.25 volts. There is another consideration that we have been aware of and this is temperature problem of the battery. We have widely varying temperature conditions due to the vehicle position in orbit as the seasons change and because of the change in power dissipated by the experiments on board. The load or energy utilization in the vehicle can vary by a factor of ten. We therefore compensate the voltage regulator by a temperature pickup at the battery.

162: Do I understand that one panel would supply all the load? What would happen to your system if just one panel came out?

134: If we lose half of one panel electrically the system can survive indefinitely. We can lose one panel and we can program the load and survive.

165: Where does the power go when you have all panels deployed and operating?

134: It stays out in the paddle. The regulator can be used as a switch. (See figure 19.) When the voltage rises and the battery is charged (29.25) this regulator will maintain just enough charge to hold that voltage. This is also temperature compensated so that when the battery is real hot the regulator drops to a lower maximum voltage point. With the system at 70°F the cutout point weather regulator cuts in 28.25 volts. If the temperature goes down to 30° F the voltage goes up to 29.25 volts. The temperature of the battery goes to 125° F, the voltage goes down to 26.5 volts.

165: If you are at the 29.25 mark you still have extra power coming from the solar array. Where does this power go to?

134: It's dissipated as heat. If the load under these conditions is 350 watts the array is generating (on a twilight orbit) about three times that much or about one kw. The regulator functions only to let 350 watts come through. The rest of it stays out in the panels.

138: How does it do it? By limiting the current drawn from the arrays or does it by-pass current into a resistor?

134: It limits the current. By bringing it in to a resistor would just add to our thermal problem.

By isolating each of the four electrical panel systems by a diode we get isolation during the ascent phase so that when we fire the separation volts and other pyrotechnics the heavy current peaks are not seen by the main part of the system. As you know this diode would cost us 3% of the total energy.

148: Do you have blocking diodes in the regulator box or on the array?

134: On the array. Each panel has a separate blocking diode. (See figure 20.) From the array cells themselves we have one diode in the array; we have our voltage regulator (fig 21) which consists of a transistor shunted by a contactor. The contactor is connected so that when the battery voltage is low the contactor is closed; therefore there is no voltage loss across the transistor. Power then goes through another blocking diode to the buss. Battery is connected between the regulator and the last blocking diode.

148: What is the current carrying capacity of the contactor?

134: Six amperes.

148: What is the reliability of that contactor?

134: We would estimate that the thing would operate about once per pass. For the noon orbit it would operate every time it went into the dark. It would close. From that point of view a contactor with a 5000 cycle capability should be satisfactory. If it fails in the closed position it wipes out the voltage regulator and your battery would be overcharged. If it locked out in the open position your battery charging rate would be reduced. This could only occur by electrical failure and we have selected the coil so that it will fall out when the system reaches 18 volts. The probable point of failure of the device is the transistor itself which would fail as a closed circuit. If that fails as a closed circuit it causes a 1 ohm resistance to be inserted between the array and the battery. The regulator then would consist of the contactor and a one ohm resistor. This would permit a two rate charging control. Under these conditions the relay would cycle quite rapidly.

138: Is this a mechanical contactor? Does it work in a vacuum?

134: It's just an electrical relay in a hermetically sealed package.

Comment: If the relay leaks in space the contacts will weld together.

138: Have you looked into this problem of cold welding in space?

134: We have. For the last five years. And we are not worried about this. We've got lots of other worries.

168: Do you have any reports or data on these kinds of tests?

134: Most of the detail was done by Eastman Kodak in the development of the payload system. There are a stack of reports. The main assumption of the cold welding is that the oxidation will go away and you will then get molecular bonding between the contacts. It is my understanding that you have to maintain the surfaces in intimate contact for a long time. I think that the relay operating once per orbit (1.5 hours) will be enough motion to prohibit welding. We might be surprised.

151: There are people who are not convinced that relays in vacuum or any mechanical contact are going to be perfectly reliable. There is a paper by some Lockheed people on this subject.

134: I know. We have a Lockheed paper which says batteries will not operate in orbit. But they do. While we are on a discussion of the vacuum problem I might point out that the bearings will be a challenge. This question arises from the desire to move the array in both rotation and translation. (See figure 22 .) We need a drive system that has the least possible bearing surfaces unit. If possible we want to select those bearings so they are not operating under conditions which will cause bonding. Lubricating the bearings may offer a possible solution. We have a set up in which the main drive for the array is a stepper-motor combination. The stepper-motor is a continuous relay of a sort. The particular ones in this design operate three degrees in every step. We then arrange the system so that one motor is above the other and are connected to the array to bevel gears. This then gives us two bearings for each of the motors. The ratio of the bevel is two to one. With one motor turning clockwise and the other turning counter-clockwise the array moves about its own axis. To get a translation from the vehicle X to Y axis both motors are operated in the same direction. The drive motor electronics is probably the most complex part of the orientation system. It takes a rather intricate series of pulses to actuate the stepper motors in the desired directions and at the appropriate time.

138: If you turn both motors in the same direction how does the array move?

134: The array moves in an annular motion (around the axis of the motor). (See figure 23 for the following discussion):

For an absolute polar orbit, where the vehicle orbit plane stays fixed in space we maintain the arrays on the Y axis position unti we get down to the point shown. After this point we command a translation to the X axis at this 45° point. If the ground command fails to affect the translation the system will program the translation itself 15° after the 45° point.

138: Does the vehicle use expulsive gas for control during this translation period?

134: It takes about six hours for the vehicle system to recover from this translation. Fly wheels are used for the stabilizing forces during this period. We hope that we will not have to use the gas system to slow down the fly wheels. However, the gas jet system is there to be used if required. Supposedly the fly wheel would slow down due to the EDDY currents of the earth's magnetic field.

165: Do you have four separate batteries in there?

134: Yes. They weigh 57 lbs apiece.

165: When the four panels are operating is the depth of discharge 10%?

134: That is right. With one it would be about 35 to 40%.

170: When you are at the minimum power collection value (roughly 50%) do you need all four electrical arrays? Or can you get along with just three arrays?

134: We can get along with just three arrays. We have 153 sq. feet for 350 watts. The collectors are 6.2 watts per sq. foot.

150: Could you drive the V-I curves and show the operating point?

134: Not at this time.

150: In calculating the operating point you stated that the temperature would be 108° F and a per cell voltage of 0.39 volts and 74 cells in series. This would give you 28.86 volts maximum. You have two diodes and a transistor in series with it. Depending on where you are operating I cannot understand how you get 29.25 volts.

134: It depends on the battery temperature. The characteristics of the regulator are such that the operating voltage can vary between 26.5 and 29.25 volts depending on the battery temperature.

150: If the maximum voltage from the array is 28.8 volts how can the condition of the battery increase the voltage to 29.25? The solar array would determine the highest voltage.

134: Yes - at the highest array temperature. We would go up in array voltage as the array temperature decreases.

138: What is the life objective of MIDAS in the 2,000 mile orbit?

134: One Year.

138: What are you doing to determine the thicknesses of protection needed for the solar cells against the Van Allen radiation?

134: We consulted everybody who wants to talk about it. We ran a number of tests with our own radiation source and had a program with Berkeley to radiate cells in their equipment.

138: What is Berkeley going to do? Is this electron and proton radiation?

134: Yes, both electrons and protons. We would sure like to have anybody else give us additional information - the information we have is confined to what we read in the San Francisco Chronicle, Life Magazine, and other things. Are there any other written reports or other information that we can get that anybody knows of that is formalized and can tell us what it is that we are supposed to be worrying about?

138: I have a report here containing advice that Van Allen gave to our Goddard people on this last S-46 satellite that failed orbit. This summarizes what was known as of a couple of months ago. There is another Van Allen paper presented a week ago in Los Angeles in which he makes the statement that cells probably will not last more than a few months if they are bare. In conjunction with his discussion on this S-46 satellite, Van Allen recommended three courses of action:

(1) Add 25 mg/sq. cm. of mica to the cells.

(2) Lower the apogee by about 3,000 kilometers.

(3) Add 100 mg/sq. cm. of mica.

The expectation of life time increases with each of the above courses of action. We have to know better about the spectrum of the energy in space of both protons and electrons. In particular we need to know what is the flux of protons below ten Mev. By extrapolation we can see that there is a great number of these protons and they may integrate to give more damage than the higher energy ones. It is a fairly complicated question. It depends upon the thickness of glass and the penetration. The higher energy particles will go on through and give you damage in the critical layer.

By running cells at an elevated temperature, radiation damage will anneal out. We plan to do some design experiments using both electrons and protons using available radiation facilities.

151: In addition to Van Allen's paper there was a paper presented at the Nice Conference on Space Science about three months ago which summarized the data which had been taken up to that time including the EXPLORER VI lower energy data. Rosen of STL was one of the authors.

174: What happens to other semi-conductors on these vehicles?

151: Generally these are inside the vehicle and are shielded by the skin. The blocking diodes used on the arrays are generally protected by their packages. The high energy of the inner Van Allen belt may dictate against flying that kind of orbit.

148: I should like to point out that there may be a problem of greater degradation of higher efficiency cells as a result of radiation.

165: Can you describe some of your battery test program?

134: A series of charge - discharge cycles on a 18 minute discharge and a 72 minute charge. This amounted to removal of 60% of the energy in the battery. The cut off limits were 22.5 to 29.25 volts. We had a failure after 2500 cycles. We attribute the failure to the battery separator. Sonotone is in the process of a battery redesign to incorporate a new separator structure. We have also changed the design criteria for the battery from the original criterion of a high rate battery which in a way compromised the energy to weight ratio in order to run the electric hydraulic equipment during the ascent phase. This problem has all been resolved by including a fuel - turbine pump off the engine so that we can now drop back to a low rate battery design. This will increase the energy to weight ratio. At Lockheed at the present time we are investigating the temperature variation of the voltage/rate performance of the battery. We want a set of curves of voltage versus rate plotted for different temperatures. (See Figure 24) We will also run data for three conditions of the battery: fully charged, near discharged, and an intermediate point.

160: From this 2500 cycle test how many cells were used?

134: A complete battery - 20 cells. During the test four cells failed. Three of them probably due to the first failure. The test was run at room temperature.

(A battery discussion occurred at this point and the results are summarized later in the paper under the heading of "Battery Discussion.")

134: On the original assembly of the panels we attempted to use nickel as the base metal. However, we were unable to keep these cells together under thermal cycling. Kovar was substituted for the nickel and performed very well. The cells are bonded to the grid structure by a silicon cement. The bonding of the glass slides to the cell was done by spectrolabs and I do not know the composition of the bond material.

162. Can you describe the environmental test conditions for your array?

134: First we ran high temperature storage for 48 hours at 200° F. This is followed by low temperature storage for 48 hours at -100° F. The vibration tests are then run and consist of 7.5 g for the frequency range from 40 to 400 cps and 15 g for the range of 400 to 3000 cps with 30 mins. in each plane. This is followed by a humidity test in accordance with standard military specs. and a top temperature of 165° F. Finally, we run temperature cycling of 15 min. intervals of 175° F. in 15 min. of -80° F. with a 15 min. interval between the 175 and -80° temperature. This test is carried out until 30 complete cycles have been accomplished.

148: The low temperature point for the Advent Program will be approximately -160° F. and is primarily determined by the mass of the paddles. The temperature will drop lower as the weight per unit area of the paddle is decreased.

174: We have done temperature cycling tests of cells and shingles down to the temperatures of liquid nitrogen and have found that a plated molybdenum makes an excellent mounting surface any gridded cells?

130: Did you thermally cycle any gridded cells?

174: I do not recall any tests of shingles at low temperature but I am sure that cells have been cycled at the temperature of liquid nitrogen.

130: If I understand your comments your products can be cycled to -200° F. without any problem.

174: I have here two modules that contain 125 cells each. These have been subjected to 10 cycles of temperature from +160° F. to -200° F. in our place and I think for another 10 cycles at STL, and there is no visible deterioration.

130: I notice that the two modules you have are shingled assemblies.

174: Shingling permits faster assembly than soldering.

162: We have tested individual modules of 5 cells, down to liquid nitrogen temperatures. These modules had glass covers cemented on them. We agree with the thought that you get the least damage by temperature of a single cell and less damage in a 5 cell module than you do bonded to a large substrate. Most of our tests have consisted of thermal cycling from 200 F. to -100° F. The time rate of change is very important for these tests I'd like to make the observation that the 3° per minute rate mentioned by Lockheed appears to be a very slow change and would tend to minimize damage. We have used the approach to produce this change as rapidly as possible within our existing facilities. This gives us a more rapid evaluation of the materials involved. We have achieved rates as high as 300° per min. during the initial portions of the test cycle. Of course, as the panel approaches oven temperature the rate decreases proportionately.

168: What was the cement that you used?

174: The cements have been varied. The cement on these panels is a Hysol epoxy.

162: If my memory is correct the resin that we have used is Hysol #1055. I will have to check this number.

151: I should like to make a comment on the high rates of temperature change previously mentioned. I think in most normal designs that the rates achieved by running from the oven to the icebox is excessive over that which will be experienced by a space power system. I do feel that the rate will be more rapid than the 3° per minute mentioned by Lockheed but this figure is only for the end of an eclipse.

162: I agree with your comments and feel that you are fortunate to be able to calculate these rates of temperature change. We were not in a position to do this work in support of our Ranger program.

174: I just recalled a test which I had performed a few weeks ago. During this test cells soldered to a molybdenum substrate were taken from $+100^{\circ}$ C to liquid nitrogen temperature and the liquid nitrogen boiling stopped in 30 seconds. The results of this were a 300° C change in 30 seconds. No damage was visible. It has been my observation that the rate of change is not as important as the final temperature value. Just leaving the cells at the liquid nitrogen temperature brought about failures of the glass and the bonding.

151: When does the damage occur?

174: Sometime after the cells have reached a stable temperature.

134: We have performed similar tests with a very high rate of failure and feel that the humidity in the cells is one of the biggest factors causing the damage. We have found that vacuum drying the cells prior to the cold temperature test reduced the failure rate considerably.

162: I think that is a good point that you raise concerning the water content. In order to avoid such a problem during our testing we have always dried the cells for 15 minutes in an oven prior to the cold temperature testing. (Dired out 200° F.) We feel that it is unreasonable to consider vehicles in outer space as having much moisture because we expect that this would soon be drawn out by the high vacuum

148: I should like to ask a question to determine what happens to the glass under these extreme temperature tests. Does it crack or shatter or have any other serious results?

152: I think that if you are going to try to use large pieces of glass with a mastic between the glass and the cells you might get away with it. But if you actually bond the glass to the cells I would expect severe cracking of the glass. There are some mutually exclusive requirements for resins and it is difficult to meet the requirements for humidity and those for temperature cycling. If you are talking about using thick glasses you will probably have more stability and resistance than in the thinner slides conventionally used.

174: We have found that even when glass cracks at these low temperatures there is little or no degradation of the electrical output because the cracks are so fine that one has a hard time seeing them. Only at a very oblique incidence of light and under a microscope do they show up. Because we do not have any delamination the glass stays in place and does not affect performance.

152: It is probably not very important in small pieces of glass but it might induce shattering in larger plates.

174: On some tests that we performed for STL we had two cracked glasses out of 160 when cycled out -130° F.

154: There has been a considerable amount of discussion about the Advent panels and the -200° F number. We are anticipating to experience (in a lunar orbit) -200° F. temperature at the end of a 2½ hour eclipse period. This might indicate the rate of temperature change which would be appropriate for testing purposes. I have another comment-as a result of our experience we find that minimum damages occur when the amount of solder on the connecting wire is kept to a minimum.

138: I was wondering if this is as much of a black art as everybody says or is somebody trying to use some design engineering in it? First acquiring the test data you need on the strength of glues and the thermal expansion coefficience of materials, and second doing some detailed thermal analysis.

148: Our program involves the evaluation of a number of bonds in shear strength, tensile strength, radiation tolerance, thermal cycling, humidity degradation, and we are also looking at the effects upon the other components such as the glass and the cells. The analogue computer program is aimed at an engineering approach to the indicated experiments.

162: Our one experience at approaching the problem this way did not meet expectations. We found it very difficult to correlate the results from sub-assembly tests to the final performance on the integrated assembly.

V. Discussion of TIROS - S. Winkler - RCA, Astro, Princeton, N. J.

173. After hearing about the sophisticated satellites, I have some information on our big base drum, TIROS. As far as we know TIROS is still working -- we get pictures back from it every day. Apparently, lower California is still there. We got a nice picture of that the other day--if you took a map and put it next to the picture, it has the shape that the geodetic people say it did. TIROS started off as an ABMA program, and it was to be a JANUS series satellite. The original shape of the vehicle was to be a long thin profile with a requirement for seven to eight watts. This was to use only a single camera for observations. Since that time the profile has become that of the present TIROS employing three cameras with one camera out the side and two looking out the bottom. (See Fig. 25) For budgetary reasons as well as excess weight the side camera was deleted from the program. The main design criterion was to produce a pancake-shaped vehicle so that it would continue to spin and remain stable throughout its life. This dictated the configuration of the solar array. The lifetime of this vehicle is to be 100 days, at this time the cameras will be looking at the sun and not producing useful information. The satellite is covered with solar cells around the periphery and over the top. The bottom has no cells because this surface is not expected to see the sun. Because of design considerations we decided not to deploy any collectors at this early date. We consider this a Vanguard generation satellite. It was decided to minimize mechanical complexities, and this dictated arranging the converters on the surface of the vehicle. Obviously this imposes a serious thermal problem as well as a severe mechanical design problem. Because the

launch forces are acting perpendicular to the plane of the top surface, structural requirements are quite severe. Some of the thermal considerations were based on conclusions that a honeycomb structure would act as a radiation baffle and would adversely affect performance. We have to dissipate the heat from the solar cells by radiative coupling from the bottom surface. The top surface heat and some of that from the sides is radiated to the payload black boxes where it is conducted to the bottom surface and then radiated through space. This bottom plate in operation is looking away from the sun and makes the best surface for the vehicle heat dissipator. The top surface is constructed of a skin stiffened with aircraft type braces arranged in a spoke shape. Stiffeners between the spokes serve to give the required rigidity. Because of this heavy structure the weight and efficiency is far from optimum. Because of these heavy structural requirements the weight of the solar array portion is probably on the order of three lbs. per square foot. (See Fig. 26) During the time that the sun is as indicated on the diagram, it will go from a 45 degree angle from the vehicle spin axis down through a 90 degree position and on to a 45 degree below the horizon position and then back again through the season variations. This design permits the sun to adequately illuminate the vehicle, even though the sun is not all perpendicular to the vehicle spin axis. Because we wanted to get a decent view of the earth during the time that the earth is illuminated, we had to compromise on the deviation angle of the sun from the perpendicular to the vehicle axis. Our original intent was to launch so that the angle of incidence of the solar energy would be approximately 35 degrees from the vehicle spin axis. As a result of the design maximum power producing angle would be 25 degrees. The solar cells cover the top 15 inches of the sides and completely cover the

41 - 3/4 inch diameter top. The vehicle sides form an 18 sided polygon. Because of the thermal design considerations, the hottest cell in the array would be that one in the center of the top surface. Calculations showed this cell would reach 70° C. The packing factorof 85% was one of the design criteria. The cells at the edges of the top surface will be at 45° C; those at the bottom of the sides will be 20° C, and the bottom surface between 10 and 15° C. This temperature will be influenced by the coatings which are applied to the bottom surface and to other surfaces not covered with solar cells. Because of this temperature distribution it became attractive to use the variation in operation of solar cells to give us multiple voltage outputs. Fig. 27 However, for reasons of economy this scheme was abandoned and replaced by a standard uniform module which would be employed over the total surface to be covered. This module consists of 80 cells in series mounted on a printed circuit module made of a fiber glass casting. Five cell shingles were used in construction and each had a special lead wire fabricated to each end for convenient assembly to this printed circuit casting. Fig. 29 Each shingle sets into a small well, molded integrally to the fiber glass casting. There are sixteen 5 cell shingles mounted on each board. The board size is 3-1/2 by 7 inches. (See Fig. 28) Holes were punched in the board to receive tabs mounted on the shingles. The printed circuitry is buried within the lamination of the board. In assembly the tabs from the cells were inserted through the holes and bent over to contact the printed circuit. Fig. 30 We originally tried to use a conductive cement of a silver loaded epoxy. Humidity and aging proved to be insurmountable problems. So we went back to a standard soddering technique. Each of the shingles on each board was connected in series. The open circuit potential of each board was in the order of three to four volts. Each group

of 20 cells on one board was parallel with a corresponding group of 20 cells on the adjacent board. Today we would probably use a different technique of electrical connections, but did not have sufficient information at the time this power supply was designed. This concept of construction allowed us to cut the board into quarter sections for use on the top surface in the spaces where a full board would not fit. Fig. 31 In the spaces on the top which were not covered we coated the surface with a low a/e material to take advantage of these heat dissipating surfaces. We did cover everything on the top except for a small square at the center which was required for handling and balancing. Because of the thermal mass of this design we did not experience any wild temperature swings; we are in a low altitude orbit -- 400 miles; we were told that it would always be maintained in controlled atmosphere environments even at Cape Canaveral. Because of this last requirement, humidity was not a problem which we considered. The prototype of this vehicle was tested at 50 g axial acceleration, 25 g. rms from 20 to 2000 cps for two minutes in each plane

142. The linear acceleration specification just called for 25 g. testing.

173. In one of the early vibration tests, peaks of 50 to 100 g's were experienced during the testing. You are right on your recollection of the specification.

148. In reference to your statement on paralleling you mention that you parallel all points on one board to the similar points on the adjacent board. Could you explain your reasoning?

173. The paralleling is done in groups of 20 cells only. (See Fig. 32)

168. Could you give us some idea of the power output of your system?

173. (See Fig. 33) At an illumination angle of 24 degrees, our power output at 30 degrees centigrade with full solar incidence is approximately 62 watts instantaneous power for the array. There are approximately 20 square feet of collector on this vehicle. This gives approximately 3 watts per square foot (instantaneous). The solar cell efficiency was average about 7.8%. This 7.8% was a measurement which included the effects of the covered glasses.

Comments: A discussion followed regarding the pricing of cells of varied inversion efficiencies. Fig. 34, 35

173. We purchased the cells on the basis of shingle efficiency of 7.5% with no glass slides. For the coatings we allowed a degradation of 10% (of the 7.5%). This would have netted us in efficiency 6.8%. However, during the production runs the vendor delivered 7.8% cells including the coatings and covered glass. During the process of designing and constructing this vehicle we handled about 52,000 cells or 10,000 shingles, and as a result of this task developed a simplified testing technique. For these tests we got an illuminated area which was approximately two feet square and tested 60 shingles at one time with an automatic stepping switch arrangement. Automatic voltage leveling devices were designed which forced a shingle to sit at three voltage points at a fixed temperature. fig. 36 During the design of this testing equipment a variety of filtering devices were examined and ultimately abandoned. For calibration a standard cell was used as a reference.

168. At an illumination angle of 24 degrees you expect 62 watts from your power system.

173. That is correct. When the sun swings into the twilight zone we get in the order of 24 watts from the system. If we bring this back to the period where the batteries have a considerable amount of work to do due to dark time storage, and because of our area of limitation the orbit averaged power becomes about 20 watts. The drain on this power system can be controlled by ground command, and therefore permits flexibility. Because of a delay of one hour in the launch time, the illumination angle was increased from 45 degrees (design point) to 60 degrees. This caused the entire vehicle to run considerably cooler.

148. With what accuracy have you been able to predict the performance of this system?

173. Our telemetry readings which are the result of sensors noted on two separate boards have not indicated any degradation. This is the result of over one month's time in orbit.

Comment: Following is a discussion of the definition of a solar cell efficiency.

173. A cell that we call a ten percent solar cell by definition is a solar cell which will convert the energy it receives on June 21 at high noon with an air mass of one, etc. -- that has a total flux of a 100 milowatts per square centimeter -- a ten percent cell will put out 10 milowatts per square centimeter. (See Fig. 37) If we take this same cell and expose it to an

integrated flux of 140 milliwatts per square centimeter, this cell will not give 14 milowatts but 14 times something like .85 which is the spectral factor.

134. I understand. We do ours in reverse. We consider a hundred milowatts on the earth and add a factor of 1.1.

154. Is this .85 a measure value?

173. No. This is one of the things we hope to get from the telemetry of this vehicle.

162. Has anybody made a spectral response curve of the sunlight on the day he makes the test and sticks the piroheliometer under the sun and reads his data?

Comment: Have you done this?

162. No, not yet. We're waiting on receipt of enough equipment. We will probably get to it in a couple of months.

174. We are going to do it. We are set up now. We have built a sun tracker on to our monochrometer and have made the monochrometer portable so that we can take it outside.

152. What kind of a monochrometer is it?

174. It is a Perkin-Elmer. It is a single pass, single beam device.

152. How is it calibrated?

174. We have checked this lately and found out that it is not flat.

152. There is a second problem here. This problem deals with the measurement of the sensitivity of a solar cell. At this time, we are building a monochrometer for the Bureau of Standards. This device will be capable of a 20 millimicron bandwidth with a maximum solar intensity of about 5 suns. Part of the calibration of the instrument will be measurements made on silicon cells between .1 and 5 suns. The resulting data will be reported in a technical paper. The limitation of currently available equipment is the extremely low incident energy upon the cells under test. Because of this, measurements on cells are made at levels of .01 to .001 suns. I do not believe that the data can be extrapolated from .001 sun to 1 sun with any confidence.

162. Next week we will be measuring the output of especially designed monochrometer to determine how much power we can put through an ordinary machine. We do not expect to get as high as 5 suns but do expect to get in the region of 1 sun.

152. The characteristics of this monochrometer will have a dispersion of 56 engstroms per millimeter. It will use a 4 millimeter wide slit. The light source will be a pulsed xenon lamp which is built into the system.

168. How many solar cells on the TIROS vehicle?

173. 9,260.

168. What was the cost of this whole system?

173. I cannot give you a total cost figure but I can say that the solar

cells wound up costing us $6.00 a piece delivered through the door. I would say roughly that our power supply has amounted to $330,000. Power supply development including batteries, voltage regulators, current regulators, cell mounting, and total assembly might be on the order of twice that amount. In round figures the total might be $1 million.

At this time Mr. Wiener took the floor to discuss the battery aspects of TIROS.

170. A block diagram of the power supply would be most helpful to understand the application. (See Figure 38) Diodes are used in the output of each battery to prevent the failure of one battery from affecting the performance of the other batteries. We have a system of voltage regulators which provide 24.5 volts plus or minus 1% over a temperature range of -10° to +55°C. There are also two other voltage regulators each providing the same regulated output to a camera system. Each camera system contains a clock, a tape recorder, and a TV camera and the associated controls. In the block diagram the large block at the top center has several functions. One of these functions is to provide an output of between 15 and 17 volts which feeds a 13 volt output regulator which in turn feeds the clock. In fact, there are two such regulators. One thing is obvious; we are throwing away a considerable amount of power in terms of the overall power required by the vehicle. The main reason for this design is attributed to the batteries. This same main control unit contains regulating equipment for the charging of the batteries. It includes temperature compensation circuits, so that the current to the batteries is limited to an equivalent 10 hour rate. The circuit is arranged so that the solar cells charge the batteries during the daylight portions of the orbit but the arrangement is also such that we always have a continuous load in the output of the solar cells will split

between the batteries and the load. This power transfer is arranged by this large control box shown in the diagram. The voltage and current points which are telemetered are also indicated on the diagram. The solar cell array is divided into six or seven blocks - each fed to the power input point through isolating blocking diodes. Power profile of the system is complicated by the two modes of operation of the vehicle. In the first mode, the vehicle will be ground commanded to take pictures in a remote area or it may be programmed to take pictures in the immediate vicinity of the ground station. This mode (direct mode) can only occur if the vehicle passes over the ground station in the daylight period. The telemetry is not recorded. It is only read out when commanded - we only get instantaneous readings. There is always a continuous load on the vehicle. This includes clocks, beacons, command receivers, repeaters, the losses of the voltage regulators, horizon scanners, and the few other pieces of equipment. (See Fig. 39,40) If we split the orbit period into the daylight and night portions we will have a continuous power of approximately 11 watts drawn over the total period. The direct mode can only occur and only assumes power over the daylight portion of the period. The playback mode can occur at any point over the total period, and the remote mode can only occur over the daylight period.

137. How many cells to a battery?

170. There are 21 F cells in a series. To get back to the discussion of power levels let us assume that all of the power is delivered at 24.5 volts. The continuous power required is 11 watts; in the direct mode imposes between 100 and 120 watts; the playback mode consumes the same amount of power; and the remote mode will be a function of the above. The playback mode will never

occur simultaneously with the direct mode, but it may occur sequentially. It turns out that over the total orbit the batteries supply approximately 50% of the power. The minimum average power required over a 24 hour period has been slightly in excess of 17 watts. Under present flight conditions we should be able to reach an average of 24 to 25 watts over a 24 hour period. The design approach was to hold the drain of the batteries to 10% or less. fig. 41

150. What was the criteria for the selection of your battery?

173. We limited ourselves to a 10 hour charge rate so that the battery was sized on the basis of charge that it could accept. Our design optimum would have been 2.1 rows of batteries. In the flight package we are slightly over-designed with three full rows of batteries.

165. What was your storage efficiency?

173. Energy-wise it was on the order of 60%.

170. We have 21 cells at a nominal voltage of 1.20 volts giving a total voltage of 25.2 volts. In order to drive the regulators we cannot go below a minimum voltage of 25.5 volts. This minimum voltage has never been realized in any of our systems tests.

VI. Discussion of PIONEER and EXPLORER - R. Lipkis and R. Miller - STL, Los Angeles, California

168: This morning we would like to start off with a PIONEER program, then go into the RANGER work, followed up by the TRANSIT work, and finally a discussion of COURIER. This afternoon we will get into a discussion of radiation and batteries. During the day we will limit the discussions on the above programs to approximately 30 minutes in order to cover each in the time remaining for the conference.

154: The initial requirement for our power system was to be 16 watts. The configuration was to be adaptable to three payloads (the Able Three, Able Four Thor, and an Able Four Atlas). Some of the early design assumptions were 100 mw/per square centimeters, 100° F cell temperature; the allowance for radiation degradation was 20%. The power output of this system started out to be 16 watts, but because of the conservative factors above, found by test that I actually had a 28 watt power system.

		cells	function
Able 3	Explorer VI	8,000	Earth satellite
Able 4 Atlas		8,800	35,000 ft.
Able 4 Thor	Pioneer V	4,800	Venus
Able 5		8,800	

Just a short note on the Able Four Atlas flight: solar cells don't work very well under salt water.

I'd like to go into a discussion of the schematic of the electrical system. (See Fig. 42). We have four solar cell paddies which are electrically connected in parallel. In series we have a 15 ohm resistor which is shorted out by a thermal switch which is mounted on the batteries. A current monitor connects this resistor to the battery packs. We have two 14 cell battery packs of Sonatone type F cells. Each pack is isolated by a diode. We have a constant load and a converter supplying a separate constant load. This converter supplies experiments, as well as (on a command basis) a 5 watt transmitter. A second converter supplies a ground commanded 150 watt transmitter. On ABLE Three only,we have taken the output of a temperature sensor on the tip of a paddle unit in an effort to calibrate the usable energy of a solar cell as well as the usefulness of the glass slides and the coating. The cells on these vehicles are covered with 3 mil glass slides. The quantity shown in the diagram are telemetered back for analysis. On the ABLE Five vehicle, we also have facilities for under voltage and over voltage control. The significance of the over voltage control is to turn on the 150 watt transmitter; the under voltage control turns this transmitter off. Our range of voltages is from 14.8 to 21 volts. This voltage level is modified for our lunar flight vehicles where we get into the minus 200° F temperature problem. Because the battery voltage will go up when the temperature goes down, we have opened up the voltage limits to 23 volts.

170: At what temperature does the battery thermal switch operate?

154: On the ABLE Four and Five they have been set for 140° F. You are probably asking yourself why we set the temperature so high when Mr. Belore is specifying 107° F for the maximum temperature. We have made this decision in the interests of reliability. It results from a compromise between the demands of the battery and the pay load.

Q.: Do you have an estimate of the accuracy of your telemetry system?

154: This appears to be between 5 and 10%. The transducer accuracy accounts for the major part of the error; the telemetry itself is accurate to one part in 64.

130: Are you measuring the battery case temperature or the cells within the battery?

154: We are measuring the temperature of the hottest cell in the battery package. The transducer is on the case of the cell, not on the inside. Fig. 43

148: What kind of a transducer are you using?

154: A thermistor. On future vehicle arrays we will be using wire wound transducers for our solar cell measurements to accommodate the wide temperature range. I'd like to go into a weight breakdown of this power system. The paddle and the spar structure of the modules have a total weight of 15 pounds. For both battery packages our weight is 17 pounds. For our Loads: our experimental constant load is about 0.3 amps; the five watt transmitter is a 3 amp load; and the 150 watt transmitter is a 24 amp load. The 5 watt transmitter is capable of operating for two hours; the 150 watt transmitter is capable of operating for five to six minutes. Our depth of discharge for the configuration is approximately 33%. During some testing on this program we attempted to evaluate cycling life by charging at 2 amps and discharging at 15 amps for the period of one hours' time for each cycle. We got 1562 cycles on a type F cell, using automatic cycling equipment and a constant load.

165: What was the depth of discharge?

154: 15 amps for five minutes. The criterion of failure was a cell voltage of one volt.

160: How many cells did you do this to?

154: Just one.

Q.: How long was the charge?

154: 2 amps for 55 minutes.

Q.: Is one hour the normal load cycle?

154: No. This was a very accelerated test. We normally charge at a rate between .8 and 1.5 depending on the satellite.

170: Can you give us an idea of the projected area of the silicon?

154: The average area varied between 22.5 and 25% of the total amount of cells on the vehicle.

151: The reason for the odd angles on the panels was to minimize the variation of output as the solar incidence changed. fig. 44

Mr. Lipkis exchanged places with Mr. Miller and will discuss EXPLORER.

151: The temperatures on EXPLORER VI rose a fair amount because of the variation in projected area exposed to the sun. (See Fig. 44). If we plot the sun look angle versus projected area we will get a curve as shown in the figure. Over a two months period in which we have received data for EXPLORER VI the temperatures rose about 13° more than anticipated and in PIONEER V the same thing has occurred. In the case of EXPLORER VI, the paddles started off at 5 to 10° F and went up to 15°. This temperature rise may be due to darkening of the glass (these are neither quartz nor cerium oxide).

162: Have you been able to determine any correlation between the increase in temperature and the performance of the power supply system?

151: The darkening of the glass may not have occurred in the region of visible light so that the solar cells would be producing constant electrical power. As the intensity of the discoloration increases, we would expect electrical degradation. On the subject of the communication satellite, the ordinary eclipse of 70 minutes will not create a major disturbance on the electrical power system because the vehicle will be oriented to within a few degrees of the sun. However, during the ascent phase there is a six hour eclipse because of the design of the CENTAUR vehicle. This will be a real critical problem from the standpoint of low temperature on the cells. Possibly this problem could be overcome by providing auxiliary shrouds which would be blown off at the end of the ascent phase. This requires additional weight which is not desirable. We have some experimental data on the effects of radiation on solar cells from both ground tests and space flights. The ground data was done to give us a quick feel of the effect on STEER. These tests were run between 400 and 800 kev. There is a report dated February; report number STL/TR-60-000-04057. The significance of this data leads to the conclusion that 800 kev radiation requires .065 inches of glass to stop the radiation. That is to drop an 800 kev particle down to 145 kev which is the threshold of damage in the silicon solar cell. This is in disagreement with the GE data.

162: What kind of glass was on the cells?

151: For maximum lifetime, pure quartz or cerium oxide glass appear most attractive until we have good evidence that other glasses are capable of withstanding radiation and not darkening.

162: Did you evaluate Corning Microsheet?

151: No. Neither do we have radiation data on the borosilicate glasses which Al Mann is using.

190: Could you give us one point on the results of your testing?

151: The total flux was $5x10^{13}$ electrons per square centimeter and the resulting degradation was about 25%.

152: I am aware of three sets of slides that were radiated by GE and the ones which are of interest show no appreciable damage after irradiation by $6x10^{15}$ electrons at 750 kev (borosilicate).

148: I have the results of some of these radiations on glass. They seem to contradict the STL data. The Corning Nonbrowning Glass No. 8365 which is cerium stabilized and also Pittsburgh Plate Glass Nonbrowning No. 6740 were not as good as the Corning Sheet Silica No. 7940 or another Corning product, Spectrasil. The latter two glasses did not have any apparent degradation at 10^{16} electrons per square centimeter. The Corning Fused silica showed a transmission of 92% before the irradiation and 90% after exposure to 10^{16} electrons per square centimeter.

151: We have some confirmation of this data from space showing the effect upon charging current from the solar cells as time passes. By averaging many readings, we find a decrease in this charging current down to approximately 25% of the original current. After approximately one months' period, an equipment failure caused erratic readings. Fig 45 Because this orbit was eliptical in shape and extended out to 22,000 miles, most of the vehicle exposure occurred in the outer belt and was exposed only slightly to the effects of the inner belt. Just for information I should like to interject the comment on the VANGUARD power system which is still working after two years. The design of the solar cell modules is such that the windows are physically separated from the solar cells and thereby creating heating of the solar cells by the "greenhouse" effect. This high temperature is probably annealing the solar cells, thereby reducing the radiation damage.

144: We use this same "greenhouse" effect in EXPLORER VII, the fused silica window is 0.065 inches thick. The glass of that thickness will stop up to 1 mev electrons.

151: VANGUARD doesn't get into the outer belt but it does sweep the inner belt. The glass slides on the vehicle won't stop the high energy protons of the inner belt, so you would expect radiation damage. There was a paper presented at the first International Space Science Symposium in Nice, France a few months ago by Rosenfarly and Sonnett of STL, titled, "Soft Radiations on EXPLORER VI Earth Satellite." Yesterday, GE quoted a figure of 15% damage estimated as a result of micro-meteorite erosion. I think I'm responsible for that number and I had better explain it's derivation. What we attempted was to get an estimate of the damage to glass was then measured. Al Mann has also evaluated the loss in transmission by grinding grinding the surface of glass; he also noted a 15% deterioration.

154: I'd like to point out that on EXPLORER VI we had mu-metal around the batteries because of a magnetometer experiment on the vehicle. This shield acts as an excellent thermal barrier and caused our battery temperature to be about 30° higher.

VII. Discussion of RANGER - K. Ray - JPL, Pasadena, California

162: The RANGER program is basically the old VEGA spacecraft with the ATLAS AGENA booster. The first two shots are escape out of the atmosphere. They are not intended for any specific target but rather to check long range communication. The second two shots are lunar capsules - capsules are to be carried near the moon and be ejected to impact on the moon. (See Fig. 46). There are two panels used in the program. They are trapizoidal in shape and are connected in parallel. These are connected through a blocking diode to a static converter. The battery is connected between the diode and the inverter. On the first two shots we will fly what we call a launch, acquisition, and back-up battery. The panels are six feet long, 11 inches wide at the tip and thirty inches wide at the base. They have approximately ten square feet of area. There are 4,340 cells on each panel, 84% area coverage, 95 watts output from each panel at a stabilized temperature of 39° C. During the launch and acquisition phase, the battery supplies the load until the panels are illuminated. The panels are fixed to the vehicle which is sun-oriented. There is a high gain antenna which is earth-oriented. Basically, the power system is designed to operate at 28 volts. The launch battery is a primary silver zinc type weighing 120 lbs. and delivers approximately 70 watt hours per pound. In the event that the solar panels do not supply power, the battery is capable of supplying the load for 45 hours. There are no rechargeable batteries in the system. Prior to launch, the number of cells of the battery are selected and appropriate connection is made. That is, we select 18 or 19 cells, make the connection and launch the vehicle. This connection is not altered in space. The discharge rate of this battery varies as the solar panel output fluctuates - the two are arranged so that they always share the load. The total load on this sytem is approximately 170 watts maximum.

154: How many cells do you have in series on the solar array?

162: There are 62 in series. These cells are something over 11% efficiency (gridded cells). Each shingle on this array is parallel to the corresponding shingle in the adjacent series string. (See Fig. 47). The shingles used for this program are both 5 and 6 cell types. This variation was used to get voltage matching. We assume that the predominate mode failure would be an open circuit and therefore chose the design approach indicated. We found it difficult to come up with a short that is less than 100 ohms. See Fig. 48 for a discussion of the vehicle configuration. The design life of the vehicle is on the order of 60 days.

174: We use the cell matching method by a constant current technique and grade the cells according to the voltage drop at this current. This current is 52 ma. and is maintained by a variable load connected to the cell. fig. 49 The cells are grouped in 10 mv. steps. In assembling the shingles, cells are selected so as to be uniform to within 50 mv. In assembling these shingles, a special fixture is used so as to insure proper alignment and minimize excessive solder accumulation on the reverse side. (See Fig. 50). The assembled shingle is mechanically tested by a fixture shown in Fig. 51 . We use .006 inch thick cover glasses with an anti-reflection coating on the top surface and a UV reflector on the bottom. The cut-off is at 450 millimicrons. Our transmission under 400 down to 200 is 1.7. The transmission over 550 to 1.0 is over 90%. These measurements are for the filter alone (measured against air).

VIII. Discussion of TRANSIT - W. Scott, Applied Physics Lab., Silver Spring, Md.

167: The TRANSIT satellite is part of a navigation system intended to serve as an all weather worldwide navigation reference. Solar panels are arranged in a ring around the equator of the vehicle. This is the only area available because of antenna considerations. The original version had twelve solar panels of 70 cells each with all twelve panels connected in parallel, each with an isolating diode. The One B version had a complete set of 24 panels; the current version (2a) will have a larger array to be described later. (See fig. 52). The frequency determining crystals for the transmitter are mounted in separate dewar flasks each suspended by nylon webbing. The whole inside surface of the vehicle is coated with a laminated fiber glass and mylar blanket for thermal insulation. The vehicle is designed to operate stabilized only by spinning. If we plot the power output vs. the angle of incidence of the sun we will find an output variation as shown in fig. 53. The configuration of the power system for the One B vehicle was twenty-four panels each with a blocking diode coming in to a tapped battery through a thermal switch and command switch network and then was connected to a second battery. fig. 54 The second battery is trickle charged throughout operation and is never fully recharged. The main battery consisted of 15 F cells; the second battery of 10 D cells. The two thermal switches between the array and the batteries are set at 105 and the other at 100° F. These are intended to protect the payload from excess heat of overcharging the batteries. In the 2a system we have gone to the larger solar assembly and is shown in fig. 55. We used a 12 cell battery. Each array has an isolating diode in series with it for protection. In this system we have a voltage regulator which regulates the output of the main battery and delivers plus or minus 2% accurate output. We use fuses to protect the system from converter short circuits. These only protect against a 1 or 2 ohm short circuit and therefore should not impose degradation of reliability. The battery has 12 cells, F size. The solar power supply has an instantaneous capability of 15.4 to 19.5 watts. Depending upon the mode of operation the load on the system can vary between 3.5 and 8.5 watts. These vehicles are designed for flight at a 400 mile circular orbit.

154: How many panels do you have on the 2A vehicle?

167: There are 24 panels consisting of 150 cells split in three 50 cell series sections. So there are 72 circuits in parallel, each protected by an isolating diode. We are using glass slides with a UV reflective coating in order to reduce our operating temperature. 2A is split into two halves as far as the solar array is concerned. This is required to accommodate the despin mechanism running around the equator of the vehicle.

151: Is the glass on the current flying vehicle cemented to the cells?

167: No. This is similar to the Vanguard design and use epoxy cement to hold the glass to within 1/16 of an inch of the surface of the cell. The construction is such that the trapped air will readily escape in space.

132: Do you have any nickel cadmium batteries in your system?

167: Yes, the main battery is nickel cadmium and the smaller tensile unit is silver zinc.

162: What is the designation of the cells in the silver zinc battery?

167: These are Yardney LR 100 cells. These weigh about 32 lbs.

IX. Discussion of Courier- G. Hunrath - USASRDL, Fort Monmouth, New Jersey

144: For this particular satellite, including series of planned optimizations, the orbit will be 109 minute (70 minute light, 39 dark) and the peak load is 255 watts. The continuous load is 4.2 watts. Designed voltage is 28 volts, $^{+4}_{-2}$ for the 58 watt system. There is a possibility here that we can control the number of cells depending on how the system will behave out in space. Design on this particular point is pretty tight due to limitations on the available area.

161: For this particular design, the solar cell modules are constructed so that we have 84 cells in series, (1 by 2 centimeter cells) constructed in 7-cell shingles per module arrayed in six strips in this hemisphere. (See Figure 56; 114 "A" modules in parallel and "114" B in parallel, each connected to a battery). The maximum power capability will be in the area of the equator. Battery-cell connections are shown in the figure (57).

These particular batteries are 12 ampere-hour batteries with 22 cells (actually two 11-cell batteries) in series (similar to batteries developed for Lockheed). They have a pressure relief valve at 200 psi.

144: Based on their (Philco) thermo analysis they don't anticipate temperatures higher than probably 90°. Solar-cell and battery temperatures will be monitored.

161: Temperatures have been estimated at six different points (refer to Figure 58). At an ambient temperature of 76 F they got temperatures of 85, 84, 79, 85, 82 and 80 at locations 1 through 6 respectively. This was on the 679th cycle, but they ran a total of 1507 cycles. The last 100 cycles were in a pressure of 170 microns and there wasn't too much variation in temperature over that period. The highest I see here is about 84° on the center cell and the lowest I see here is at 77° - I believe is the lowest. At an ambient of 76° which was maintained throughout the test, variations ran from 77° to 84°. The charging of current I think was 1.7 amps. The actual cycle was 35 minutes charge at 1.7 amperes and a five minute discharge at nine amperes. The one problem they had was that the overcharge voltage after about 700 cycles went up well over 32, and maximum allowable overcharge voltage is 32. However, this is not a problem because they are using two arrays so the charge current will be about half of this. It was originally intended to use two batteries, but they couldn't switch them.

130: How do you maintain a temperature of 100° F in space, with a large part of the sphere covered with cells.

144: This is a result of Philco's final analysis and they are making a re-run. I will see if this report can be made available for the minutes of the meeting. The sphere is spin-stabilized.

162: Will you draw a cross section of the skin and cell?

144: (See Figure 59) This is the six mil quartz slide. We have one silicon resin and another which bonds the 7-cell unit to the skin. The resin used for bonding glass slides to cell is Q30400 and resin used to bond shingle to skin and skin to call is Q30121. (These are Dow-Corning Silicon Resin Numbers).

156: A heat-exchanger may have been used; this would help explain some of the temperature estimates.

134: Did you run some low temperature tests:

144: Yes. We ran a discharge at +30° F and Philco at 30° and 95.

57: Regarding the remarks that Dr. Snyder made before lunch, he intimated that maybe photo-chemical or thermo-chemical systems might be more complicated than conventional batteries. That is probably a correct statement but I think we have to consider the potential of regenerative systems. They are in the early stages - I don't think they should be written off completely at this time; most certainly R&D work should be continued in those areas.

168: I am not writing them off completely. However, it appears that the best you can do with an H_2 - O_2 regenerative system is about five watt hours per pound on a charge/discharge basis.

147: That depends on total system power, doesn't it?

168: Yes. This was for about a 500 watt unit. However, by the time they build a complete unit involving pumps, etc., the weight is there. In any event when you get above 3KW, I would worry about any solar system.

X. Discussion of Ni-Cd Storage Batteries - A. Mundel - Sonotone, Elmsford, New York

156: Fundamentally the Ni-Cd battery system consists of two plates. Both of these plates in our particular embodiment of this battery are made on a very porous nickel base. A nickel salt is placed on the positive plate and a cadmium salt on the negative plate. In ordinary vented cells, liquid is brought up to the level where both plates are immersed. There is a separator in between the two so that they don't come into mechanical contact. When you have a charged condition you get oxygen off positive plate and hydrogen off the negative plate. In the starved version there is a porous separator between the two and enough electrolyte to be absorbed. This is critical as to amount of electrolyte in the cells. In this particular case, we set this up so that the positive plate becomes charged first and the oxygen from this plate is converted back to a cadmium oxide, on a negative plate so there is a limit to the amount of pressure these generate. We believe that we never generate any hydrogen: if we do we are not quite sure what mechanism occurs to recombine that hydrogen, or whether it stays there or leaks out through the tin can around it. In the sealed version, we design so that the positive plate charges first. This permits recombination of the oxygen and minimizes the hydrogen regeneration. In an "F" cell, the plates are rolled like rolling two newspapers - it's apt to be rough on the plates mechanically. Fig. 60 This is one problem. These rolled plates are then placed in a cylindrical can. For the hermetically sealed cell, a top is welded on. The leads from the two plates are brought out through a glass seal. This is the hermetically sealed battery. There are other variations; In the Courier and Lockheed programs, the cells are rectangular. The battery is of the same type but the electrodes are just laying one on top of the other. There is a commercial version [illegible] which we actually rolled an edge of a seal over a piece of [illegible] [illegible] the disadvantages of a sealed cell over the vented cell is this: In the sealed version when you overcharge and recombine gas you have an efficient heat generator. That energy which is not converted to chemical energy is converted to heat. With a vented battery you don't really heat up; in fact, you may cool down on overcharge. However, there's a limit to how much you can overcharge in a certain time and you lose the water from the electrolyte, so there is a limitation on the number of cycles you can perform. The difficulty that you hear about in this meeting is due particularly to the rate of overcharge which warms up this cell to high temperature. Then the cellulosic separator dissolves in KOH at high temperatures. This is a very definite heat problem. It might be solved by putting in a separator which will not hydrolize at high temperatures. This could mean that you can operate cells at very high temperatures; however, the electro-chemical system does not store energy nearly so well at high temperatures. We have evidence that you can operate cells up to 212° without damaging the separator. We have gotten this far with these problems, but they need some further clarification. One difficulty with teflon as a separator is that it doesn't wet. Hence, we are working on other plastics, i.e., nylon, etc. Why does one want the KOH absorbed in the separator? Because, otherwise, if you have spinning you might drive electrolyte out of the separator to some corner and electrolyte doesn't flow back into proper place at high altitudes (zero "g" conditions). This is one problem. We also have a sealing problem and a viability problem; i.e., the problem of keeping two plates separated. However, I don't think we have a problem of the cycle ability of nickel-cadmium plates. This has been proved out by thousands of cycles made of this system either in the sealed version or in the vented version, and further proved by the fact that you can take plates from batteries, replace the separators and start over. This is a very slow (many years) etching of nickel by KOH. A battery does not charge and discharge at the same voltage, and these voltages also change with temperature. I don't think it's likely that we will change these electrochemical facts of life. I do see eliminating variations; we don't know how to make plates that are perfectly uniform. Perhaps we must control a set of each of these as they are assembled a little more closely than we do. Another question involves the use of these and a magnetometer simultaneously in a satellite. I don't think that it is going to be easy to make a battery of this type which is non-magnetic because of the nickel plates, but there are special steels which are non-magnetic, and which could be used to construct a non-magnetic case. We have tried to briefly tell you a little about this battery.

61: At the high temperature, how many cycles did you run it? It's been stated in the past that temperatures up that high have permanent effect on positive plate.

144: We haven't as yet run any cycles.

Q: Did you find any decrease in capacity (fading)?

144: The plates are exposed to those temperatures during manufacture.

Q: What temperature do you dry the plates at?

144: About 180° F.

132: We don't have the cycle data, but in doing this teflon separator we compared it directly with the present separator. The present separator fell apart; further than that, the cell made with teflon on a cycle at room temperature showed it had full capacity, at least it has promise. We feel that the system has demonstrated enough promise to warrant further work. It isn't just a battery that will never work but a great deal of work is still to be done. Whether we can do it for satellites remains to be seen. One thing that was pointed out is that we don't get a chance to get a concentrated production run on these satellite batteries. An order comes through with three weeks delivery for a certain number of cells, but not a real production set up. As production continues, one can improve quality, but not if the lines are opened and closed continually. We want to get this into a production set up where characteristics will improve. There are two main problems.(separators and thermal). One problem is separator disintegration. This we know we can solve with a proper choice of separator. The other problem is up to the design engineers. We know that at high temperatures you must expect a loss in efficiency. This means that in thinking of a battery you think in terms of its thermal properties and measures must be taken to dissipate waste heat. We can attack it with improvement of the separator - you design engineers must dissipate heat. We will then have overcome most of the problems.

137: What is the number of cycles you have obtained on teflon cells and do you have any qualms about cold flow of teflon?

144: We have no qualms about the cold flow of teflon because it is not under compression. In order to achieve a compact battery we do not try to squeeze the separator into the can because this will be placing the separator under conditions where it won't last long. However, when you roll you get sharp corners at times.

Q: Isn't there a possibility that these could give you compression on the separator?

144: I believe so but this doesn't bother me because there's a way of rolling plates where you don't get sharp corners.

57: Concerning non-magnetic cases - one was developed for mine-applications.

Q: That's the casing.

Q: There's a nickel-plated steel - they had a problem with high temperatures. We know we can make the plate and in rolling you need not place teflon under compression. We have not done cycling but we have undertaken more effort. As you have seen here the problem is a thermal problem - the heat is generated in the over-charge part of cycle. This part we have tried to answer by placing the cells in a elevated temperature environment and keeping them on continuing charge.

167: Could we ask for a summary of all test results at your place?

144: We have a summary - it will be placed into the record.

167: Can we add ours to yours? We have had four failures out of 25 in teflon...

144: These are internal shorts. I would like to bring something out - just think back to the delivery schedule on these.

Q: Yes, the companion order for paper cells was extremely short, but teflon was at your convenience. We didn't place any restrictions on that.

144: I remember this - these cells were among the first teflon cells - these failures were mechanical that could be controlled in manufacturing.

168: When I first came into ARPA I looked at the battery problem and thought here's a whole agency (USASR-DL) devoted to it. The military have been using batteries for years and they should have done research. Hence I would put my money on newer things, but it's now obvious that I should have put a good chunk of my money into this field. There ought to be significant funds for this NASA indicated their interest and DOD indicated interest in doing something involving a lost of R&D - in order to approve these and do proper testing you need almost a separate program. But it will be straight R&D money and its difficult to get it. The problem remains that we recognize a difficulty and there just hasn't been enough batteries bought for the manufactures to do much research. A similar situation has held true for solar cells. However, we have put, in terms of government agencies, very little money into R&D on rechargeable batteries for space vehicles. This is a weak point. The one bright spot has been the fact that through AFBMD, Lockheed had a development program and this was really just to do something a little different. There is some research going on at Lockheed with this same battery, isn't there, Chuck?

Chuck: Yes.

130: Disregarding teflon, are you using your celluloic separator in all batteries including "F" and Lockheed types, or are there several different ones in use?

I assume there are.

144: We are using cellulose completely - "F" cells have the same separator as the batteries on Courier.

130: I find it hard to bridge the gap between temperatures. What is the limiting temperature? We ran some tests at RCA's and Signal Corps' request at three temperatures - 95 F, 120 F and 131 F. These tests consisted of placing "F" cells into these temperatures and charging them at a 9-hour rate which is the rate RCA used in Tiros. We are trying to double check information to see whether failures would be experienced and to see whether we could arrive at safe temperatures. Results are: - did fail at 131 - did fail at 120 - those run at 95 did not show failures at that time. This was ambient temperature.

132: Doesn't a measurement of cell temperature depend on configuration of cells as used in a battery? During some work at Lockheed, battery people in the lab found that as temperature rose above 105° they got peculiar voltage reading. Then when they dropped to ambient temperature, the battery recovered to where it was supposed to be and they continued on for several hundred cycles. This began to indicate that we had a thermal problem. We thought 165° was a good temperature for batteries, but these tests show us that a relatively safe operating temperature would be 100° F surface temperature of cell with cellulose separator. If 105° is the limit to permit infinite cycle life on a cell or battery you would be safe using it.

156: I don't think its at all proper to say that the only possible solution for separators is teflon. There's other evidence right in our labs that Webrill and Nylon might work satisfactorily as separators.

132: All we are pointing to in teflon is that the results of this work with teflon indicated an avenue of approach to a solution of this problem of eliminating cellulose. We want to find a separator that will be: (1) Less temperature sensitive, and (2) be porous enough to allow recombination of the oxygen. Several separators have indicated promise - teflon has one disadvantage - non-wetability.

Q: Have you considered the use of laminated separator?

Q: Yes we may have to go to a double separator.

XI. Discussion of Radiation Damage to Solar Cells- Dr. W. Cooley, NASA, Washington, D.C.

138: I want to outline some of the problems of radiation damage to solar cells as I see them. Basically, it falls into three categories: (1) What do protons and electrons do to a solar cell; (2) what is flux of protons and electrons in Van Allen belt and (3) what do you do about it? One of the points brought up is data by Rappaport and Lofevsky of RCA. The basic point is with protons at 17.6 Mev energy a bare solar cell will degrade to 75% of its output after an integrated flux of 3.5 x 10^{10} $\frac{\text{protons}}{\text{cm}^2}$. This is a very high energy proton and we do know that in lower Van Allen belt there are protons above this range. The measurements made so far only measure above about 40 kev electrons and for current equipment they only measure protons above about 40 mev. The other data from Rappaport was for 1.7 mev electrons. If you have a total dose of 5 x 10^{13} electrons/cm^2, they will suffer a 25% degradation. Dr. Shelton, in his Huntsville studies, has analysis to predict life of solar cells in radiation belt, and taking into account one set of film pack data on the protons that is reached by Freiden. The reference on emulsion is Physical Review, Letters to Editor, Vol 3, No. 1, P. 9, July 1, 1959. These are in the middle of the inner Van Allen belt at an altitude of 1200 kms. In the question of what is up there are two factors; one, what is the flux of protons and electrons and what is their energy distribution? Fig. 61 Why does it vary with position? Positions of lower and outer Van Allen belt are fairly stable, but its a problem of time variation of outer belt due to such phenomena as solar flares. The flux of solar-flares sweeps out the outer Van Allen belt and you have a fairly low density in that belt, but then it builds up again. We have no idea what the low energy proton density is. We think both are èlectrically neutral; i.e., the number of negative and positive charges are equal, but their velocity, i.e., and hence their fluxes will be different. Electrons and protons are reflected between the North and South poles, due to the magnetic mirror effect. Protection for cells: You have heard data from GE on the use of glass, and it looks like quartz or cerium glass is a possibility. For a 24-hour satellite no one will make firm estimate, but what of 40 - 70 mils of glass for two years in 24-hour orbit? This is not a firm estimate. The other possible method would be to make use of annealing phenomena, if the cells run hot enough. This damage is the sort which degrades the charge carrier lifetime. This results primarily in a loss of current carrying capacity of cell. Van Allen pointed out that it takes a thickness of glass of 280 milligrams per square cm to stop 780 kev electrons, and that weight corresponds to adding about one half pound square foot to the area.

147. If you put more and more mass on front, it may become the structural member, but you still have to have balanced masses because the cell function is a critical area. You have to have equal protection fore and aft.

138. We want to get experiments going on cells with or without glass protection at various energy levels going down to 200 kev and some further checks of the protons at 10 mev and 20 mev.

147. An additional problem of irradiation in the shadow zone must be considered. In this condition you cannot make use of high temperature annealing. Therefore, when the vehicle reacquires the sun, both a thermal shock and annealing process will have to be carried out simultaneously.

168. We also need the integrated flux through these belts.

147. Are you familiar with the nuclear emulsion recovery package?

138. A little; they will give some data.

147. Its general objective is an exploratory flight to measure low-energy particle density. Its time of flight is less than a year. The other thing would be to get some detector that measures protons and electrons that can be mounted on skin that will measure what happens in the first few milligrams of thickness.

168. Bloom of Livermore has recently given a paper on solid-state scintillation counters. We have here a broad research area - we want to get going and we need experiments on current flights to get measurements up there and a better idea of how to protect cells without adding one-half pound of glass per square foot to the skin.

XI. Radiation

Part 2

1. Per J. J. Loferski and P. Rappaport, "The Effect of Radiation on Silicon Solar-Energy Converters", R.C.A. Review XIX, 536-554 (1958):

Integrated Flux of Particles Required to Reduce Solar Cell Power Output to 75% of its Initial Value.

Particle Type	P_c (particles/cm^2)
1.7 Mev electrons	5×10^{13} (vacuum) to 1.5×10^{15} (air)
17.6 Mev protons	3.5×10^{10}
40 Mev α-particles	4.4×10^{9}

2. Per John Freeman of S.U.I.

Particle type	Integrated Flux	Effect
5 to 10 kev electrons	2 hrs at 3×10^{13}/cm^2 sec = 2×10^{17}/cm^2	No permanent damage (20% decline in short circuit during bombardment apparently due to heating only - subsequently run with 100% output).
180 dev protons	5.5 hrs at 5×10^{8}/cm^2 sec = 1×10^{13}/cm^2	35% decline in short circuit current during bombardment. Recovery to about 90% of original value after cooling.

Radiation Situation in Outer Space

(Per Nature (London) 184, 219-224 (1959))

1. In the heart of the inner zone

Electrons of E $>$ 40 kev, $2 \times 10^9/cm^2$ sec steradian

Electrons of E $>$ 600 kev, $1 \times 10^7/cm^2$ sec steradian

Protons of E $>$ 40 Mev., $2 \times 10^4/cm^2$ sec.

2. In the heart of the outer zone (3 March 1959)

Electrons of E $>$ 40 kev, $1 \times 10^{11}/cm^2$ sec

Electrons of E $>$ 200 kev, $<$ $1 \times 10^8/cm^2$ sec

Electrons of E $>$ 2.5 Mev, $<$ $1 \times 10^6/cm^2$ sec

Protons of E $>$ 60 Mev, $<$ $1 \times 10^2/cm^2$ sec.

3. In the heart of the outer zone (6 December 1958)

Electrons of E $>$ 40 kev, $6 \times 10^9/cm^2$ sec.

Lifetimes of Bare Solar Cells (to 75% of Power Output)

1. In the heart of inner zone

$\sim 5 \times 10^5$ sec = 1 week (by electrons of E $>$ 150 kev)

$\sim 2 \times 10^6$ sec = 4 months (by protons of E $>$ 40 Mev)

2. In the heart of the outer zone (3 March 1959)

$\sim 5 \times 10^5$ sec = 1 week (by electrons of E $>$ 150 kev).

3. <u>In the heart of outer zone</u> (6 December 1958)

$\sim 5x10^{6}$ sec = 10 weeks (by electrons of E $>$ 150 Kev)

<u>Lifetimes of Shielded Solar Cells</u>

1. Extrapolated Range of 780 kev electrons: 280 mg/cm^2. Such a shield would increase the lifetime in the inner zone to that determined by protons i.e. from <u>1 week</u> to <u>4 months</u>. Sputnik III and Vanguard I experience probably does not counterdict this estimate due to small fraction of time in heart of inner zone.

2. Minimum shield thickness to do <u>any good</u> for <u>electrons</u> is equal to the extrapolated range of 150 kev electrons = 25 mg/cm^2. A shield of several times this thickness, say <u>100 mg/cm^2</u> would stop all electrons of E $<$ 370 kev energy and would extend the lifetime by an order of magnitude at least - that is to $\sim$ <u>10 weeks</u> in a high intensity outer zone. (100 weeks for a low intensity outer zone) or to 4 months in inner zone.

3. Intensity of low energy protons in outer zone is unknown. Since (by L. Daivs) there is little or no voltaic effect from bombardment of solar cells with 5 kev electrons (100 μ g/cm^2 range) it might be supposed that there would be no effect of protons of same range, i.e. 50 kev protons with bare cells. A thin shield, of say 25 mg/cm^2 (a la Explorer VI) would seem prudent and 100 mg/cm^2 quite desirable.

<u>Excerpts from J. A. Van Allen Memo to N.A.S.A.</u>

XII. Discussion of Solar Cells - Dr. W. Wright - Electro-Optics, Pasadena, California.

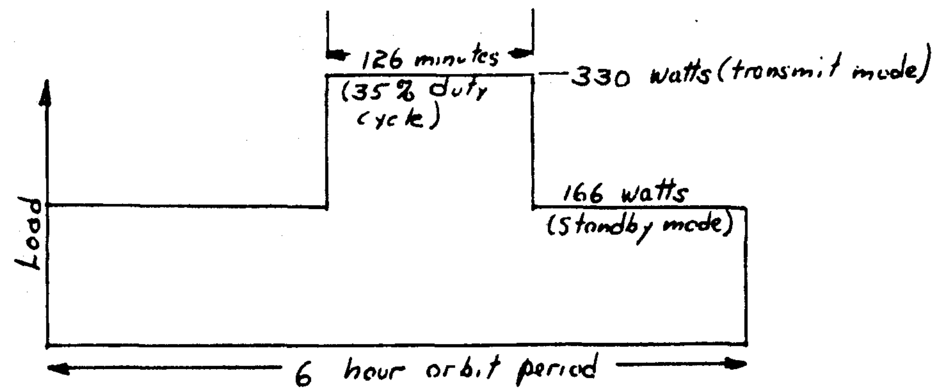
190: The radiation damage seems to be a real problem. It is essential to know what the integrated dose of radiation will be for any mission. We can either simply keep it away from cell (glass), or do a little thinking about the fundamental mechanism of the damage in the cell. This has been reported in other devices. In a semiconductor, minority carrier lifetime is the first thing to be detected. The threshold levels of damage in a silicon solar-cell are known, and they are a bit more radiation resistant than some other semiconductors. But we still see as much as a 25% power degradation or output degradation with a total electron flux as small as 10^{13} elec./cm.^{2} I think it should be possible to design the silicon solar-cells to be more radiation resistant by a factor of 10. First thing to be done is to design it to be less sensitive to minority carrier lifetime. We are interested in short circuit current and its relation to efficiency, and this is going to be approximately proportional to minority lifetime. The open circuit voltage will be proportional to the logarithm of the short-circuit current over the saturation current. Radiation will decrease the short circuit current, and increase the saturation current. This can be improved by utilizing graded cells. I think we should be able if we ask this question properly how can we maximize radiation resistance.

APPENDIX A

Communication Satellite - 6 hour orbit

Power System Design

Load Profile:



a. Maximum dark period: 45 minutes

b. Reorientation time (estimated): 10 minutes

c. Ascent time: 135 minutes

d. Power on stand: 5 minutes

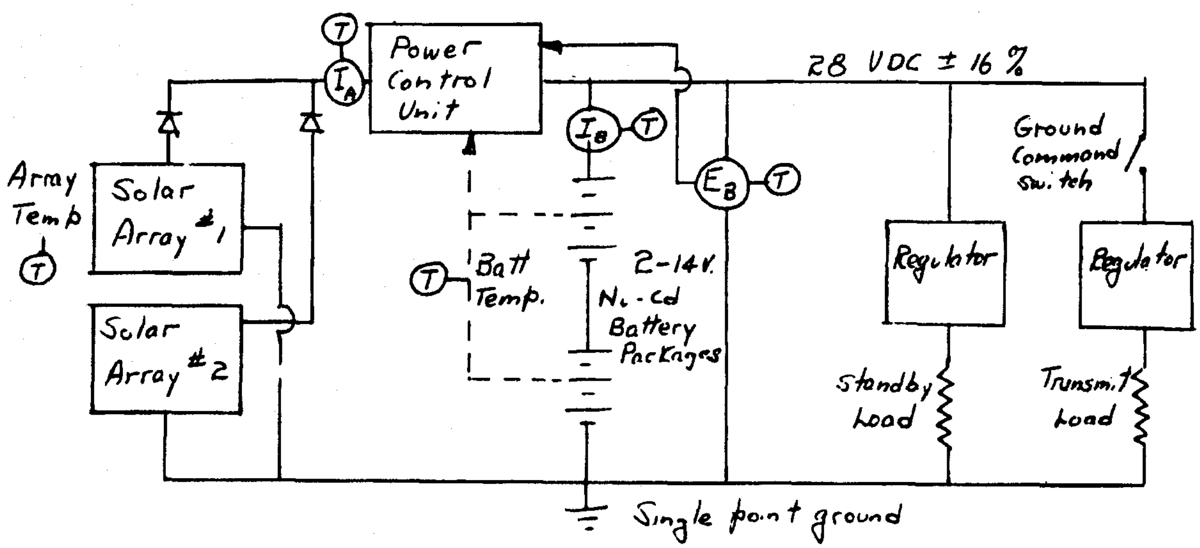
e. Load during ascent: 166 watts

f. For injection into longest dark period load during initial orbit is 166 watts.

Fig. 1a.

Pg-95-

System Schematic



T - Telemetered data

I_A - Array current

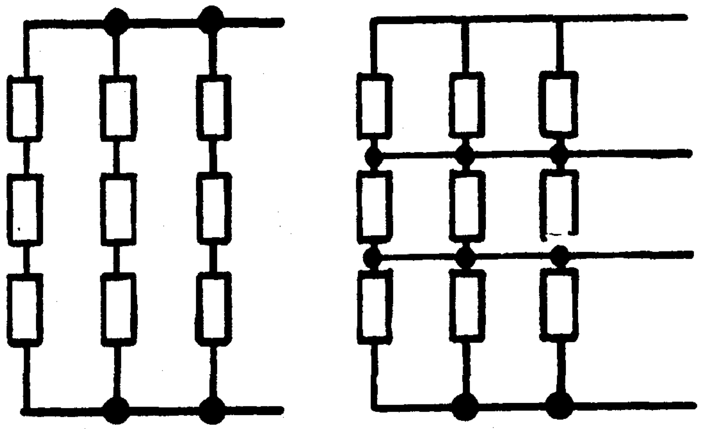
I_B - Battery "

E_B - Battery voltage

FIG. 1b

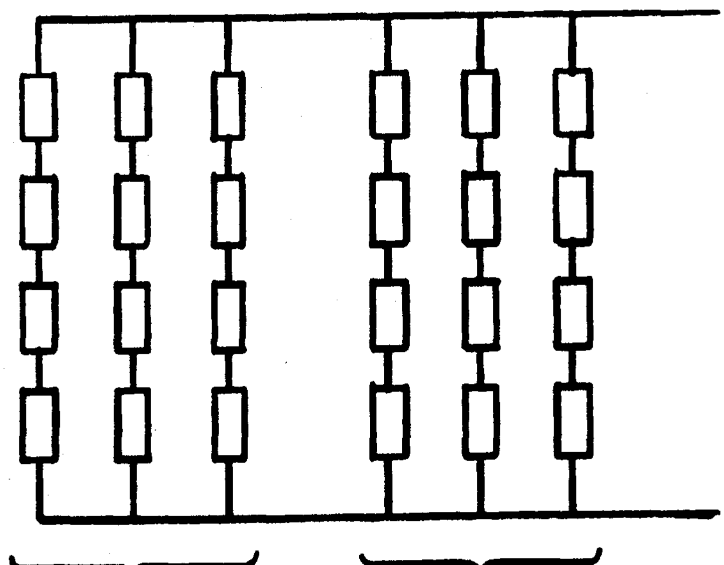
NOTES:

1. No allowance for battery or solar array redundancy
2. Battery temperature controls
   a. Heat sink control to maintain battery cell temperature at 75 ± 10°F.
   b. Combined battery temperature - voltage control to limit solar array current.



SERIES STRINGS ALL PARALLELED

FIG. 2



OPTIMUM BLOCKS

FIG. 3

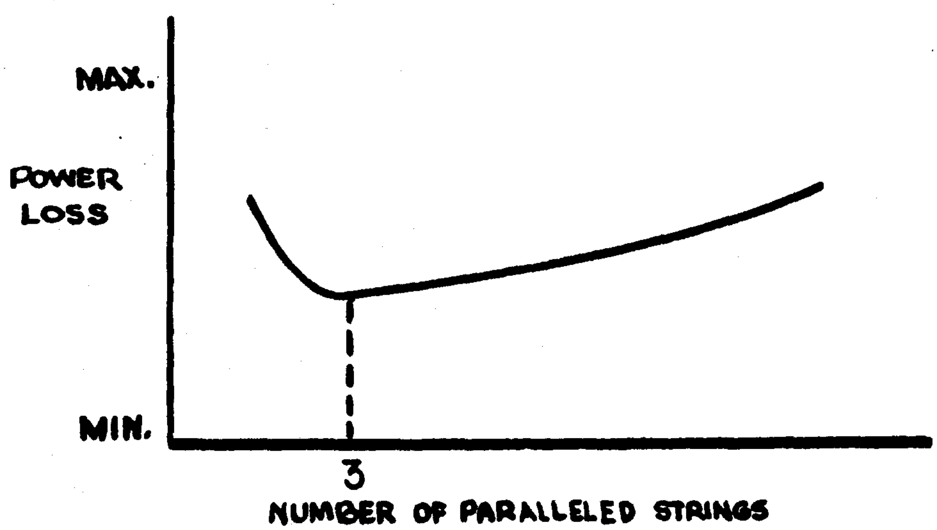


FIG. 4

ELECTRON RADIATION TESTS

$6x10^{14}$ electrons/cm^2

Electron Energy in Kev.	Quartz Cover Shield Thickness in Inches	Efficiency at 0.39 Volts Initial	Post
200	0	8.18	8.23
200	0	8.18	7.85
400	0	8.34	5.62
400	0	8.34	Broken
800	0	8.34	4.11
800	0	8.34	4.67
200	0.010	8.18	8.42
200	0.010	8.29	8.42
400	0.010	8.34	7.28
400	0.010	8.34	6.93
800	0.010	8.34	4.16
800	0.010	8.34	4.38
200	0.040	8.29	8.28
200	0.040	8.29	8.35
400	0.040	8.34	8.45
400	0.040	8.34	8.23
800	0.040	8.34	Broken
800	0.040	8.34	Broken
200	0.070	8.29	8.23
200	0.070	8.29	8.45
400	0.070	8.34	8.02
400	0.070	8.34	7.62
800	0.070	8.34	8.23
800	0.070	8.34	8.23

FIG. 5a.

ELECTRON RADIATION TESTS

$6x10^{15}$ electrons/cm^2

Electron Energy in Kev.	Quartz Cover Shield Thickness in Inches	Efficiency at 0.39 Volts Initial	Post
200	0	8.34	Broken
200	0	8.34	5.2
400	0	8.29	3.02
400	0	8.12	3.24
800	0	8.34	2.6
800	0	8.34	2.6
200	0.010	8.34	8.2
200	0.010	8.34	8.4
400	0.010	8.12	4.1
400	0.010	8.12	3.8
800	0.010	8.34	2.8
800	0.010	8.34	2.1
200	0.040	8.34	8.2
200	0.040	8.34	8.2
400	0.040	8.12	8.0
400	0.040	8.12	7.8
800	0.040	8.34	3.7
800	0.040	8.12	4.3
200	0.070	8.34	8.05
200	0.070	8.34	8.0
400	0.070	8.12	8.0
400	0.070	8.12	8.0
800	0.070	8.12	7.8
800	0.070	8.12	7.8

FIG. 56.

ELECTRON RADIATION TESTS

$6x10^{14}$ electrons/cm^2

Electron Energy in Kev.	Quartz Cover Shield Thickness in Inches	Efficiency at 0.39 Volts Initial	Post
200	0	8.6	8.0
200	0	8.9	8.1
400	0	8.4	5.2
400	0	8.3	4.7
800	0	8.6	3.5
800	0	8.7	3.2
200	0.010	8.9	8.8
200	0.010	8.3	7.2
400	0.010	8.4	5.3
400	0.010	8.7	5.00
800	0.010	8.5	2.6
800	0.010	8.6	3.2
200	0.040	8.6	8.3
200	0.040	8.3	7.2
400	0.040	8.5	8.7
400	0.040	8.9	8.9
800	0.040	8.7	5.1
800	0.040	8.6	4.6
200	0.070	8.5	7.8
200	0.070	9.1	8.2
400	0.070	8.8	8.6
400	0.070	8.7	7.8
800	0.070	8.5	8.2
800	0.070	9.2	8.7

FIG. 5C.

ELECTRON RADIATION TESTS

6×10^{15} electrons/cm^2

Electron Energy in Kev.	Quartz Cover Shield Thickness in Inches	Efficiency at 0.39 Volts Initial	Efficiency at 0.39 Volts Post
200	0	8.90	3.58
200	0	9.08	4.11
400	0	8.69	2.83
400	0	8.50	1.72
800	0	8.73	1.14
800	0	8.53	1.14
200	0.010	9.06	7.84
200	0.010	8.95	8.45
400	0.010	8.82	4.33
400	0.010	9.14	2.92
800	0.010	9.12	1.72
800	0.010	8.69	1.61
200	0.040	8.65	8.12
200	0.040	8.41	6.50
400	0.040	8.93	8.72
400	0.040	8.26	4.00
800	0.040	9.00	2.61
800	0.040	8.98	2.53
200	0.070	9.03	8.40
200	0.070	8.67	8.40
400	0.070	8.73	2.27
400	0.070	8.69	7.89
800	0.070	8.73	5.30
800	0.070	9.22	8.40

Fig. 5d.

[illegible]

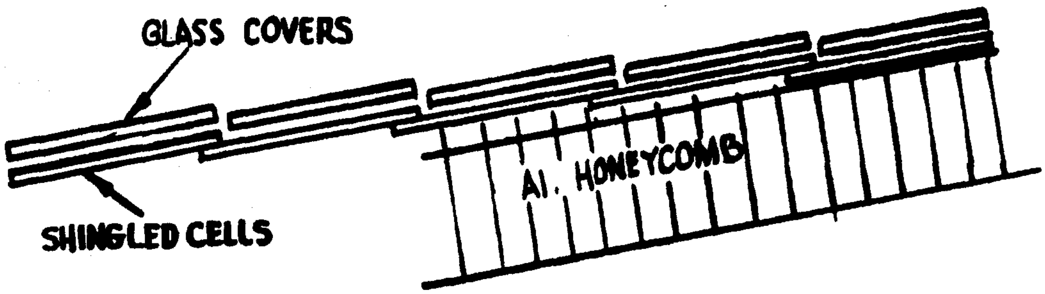


FIG. 6

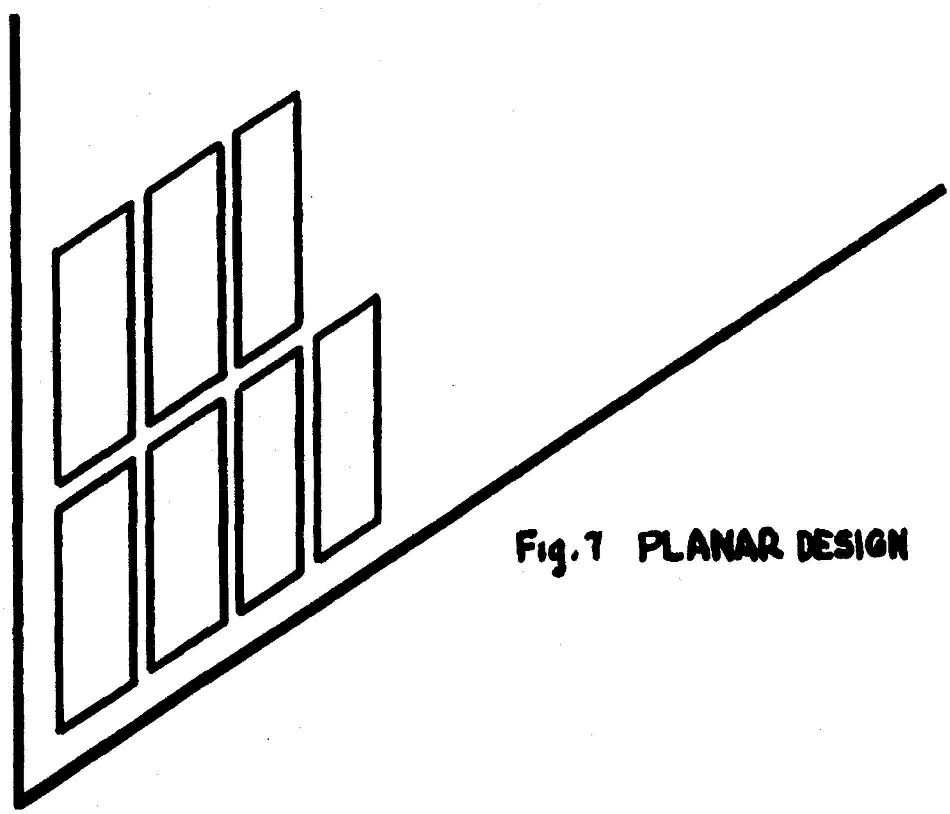


Fig. 7 PLANAR DESIGN

~~SECRET~~

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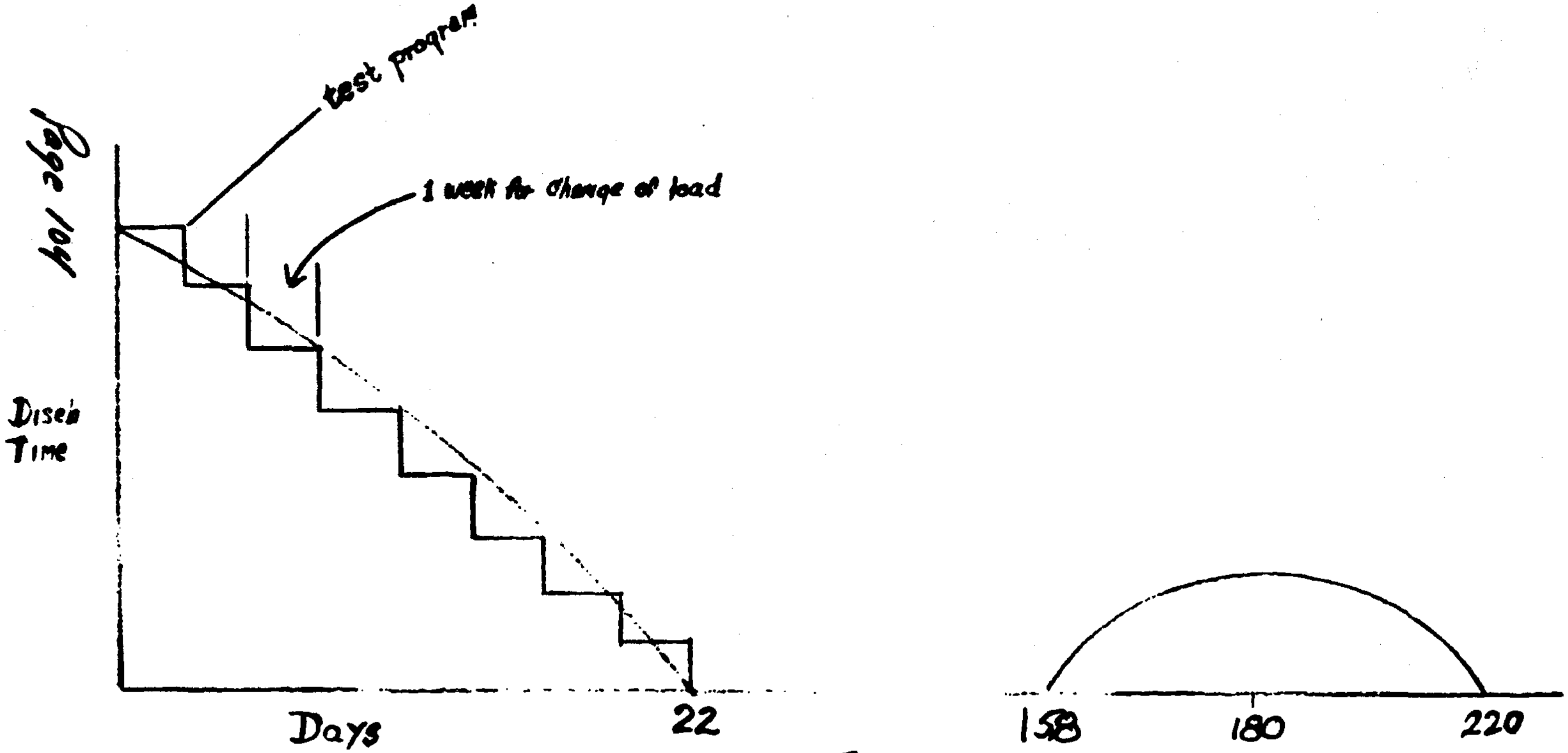

FIG. 8

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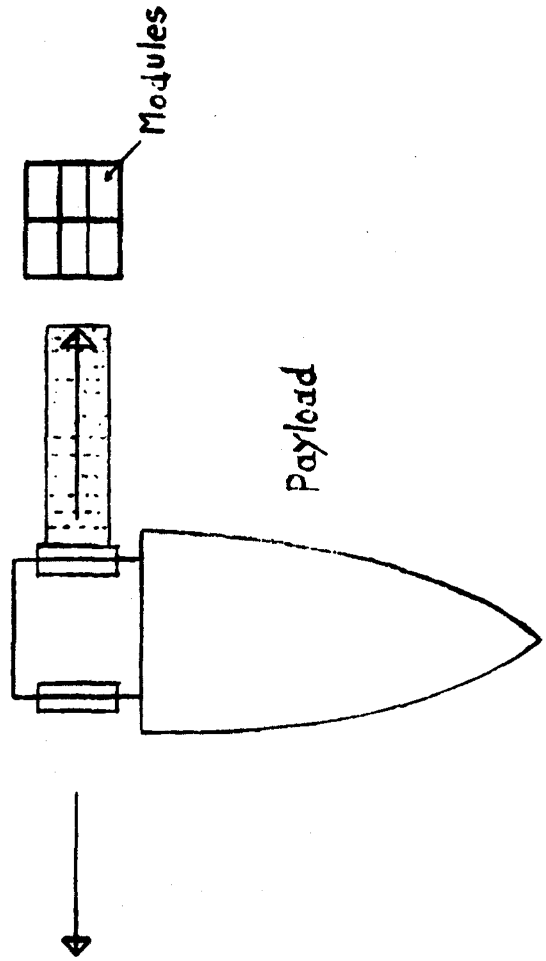


Fig. 10

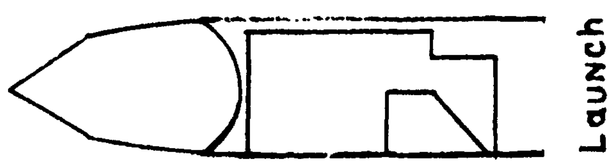


Fig. 9

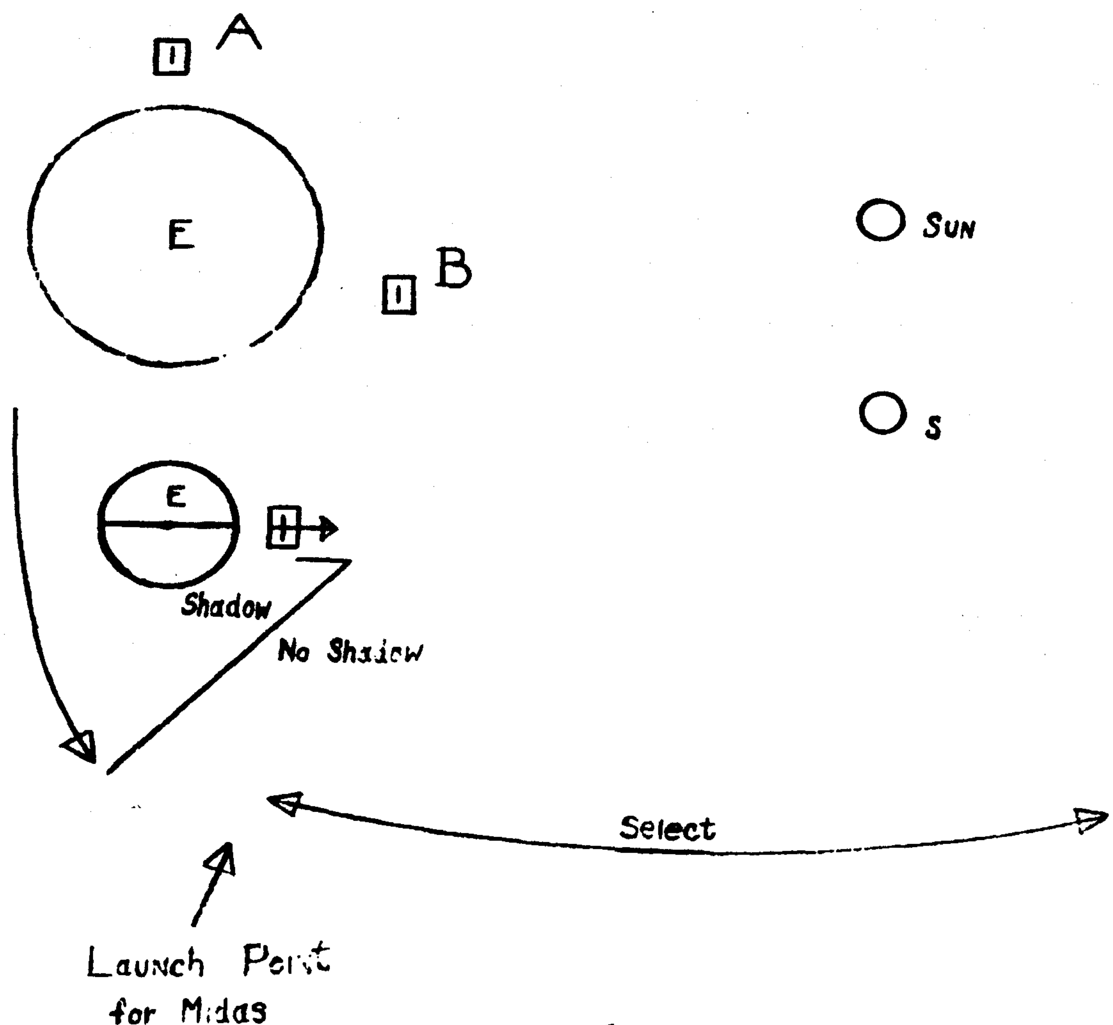


FIG 11

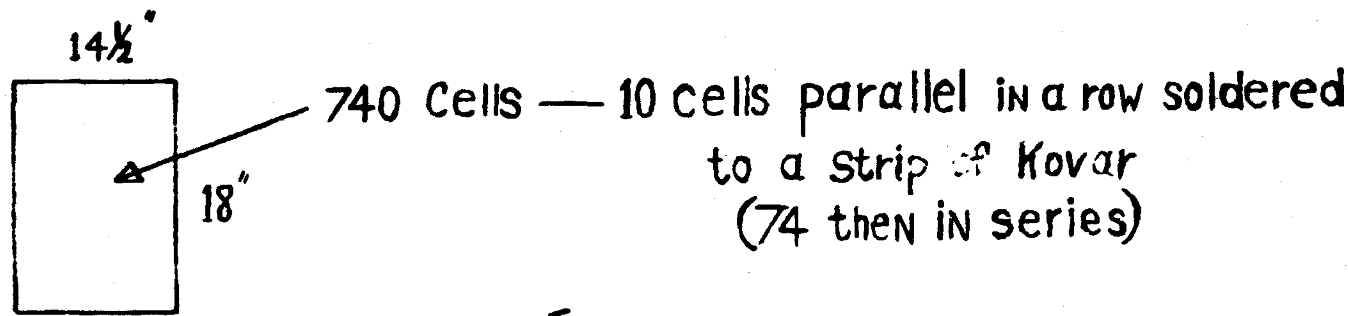

14½"
18"
740 Cells — 10 cells parallel in a row soldered to a strip of Kovar (74 then in series)

FIG. 12

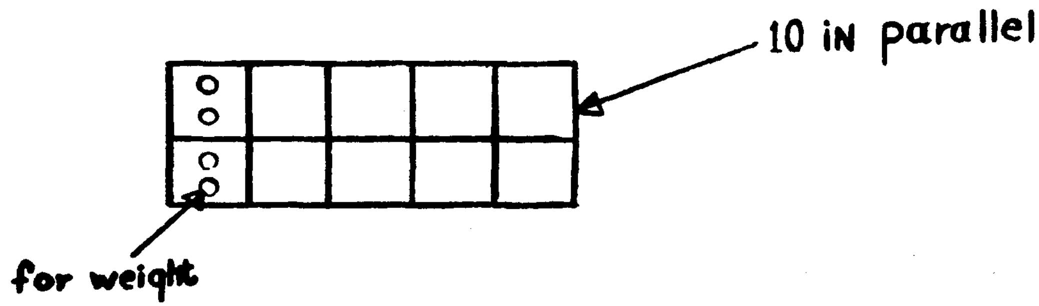

10 in parallel
for weight

FIG. 13

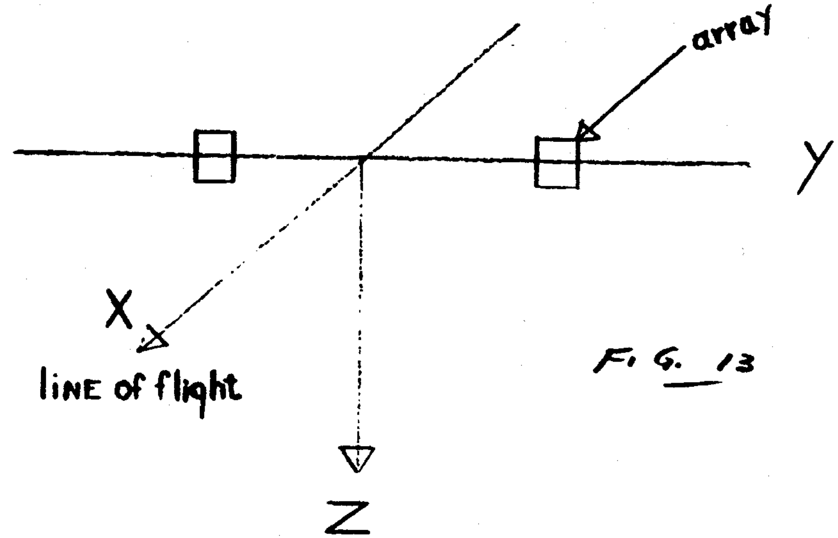


FIG. 13

~ OLD ~

NEW

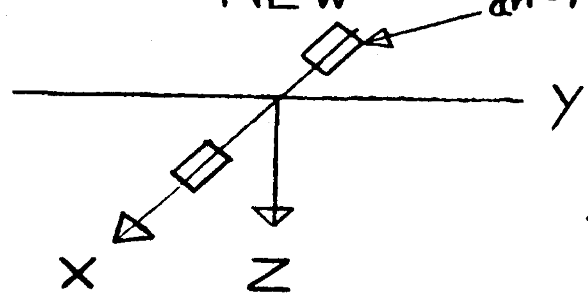


FIG. 14

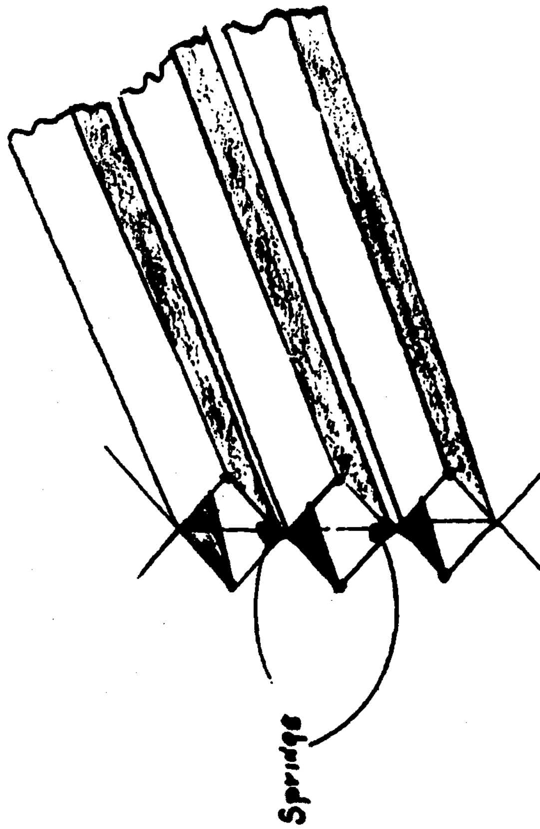


Fig. 15

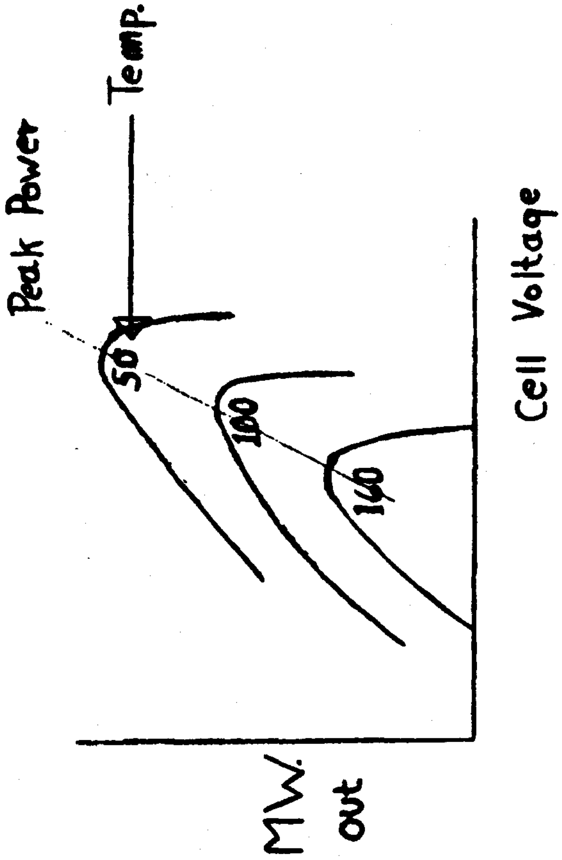


FIG. 16

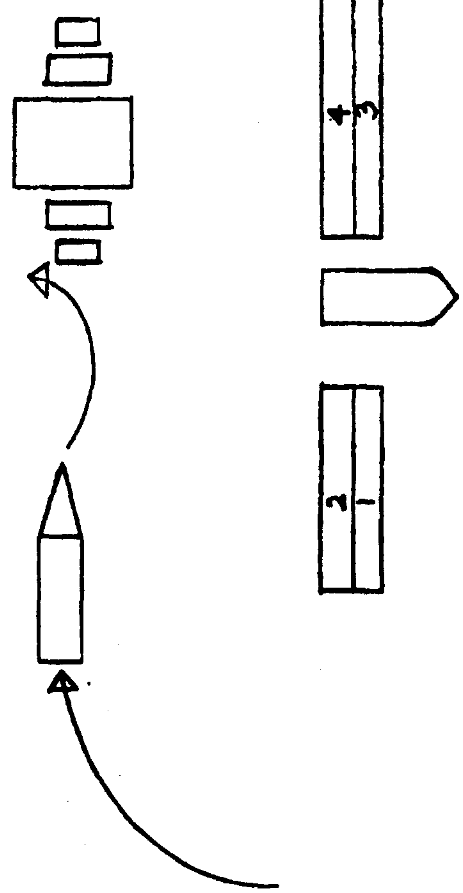
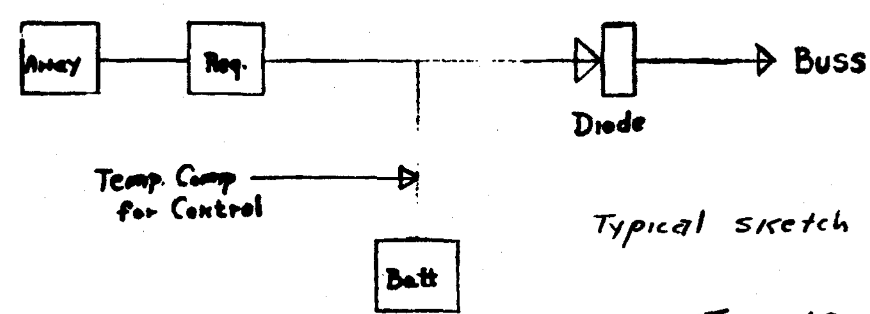


FIG. 17



Typical sketch (4 each used)

Fig 18

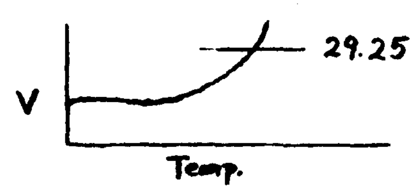


Fig 19.

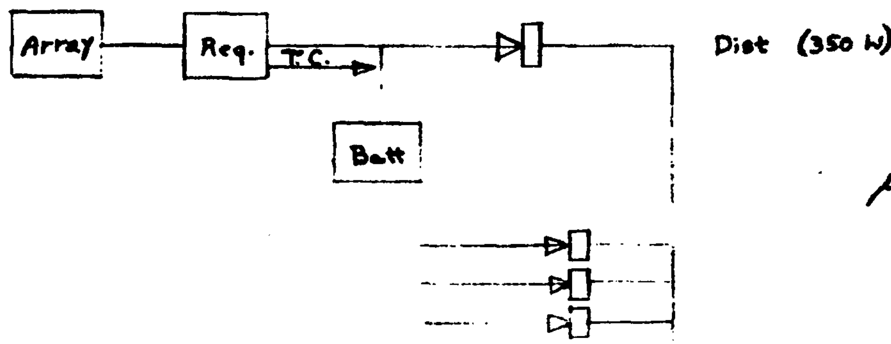


Fig. 20

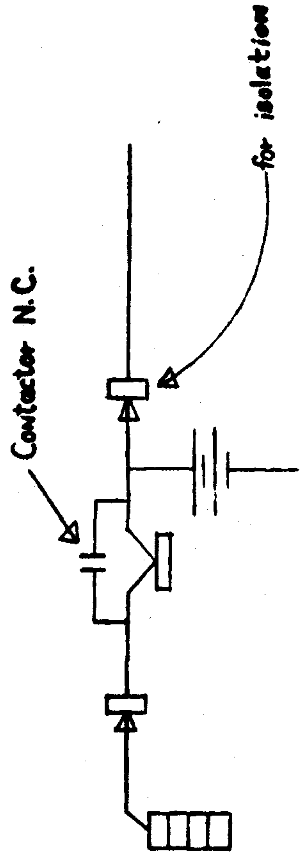


FIG. 21

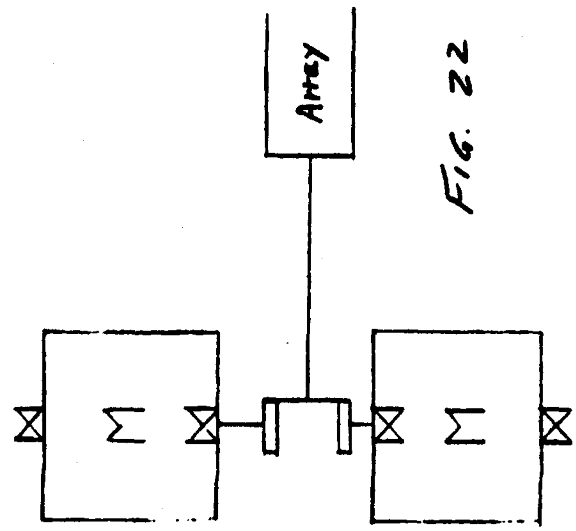
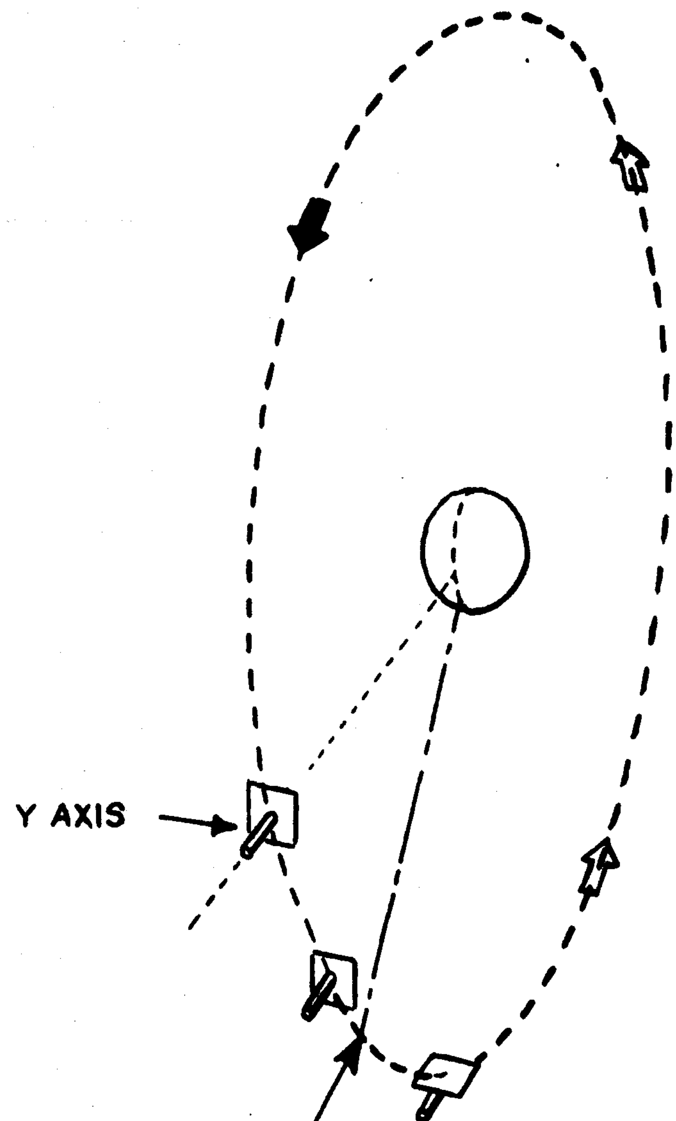


FIG. 22



1 BY GROUND COMMAND (AT 45°)
2 SELF COMMAND @ 15° AFTER 45°

FIG. 23

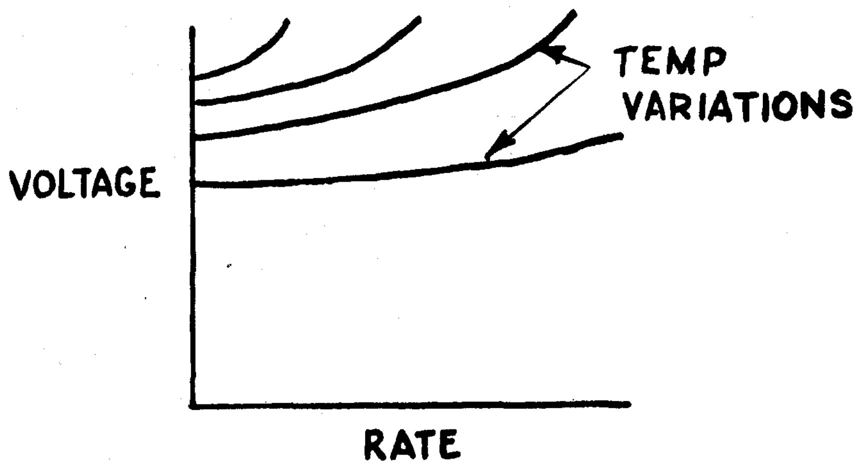


FIG. 24

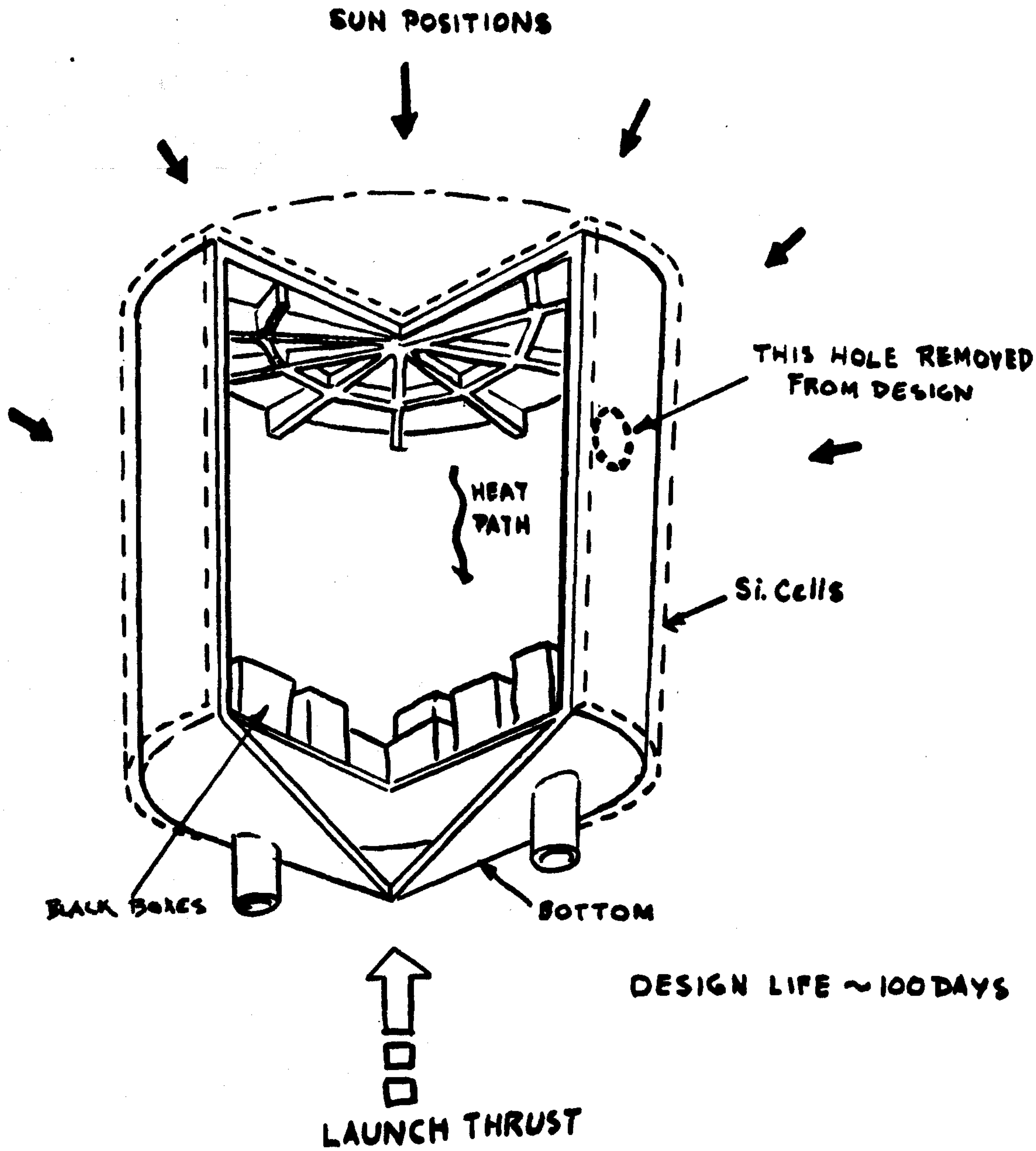

SUN POSITIONS
THIS HOLE REMOVED FROM DESIGN
HEAT PATH
Si. Cells
BLACK BOXES
BOTTOM
DESIGN LIFE ~ 100 DAYS
LAUNCH THRUST

FIG. 25

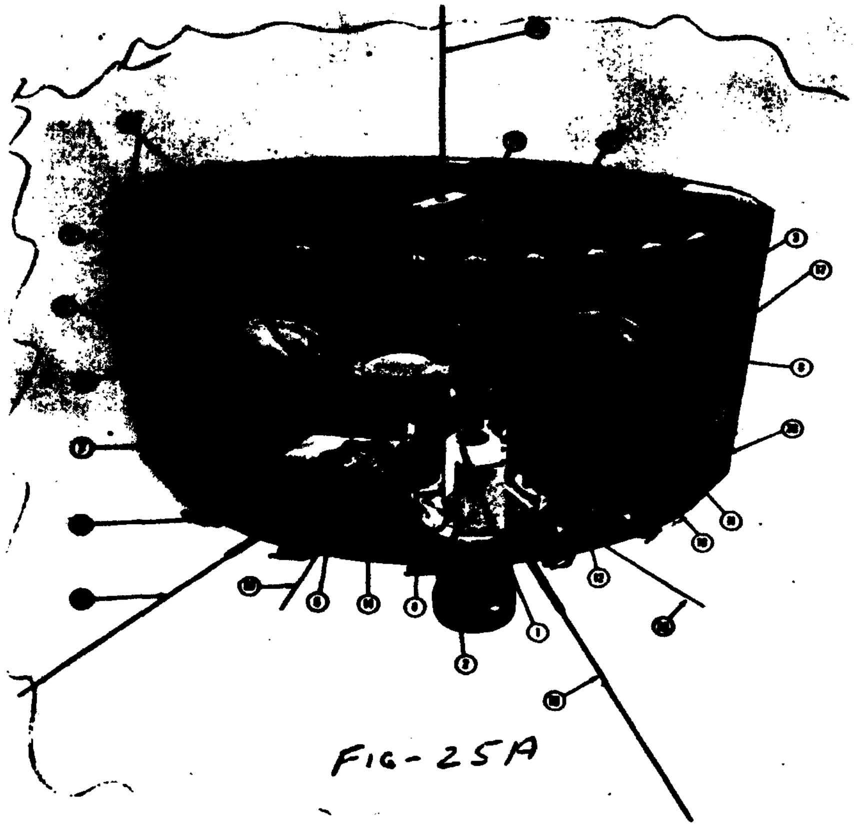


FIG-25A

Fig. 5—Cutaway of the TIROS satellite, showing: 1) one of the two half-inch vidicon TV cameras; 2) TV camera lens; 3) video tape recorders; 4) electronic "clock" for timing the operational sequence of the system; 5) TV transmitter; 6) power-supply batteries; 7) TV camera electronics; 8) tape-recorder electronics; 9) and 10) control circuits; 11) power converter for tape motor; 12) voltage regulator; 13) battery-charging regulator; 14) auxiliary synchronizing generator for TV; 15) transmitting antennas; 16) receiving antenna; 17) and 19) solar sensor for detecting sun angle at time of picture-taking; 18) solar cells; 20) de-spin "yo-yo" mechanism to slow spin rate; 21) spin-up rockets to boost spin rate as desired.

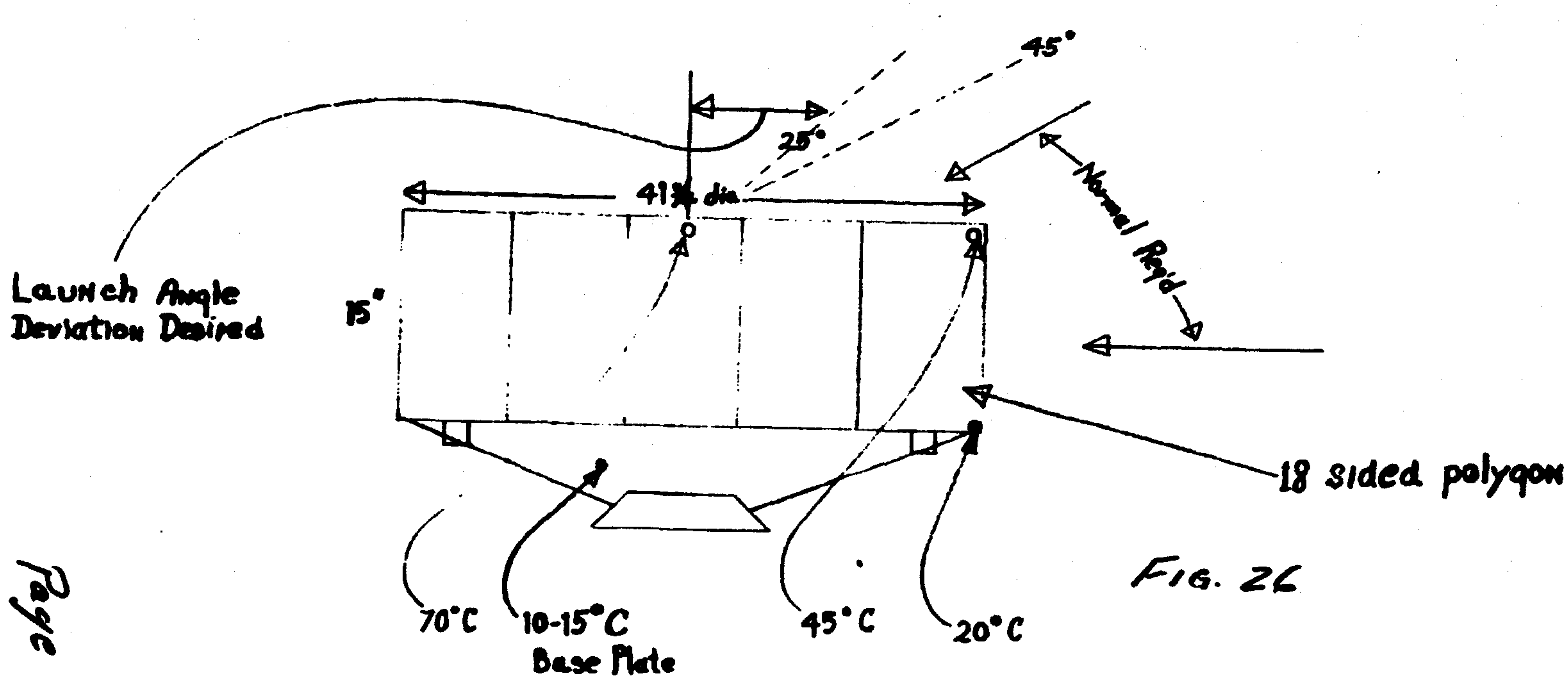


FIG. 26

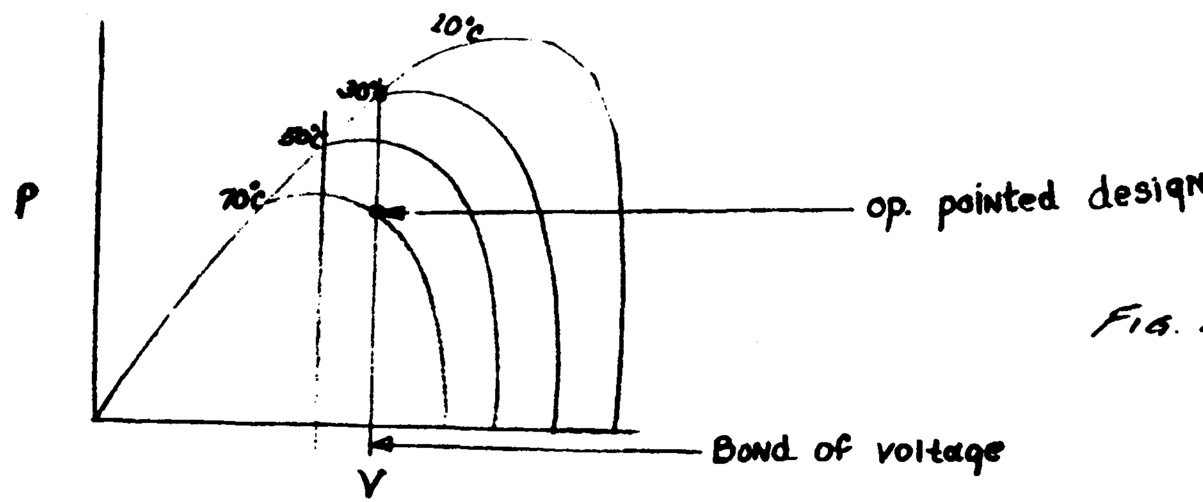
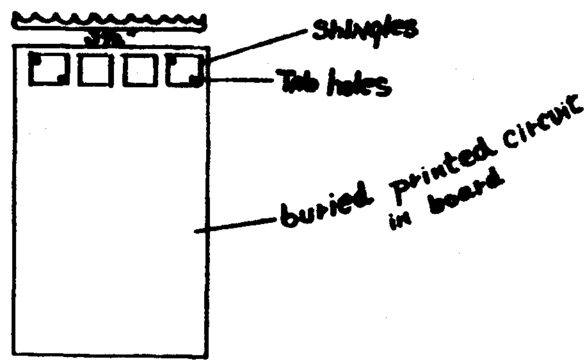


FIG. 27

SECRET



80 cells in series per module

Fig. 28

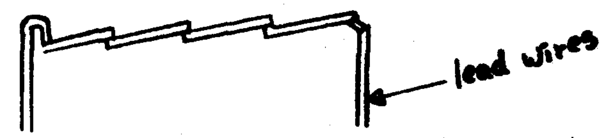


Fig. 29.

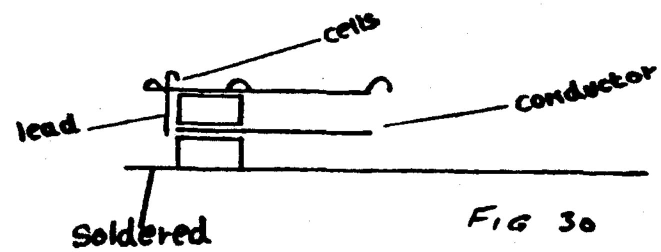


Fig 30

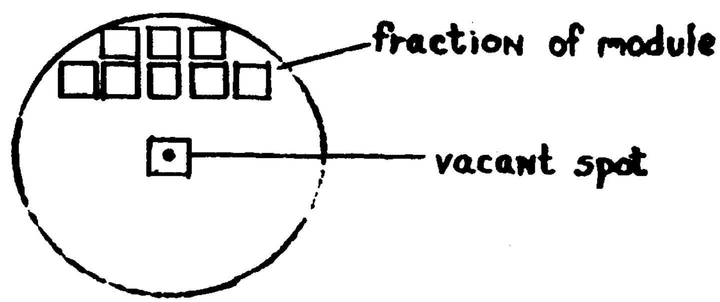
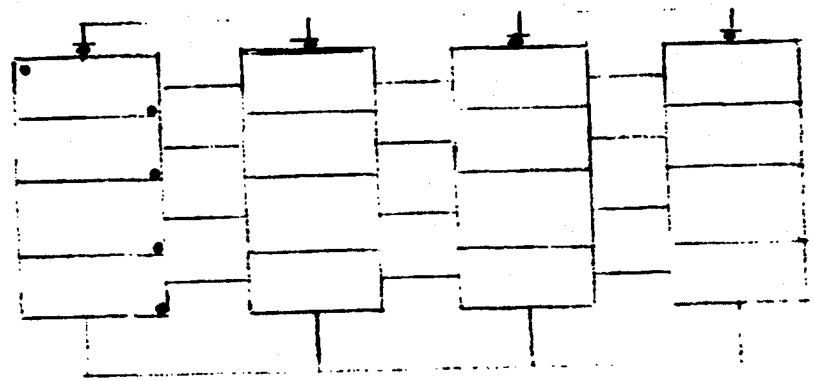


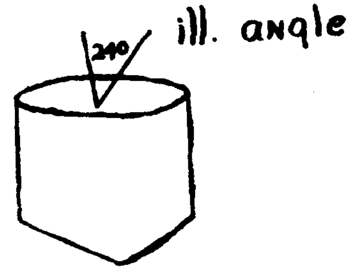
Fig. 31

SECRET



cross parallelling

Fig. 32



Power = 62 w for array

Fig. 33

SECRET

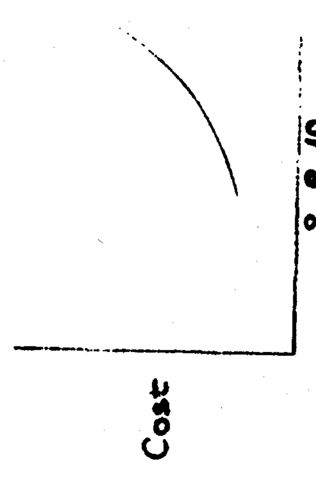


FIG. 34

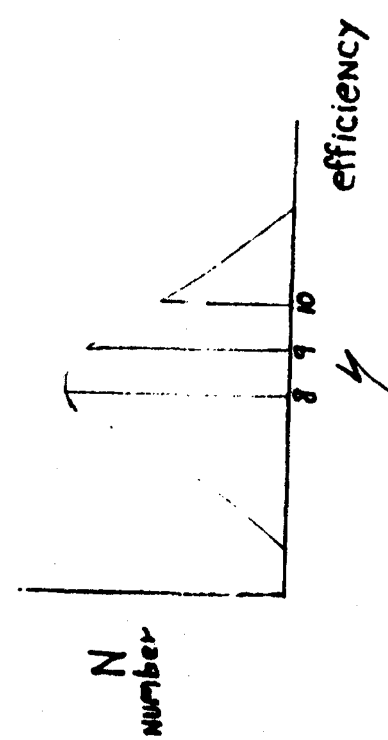


FIG 35

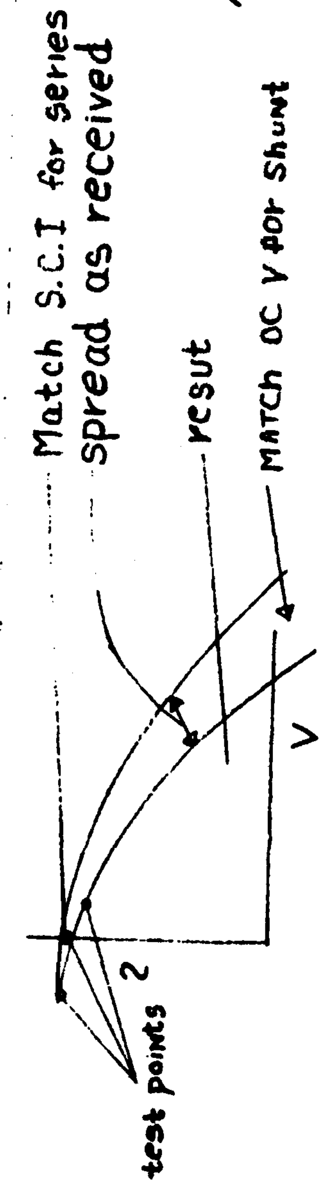


FIG 36

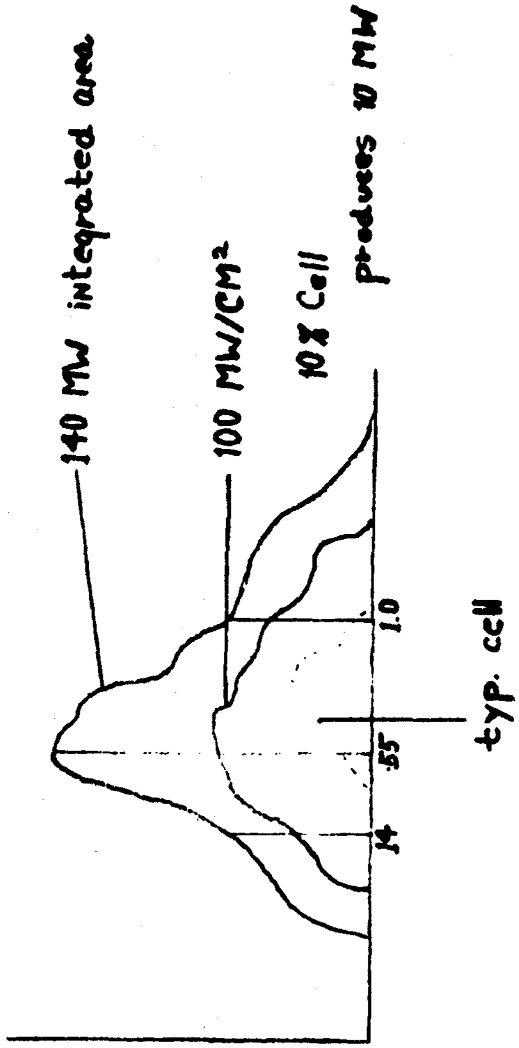
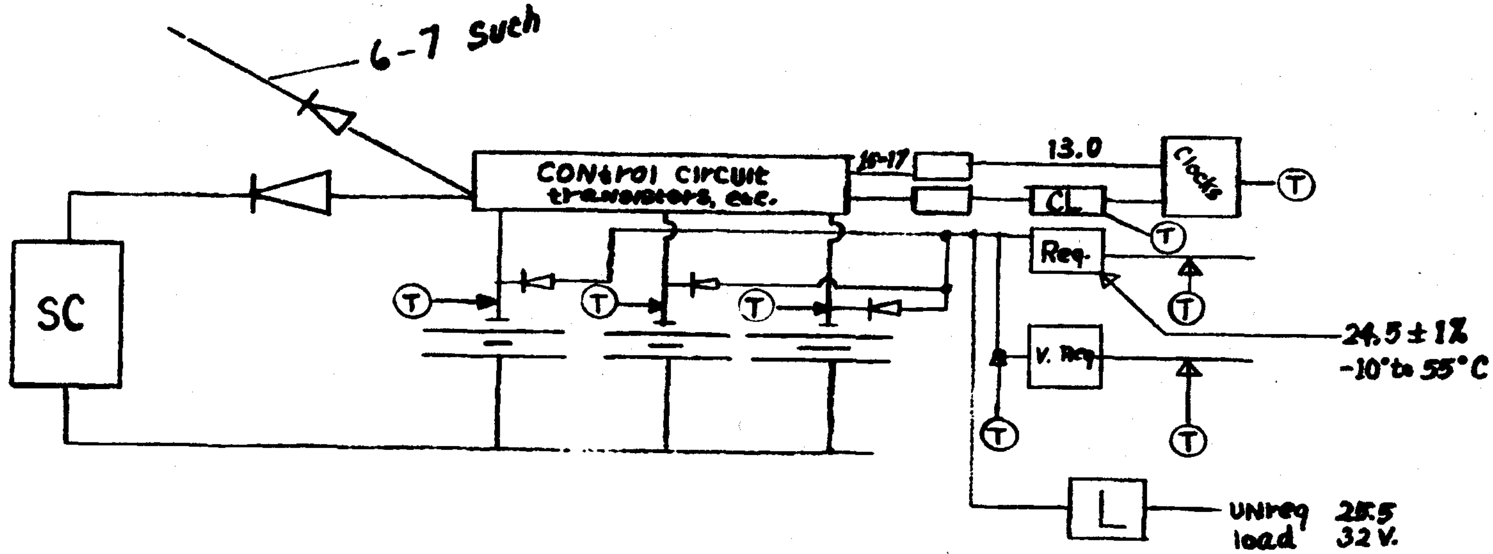

140 MW integrated area
100 MW/CM²
10% Cell
produces 10 MW
.14
.55
1.0
typ. cell

Fig 37



(T) Telemetered

FIG. 38

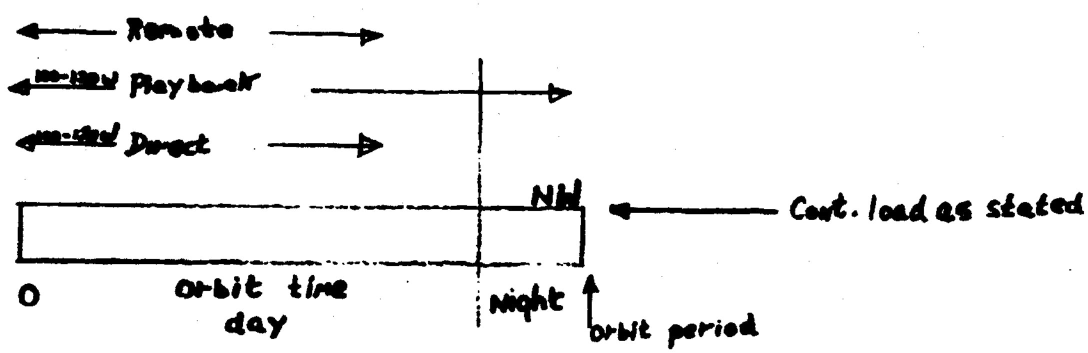


FIG. 39

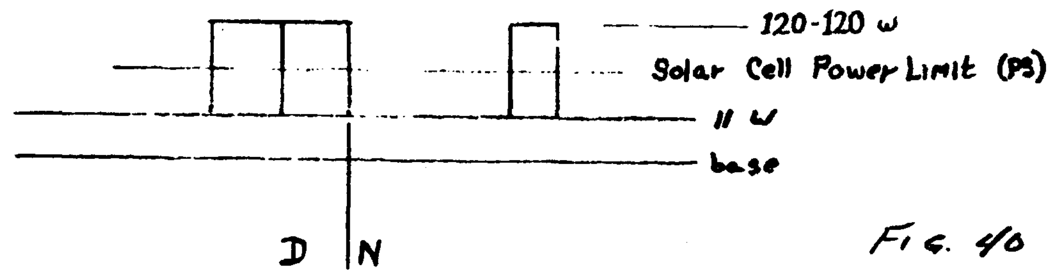


FIG. 40

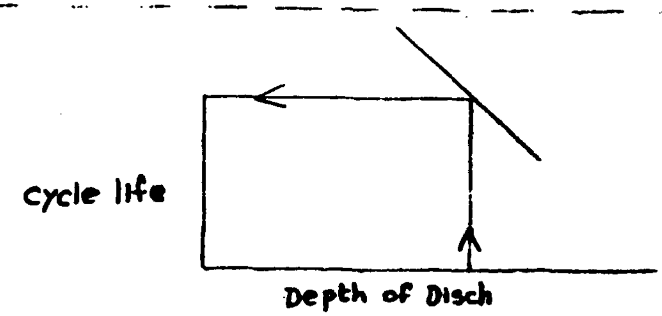


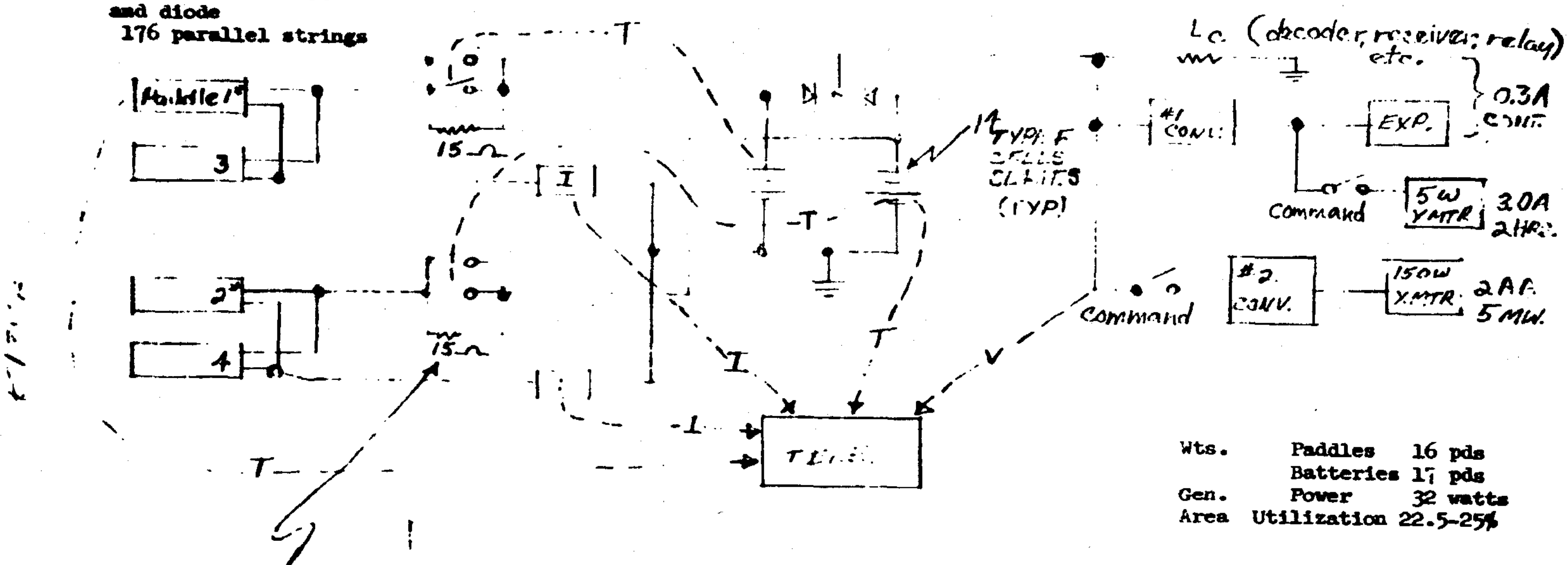
FIG. 41

SECRET

SECRET

ABLE POWER SCHEMATIC

8800 total cells
50 cells in series and diode
176 parallel strings



Resistance equivalent to allow constant load and battery trickle charge to be maintained.

- Command switch positions can be activated as well by an over or undervoltage control.
- Sensors are slaved by battery bus. reg. 14.8-23 volts.

Wts.	Paddles	16 pds
	Batteries	17 pds
Gen.	Power	32 watts
Area	Utilization	22.5-25%

Fig. 42

SECRET

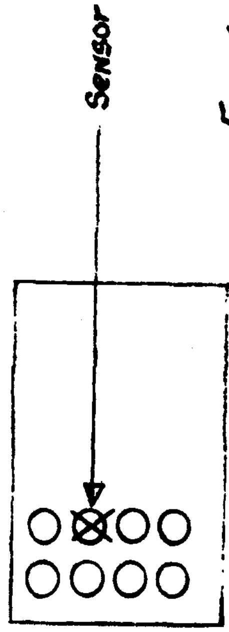


Fig 43

Fig. 44

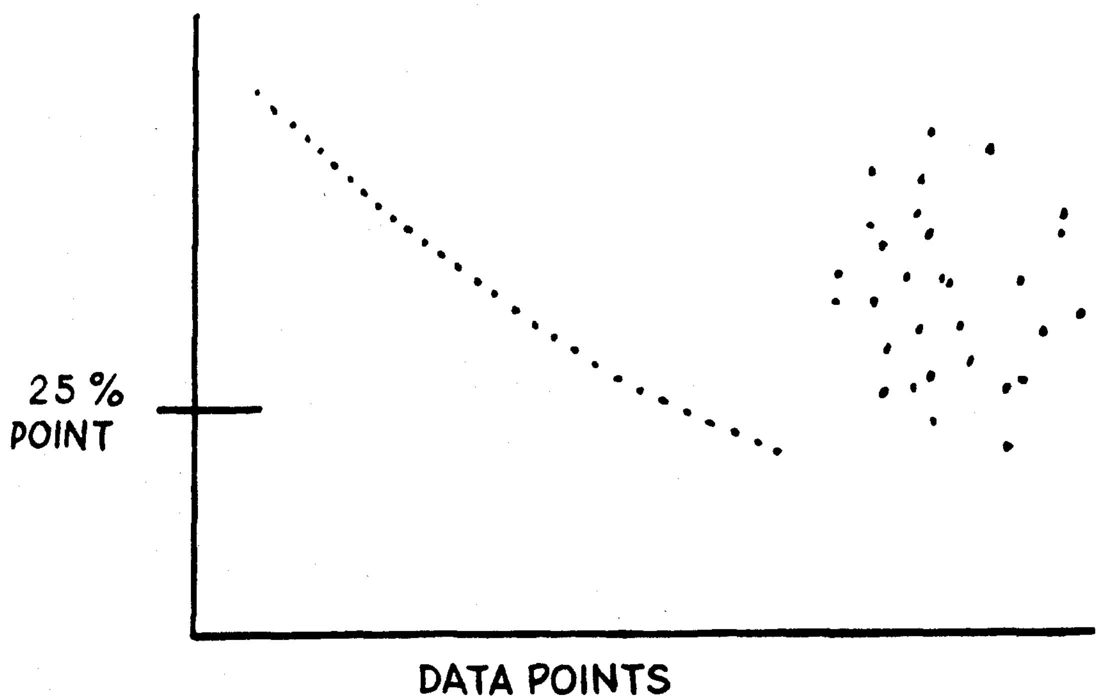


FIG. 45

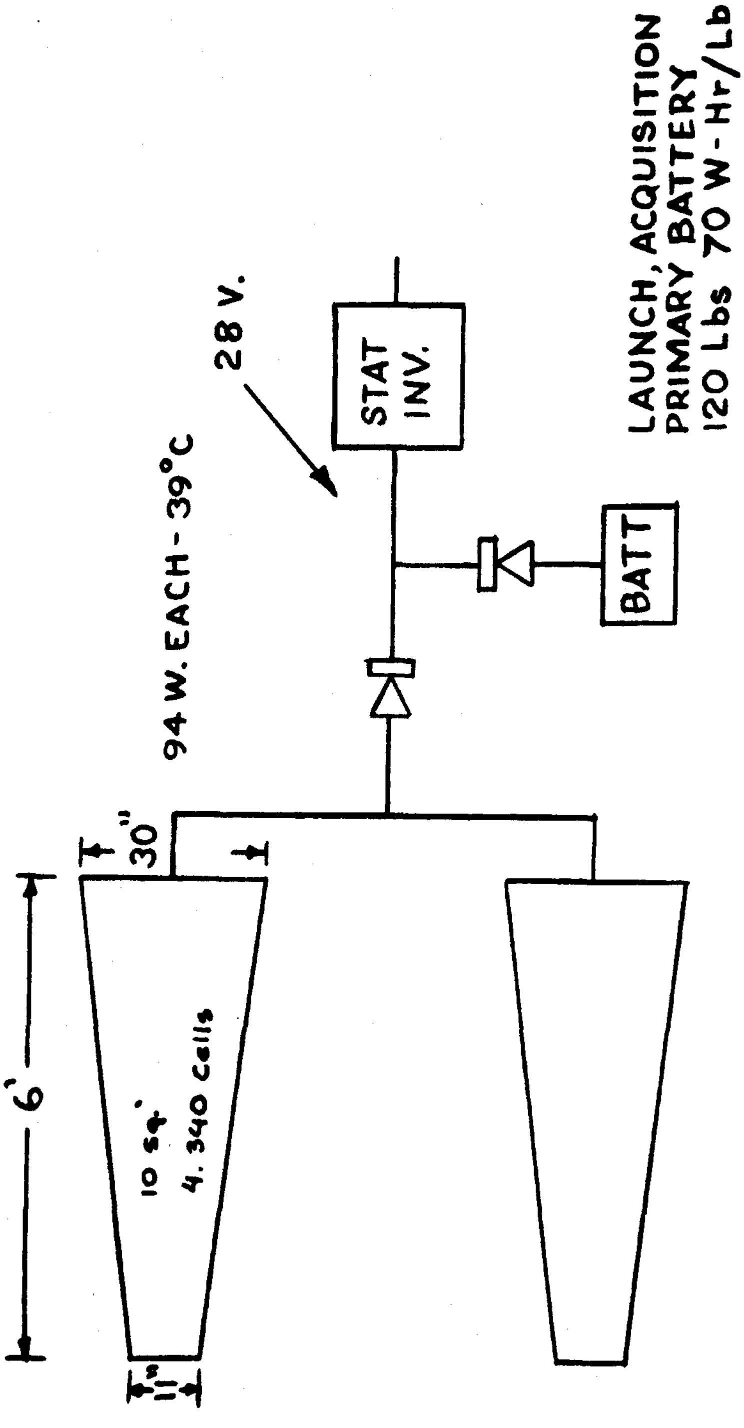

94 W. EACH - 39°C
28 V.
STAT INV.
BATT
LAUNCH, ACQUISITION
PRIMARY BATTERY
120 Lbs 70 W-Hr/Lb
30"
6'
10 sq'
4.340 cells

Fig. 46

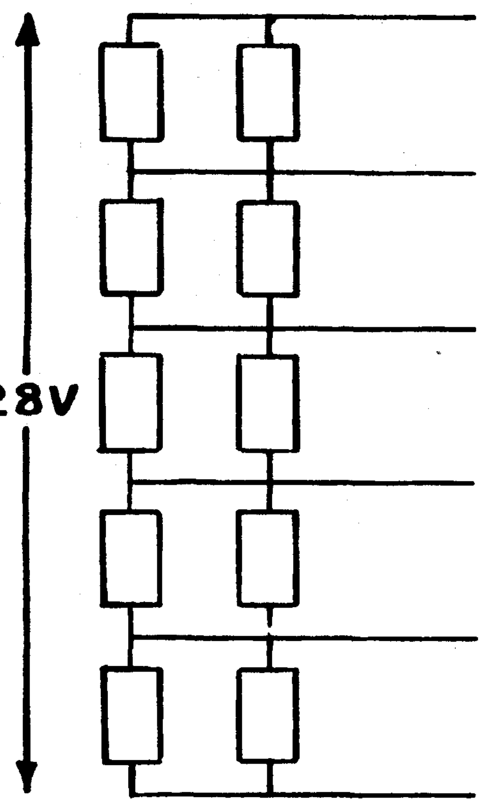


FIG. 47

70 →

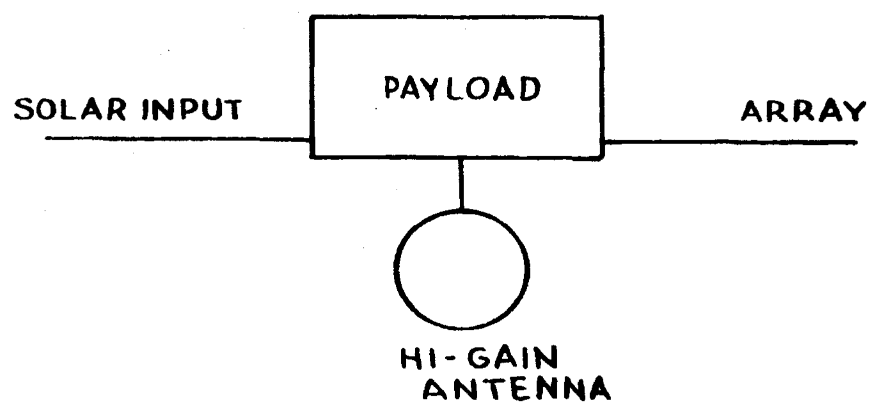


FIG 48

SECRET

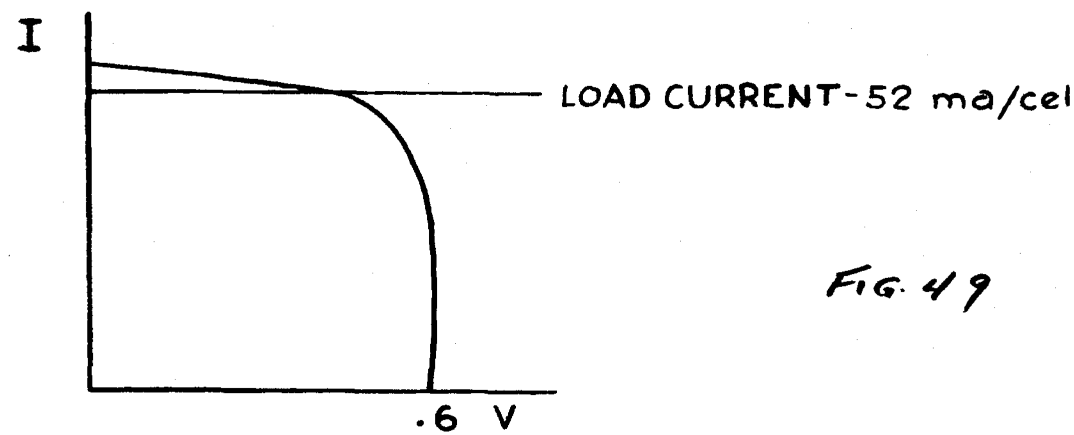


FIG. 49

FIG. 50

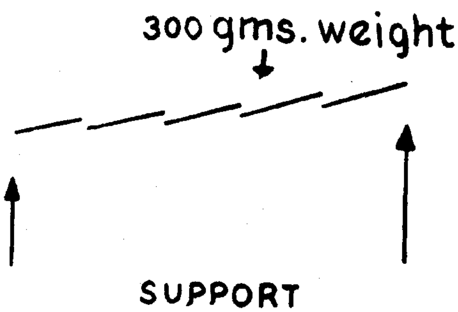


Fig. 51

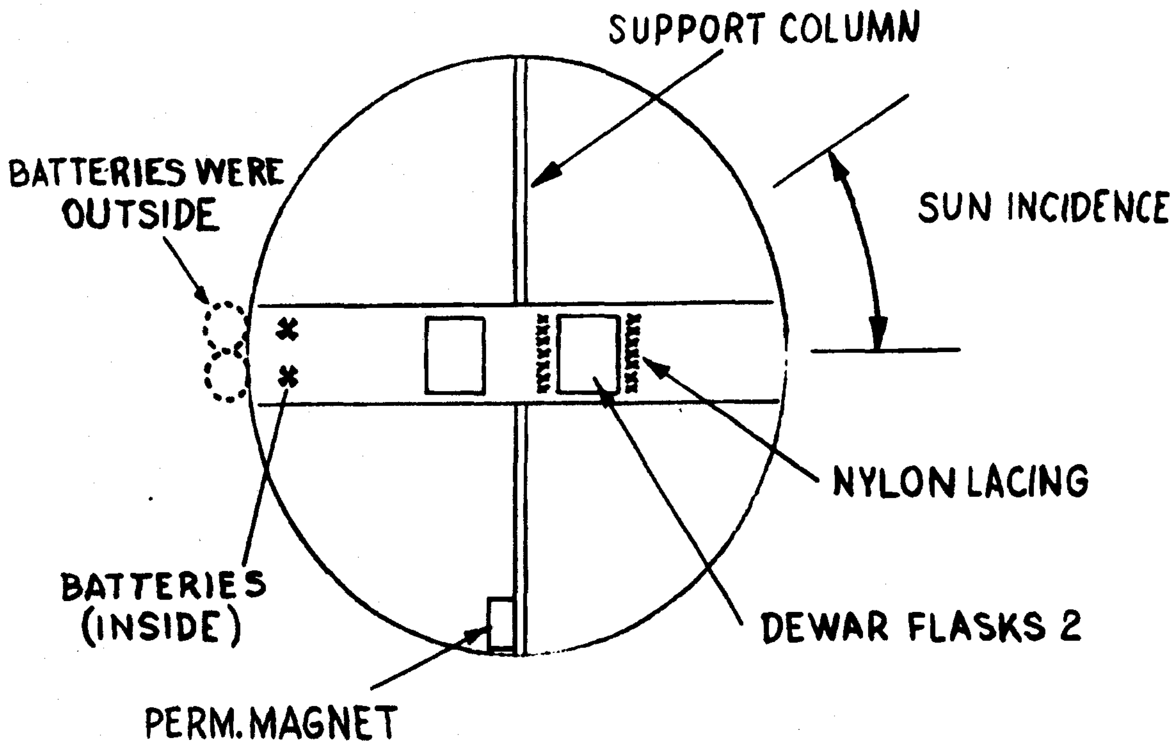

SUPPORT COLUMN
BATTERIES WERE OUTSIDE
SUN INCIDENCE
NYLON LACING
BATTERIES (INSIDE)
DEWAR FLASKS 2
PERM. MAGNET

FIG. 52

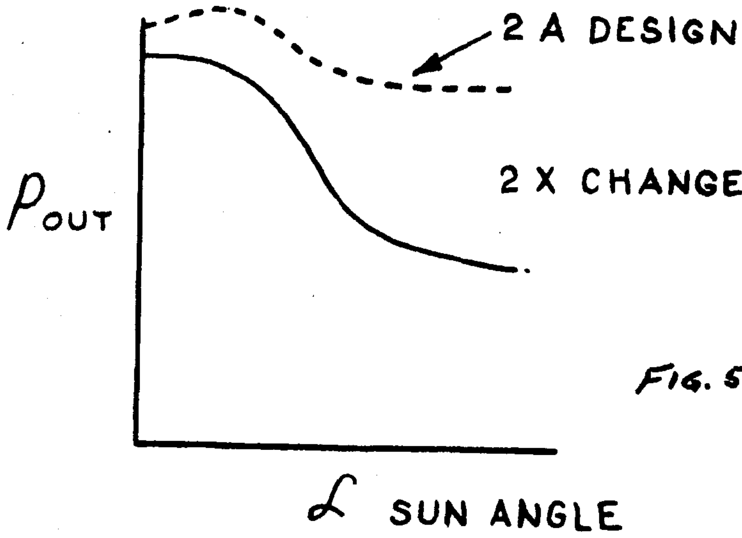
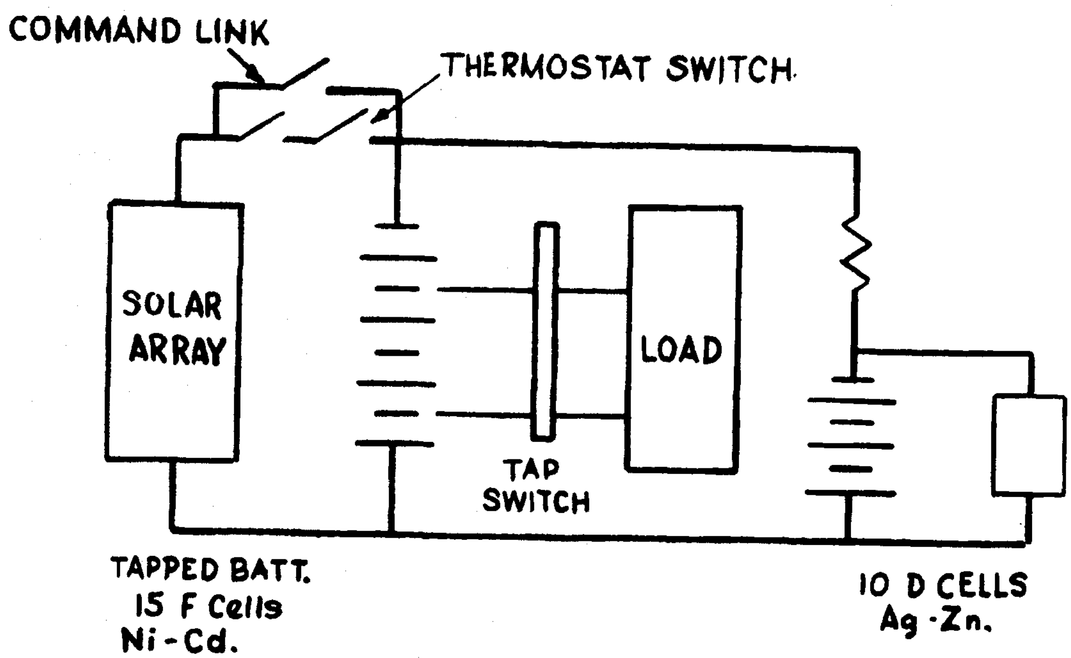


FIG. 53



1B System

FIG. 54

~~SECRET~~

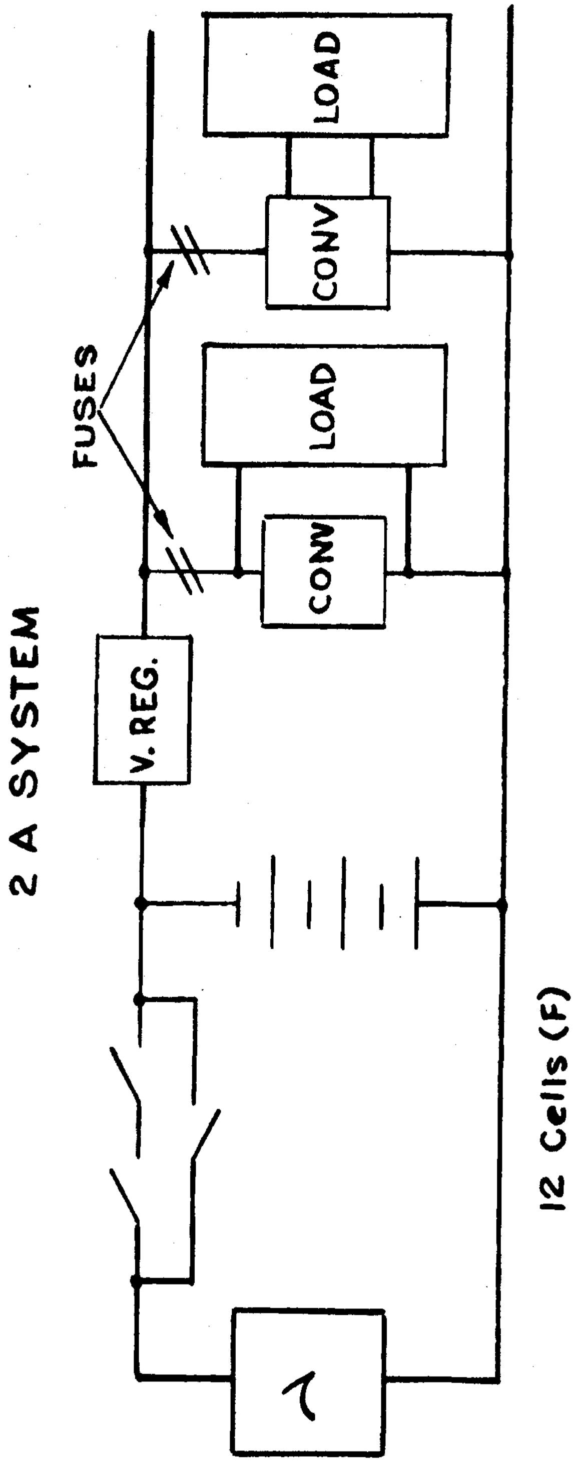


Fig. 55

~~SECRET~~

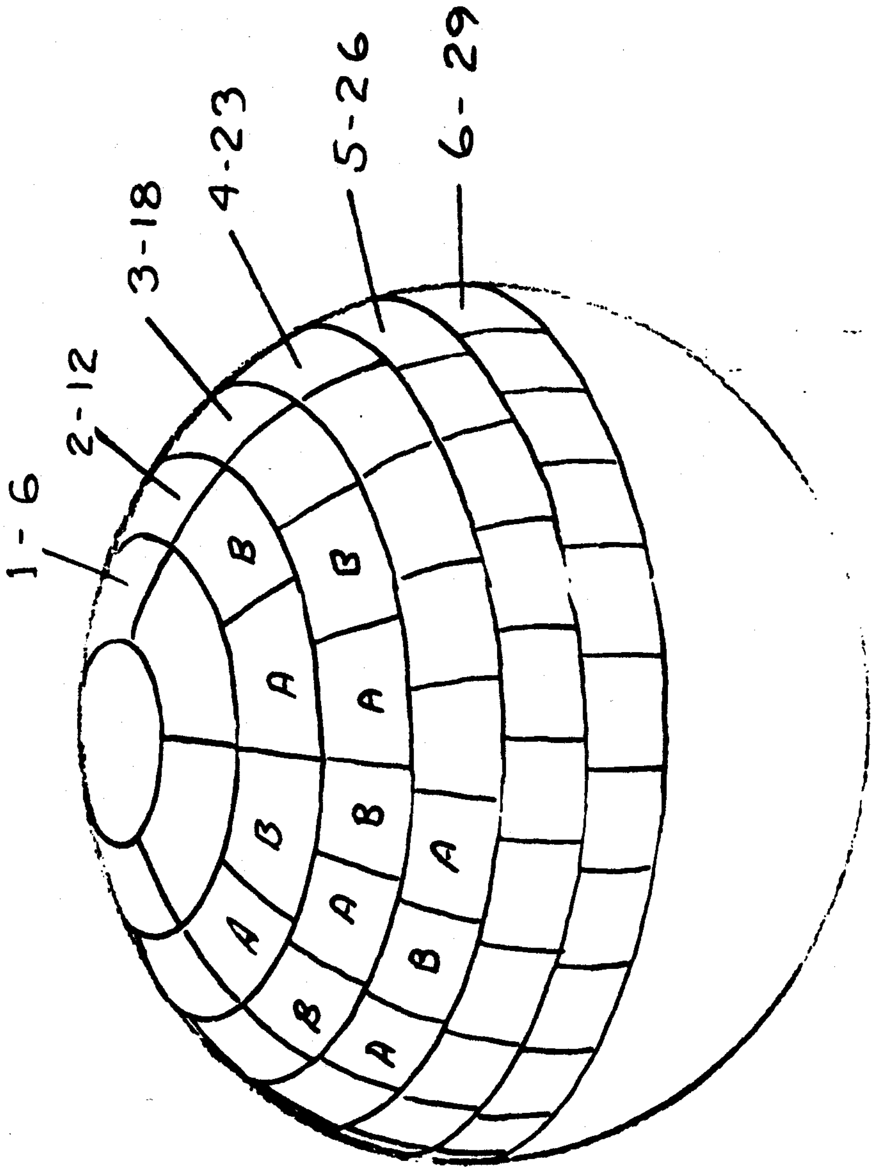


Fig. 56

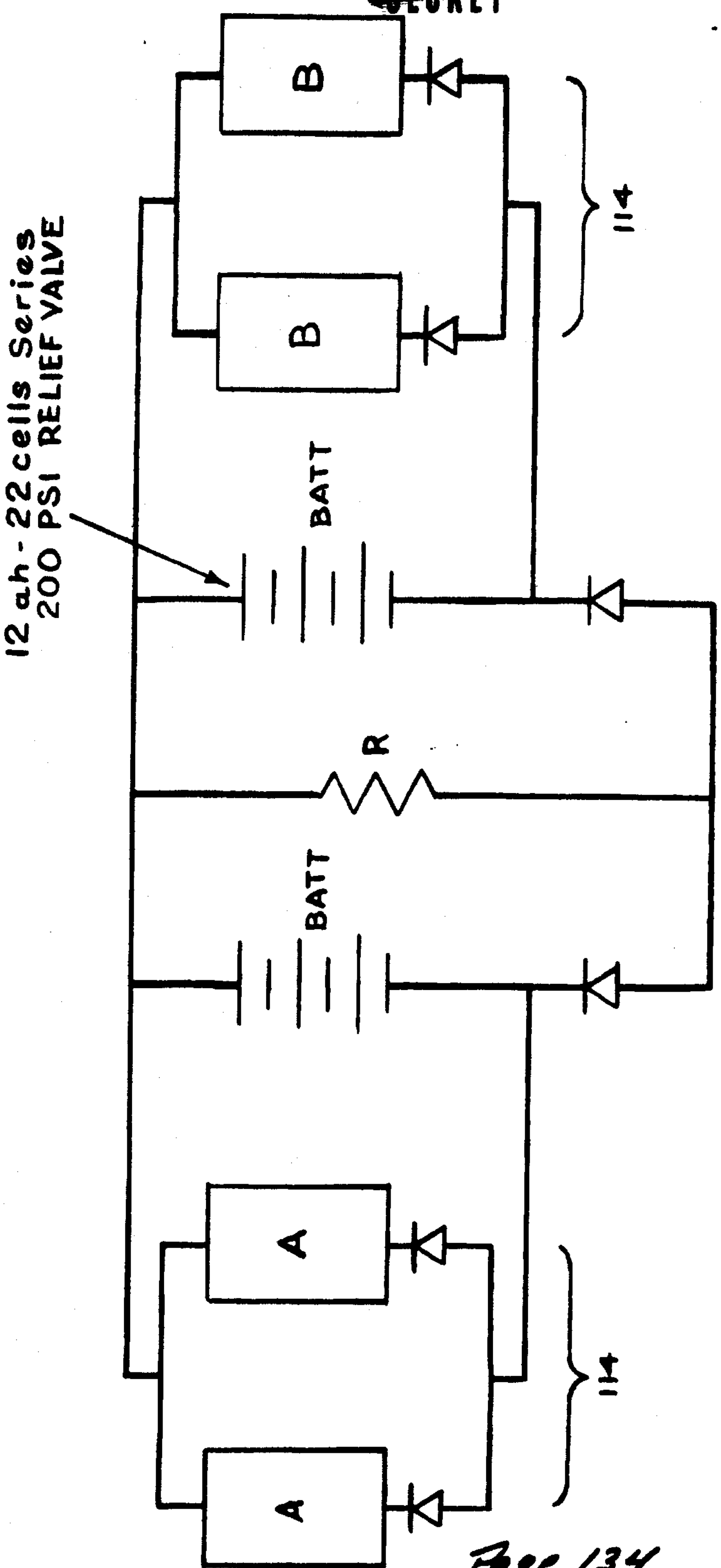


Fig. 57

Page 134

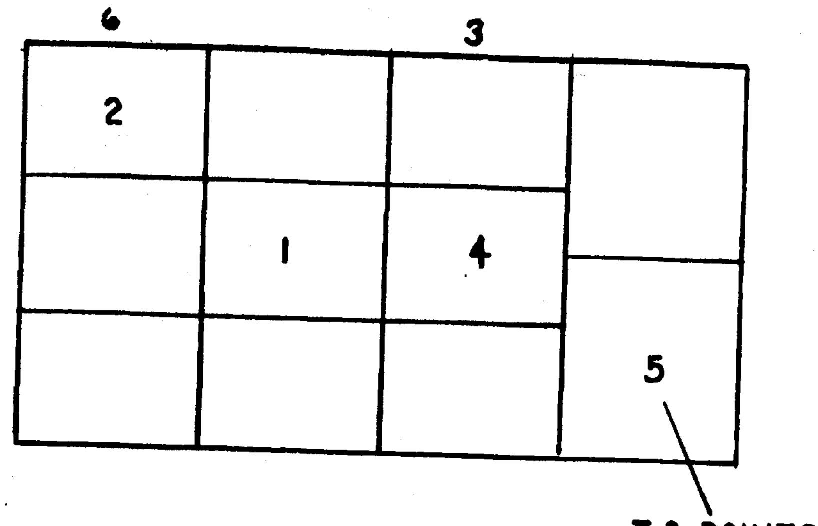

6
3
2
1
4
5
T.C. POINTS

FIG. 58

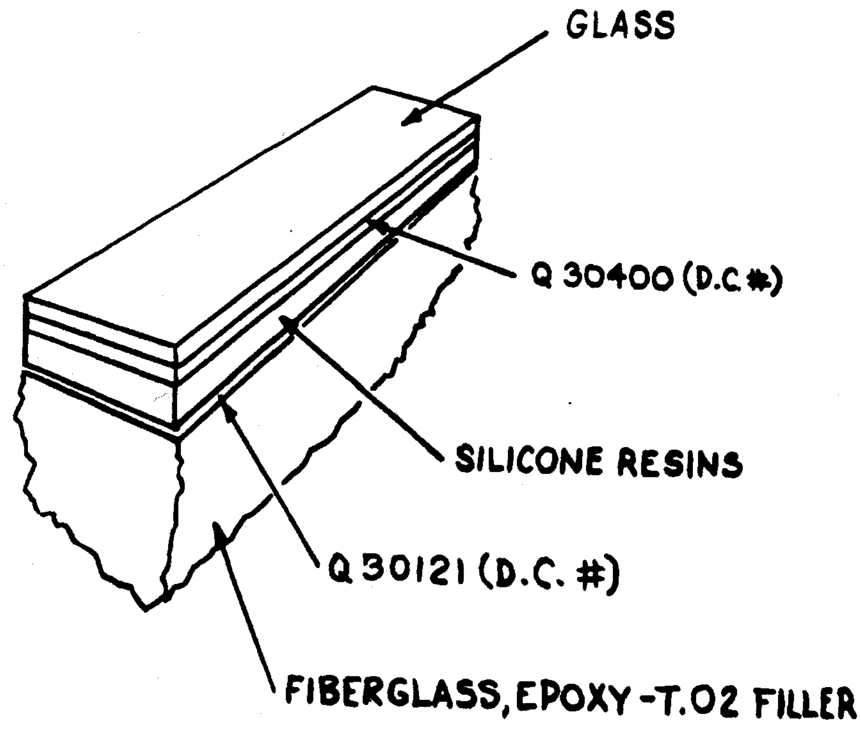

GLASS
Q 30400 (D.C #)
SILICONE RESINS
Q 30121 (D.C. #)
FIBERGLASS, EPOXY-T.O2 FILLER

Fig. 59

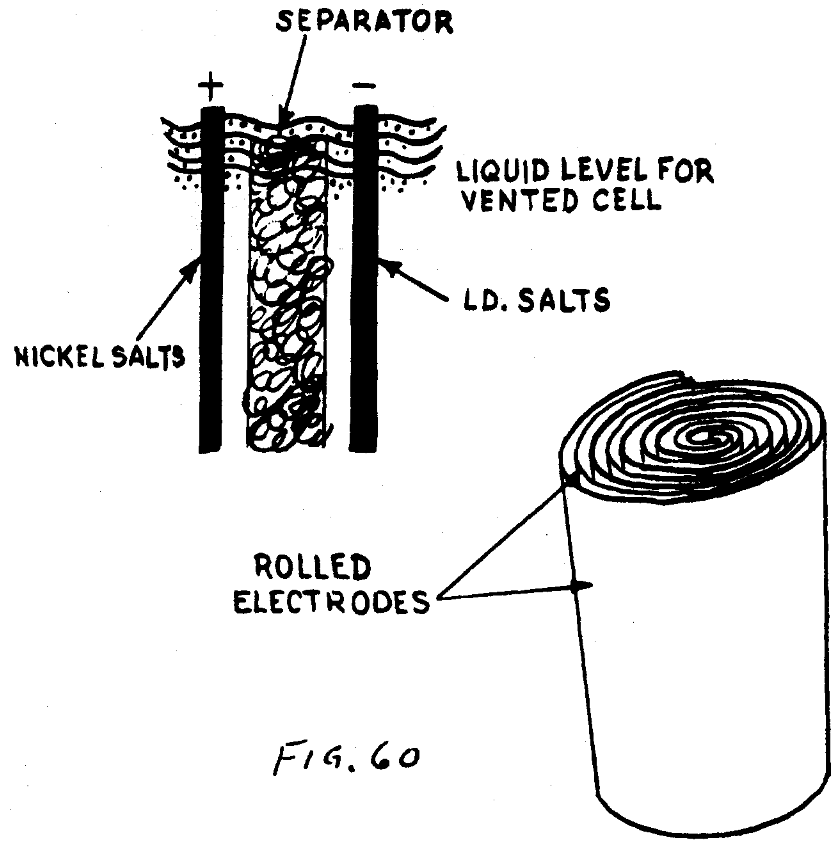

SEPARATOR
+
−
LIQUID LEVEL FOR
VENTED CELL
LD. SALTS
NICKEL SALTS
ROLLED
ELECTRODES

FIG. 60

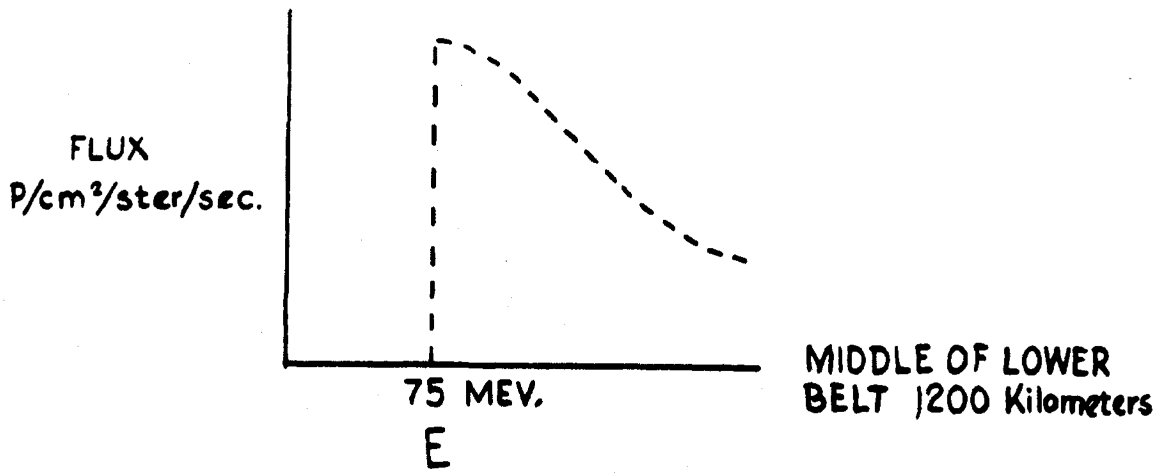

FLUX
P/cm²/ster/sec.
MIDDLE OF LOWER
BELT 1200 Kilometers
75 MEV.
E

FIG. 61

APPENDIX B-1

COMMUNICATION SATELLITE

General Electric Company
Missile & Space Vehicle Department
Philadelphia, Pennsylvania

Solar Array Design

Design Basis:

1. Paddles are sun oriented.
2. Silicon solar cells - conversion efficiency at 100 mw/cm^2 (Tungsten source) at 25°C is 9.3%
3. Paddle temperature in light is 40°C. Output loss equals 0.6%/ degree C or 8% due to 15°C rise over 25°C.
4. Solar flux in space - 140 mw/cm^2
5. Reduction due to spectral distribution in space is 15%
6. Transmission loss through cover glass is 8%
7. Packing factor - 85%

Combining above gives

$$140\ (1-.15)\ (1-.08)\times(1-.08)\times.85\ \times.093 = 7.95\ mw/cm^2$$

or

$$.00795 \times \overline{2.54}^2 \times 144 = 7.4\ \text{watts/sq ft.}$$

8. Array size tradeoff studies in progress. Approaches are:
   a. Size array to provide maximum transmit load (330 watts). This gives

$$\frac{330}{7.4} = 44.5\ \text{sq. ft.}$$

   Two paddles, each 3 x 7.5 ft.

   b. Optimum sizing is dependant on

(1) Battery cycling capability (max sizing as indicated above results in least battery cycling, but continuous overcharge may present a problem)

(2) Radiation protection requirements. For seventy mil glass weight estimates are 2.3 lbs/ft^2

BATTERY

Description: The battery will consist of 2 packages, each containing 11 series connected 40 ampere hour sealed rectangular nickel cadmium cells. The two 11 cell packages will also be series connected, and the overall battery open circuit voltage will be 28.6 volts. Each 11 cell package will weight approximately 60 lbs, and the individual package dimensions are expected to be 8" height x 6" width x 18" length. The 11 cell package case will be made of magnesium and the arrangement of the cells within each package will be based on heat transfer as well as electrical considerations. The individual cell cases within the battery will be electrically insulated from each other as well as from the battery package magnesium case.

POWER REQUIREMENTS

Ascent Phase: During the ascent phase the battery must supply 166 watts for 135 minutes. At the minimum discharge voltage of 23.5 volts, the battery must therefore supply 15.9 ampere hours at a 7.05 ampere discharge rate.

Orbit Phase: During the 6 hour orbit the battery must supply 330 watts for a maximum of 55 minutes or approximately 13 ampere hours. There is to be a 72 minute period during which time the battery will float electrically across the busses. During the remaining 234 minutes the battery will be recharged approximately 15.6 ampere hours which is a 20% overcharge. This 20% is the minimum overcharge for any 6 hour orbit. During a considerable period of the year, the battery must withstand 100% continuous overcharge without degradation.

Battery Sizing - The limiting factor in sizing the battery is the charge rate. At the present state of the art, a 10 hour charge rate is considered maximum. Applying this figure to the following equation which is similar to that projected by V. Thomas of Bell Laboratories the capacity of the battery must be 40 A. H.

$$C = I_L \; H_C \left[f (1 + \beta) \right]$$

C = Capacity of the battery in Ampere hours.

I_L = Load current supplied by battery = 14 amperes

H_C = Maximum permissible charging rate in hours. This is the time which must be taken to charge the battery from 0 to 100%.

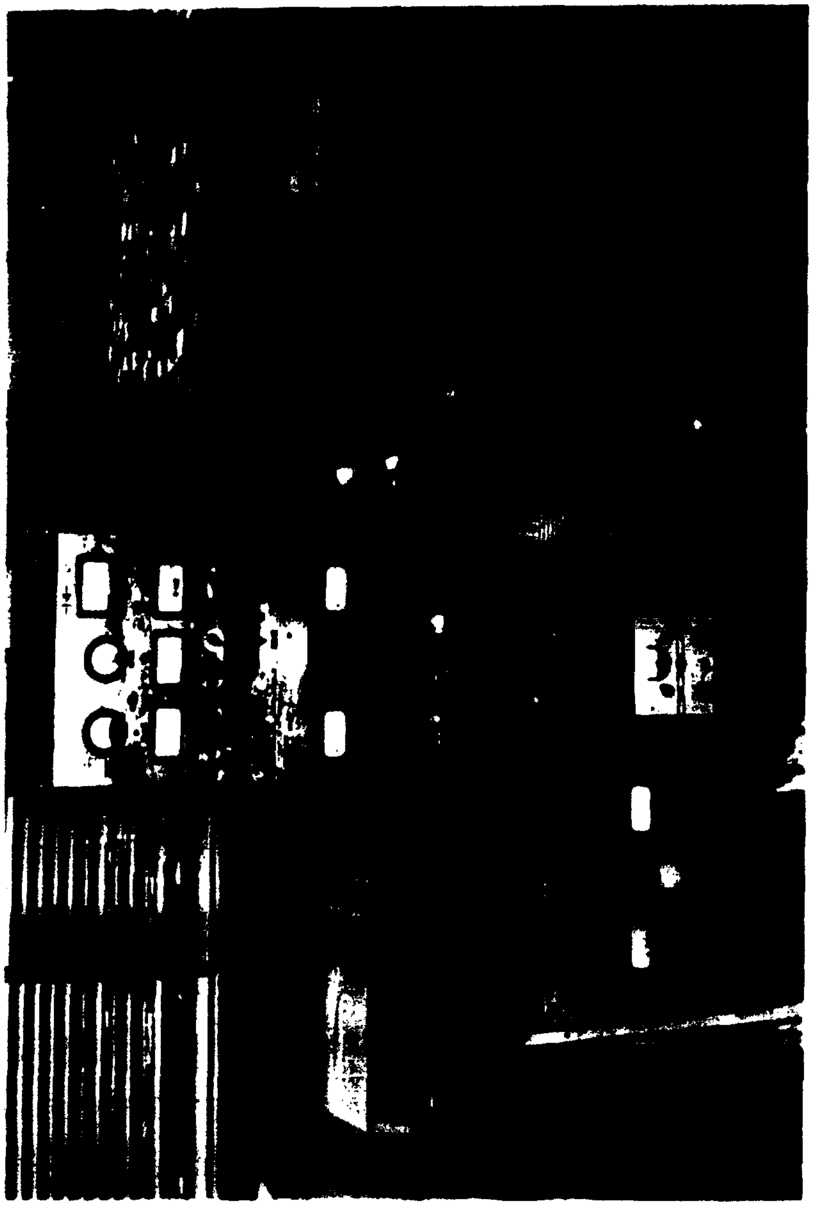
$$f = \frac{\text{Battery Discharge time}}{\text{Battery Charge Time}} = \frac{55}{234}$$

β = Minimum overcharge necessary for a continuous cycling program. This is a fraction of the capacity removed on discharge. At the present state of the art 0.2 is considered a reasonable figure.

$$C = (14 \text{ ampere}) (10 \text{ hours}) \left[\frac{55}{234} (1 + .2) \right]$$

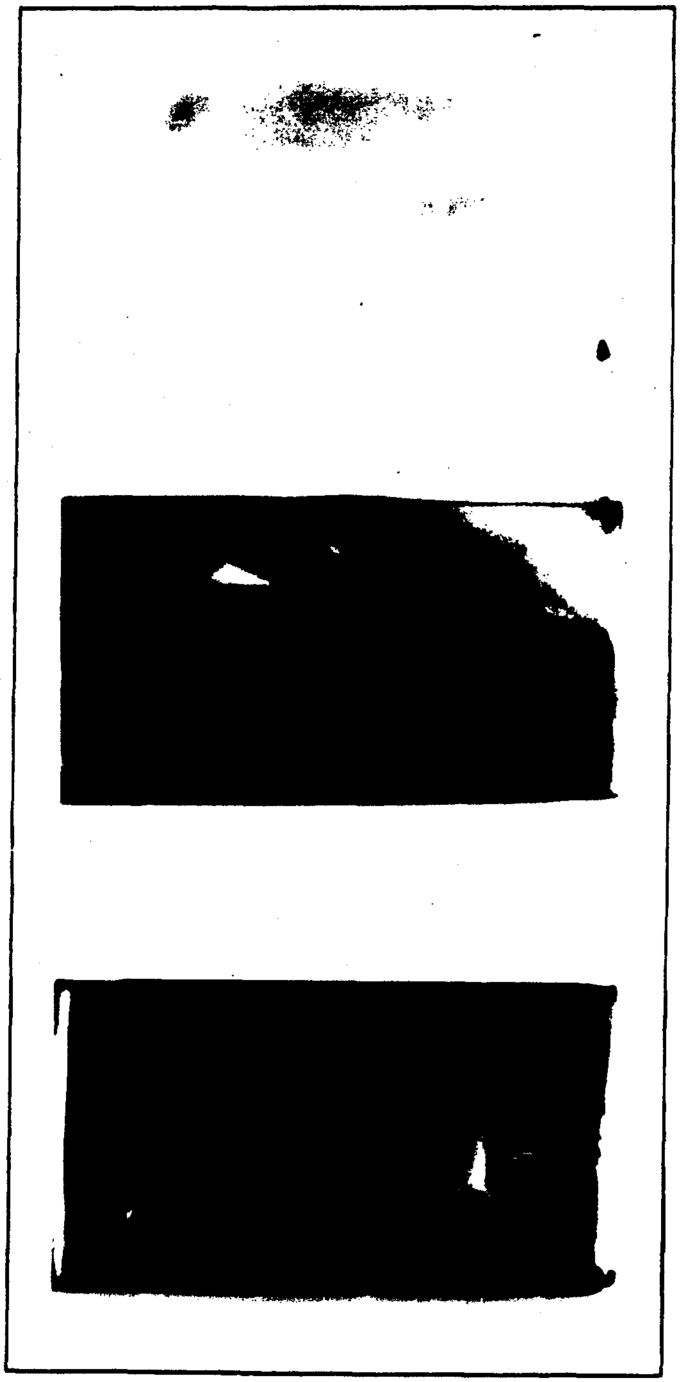
C = 39.5 ampere hours.

With a battery of 40 ampere hour capacity the % depth of discharge during orbit will be 32.5% $(\frac{13}{40})$. This battery will be able to supply the ascent requirement of 15.9 A. H. plus the 1st orbital requirement of 13 AH or a total of 28.9 AH, and still have considerable reserve.



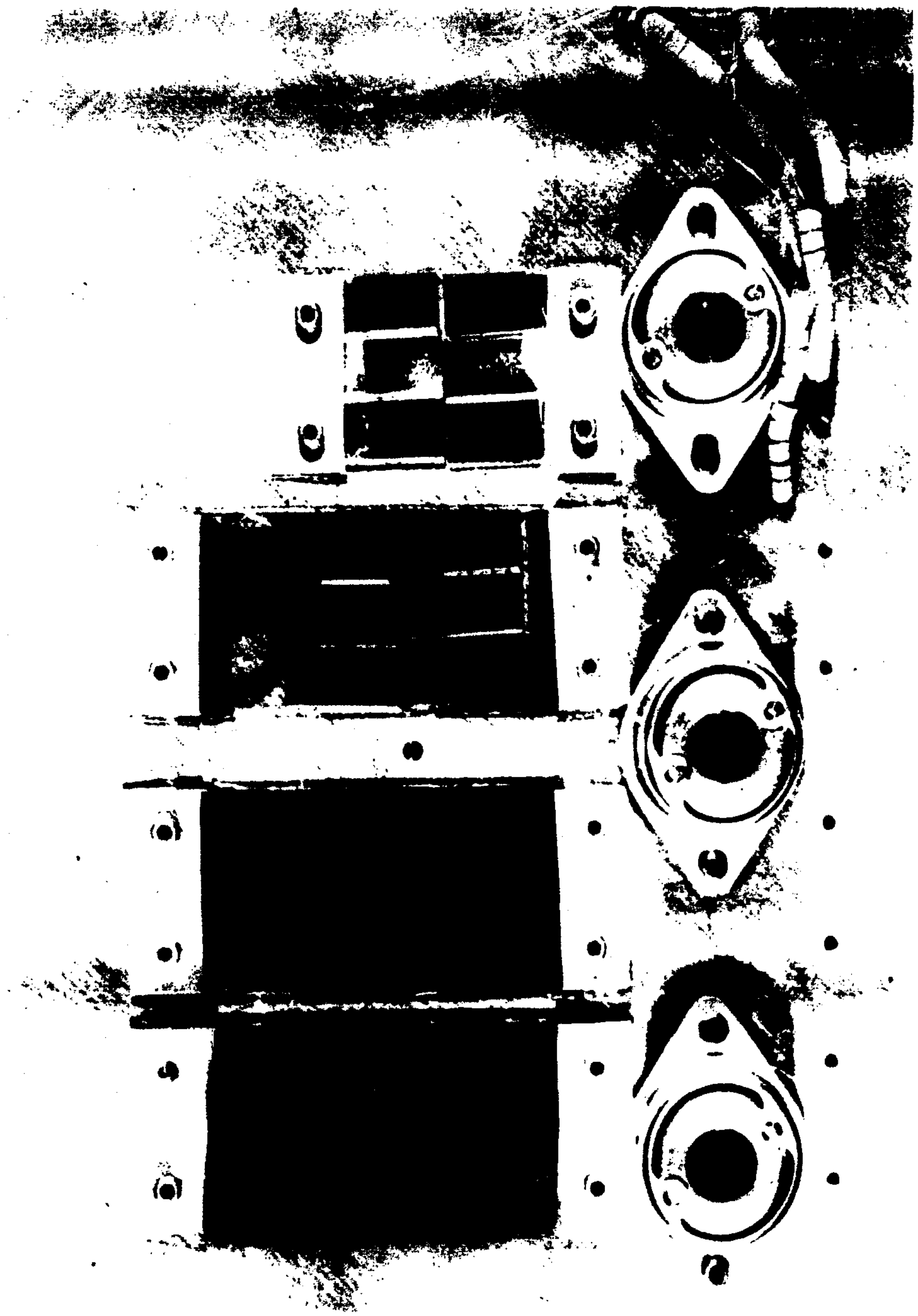
Preliminary Automatic Instrumentation

Preliminary instrumentation for automatically taking Solar Cell V-I characteristics over the temperature range of 200°F to +125°F at each 50° point in the range.



Windows Used in First Solar Cell Irradiation

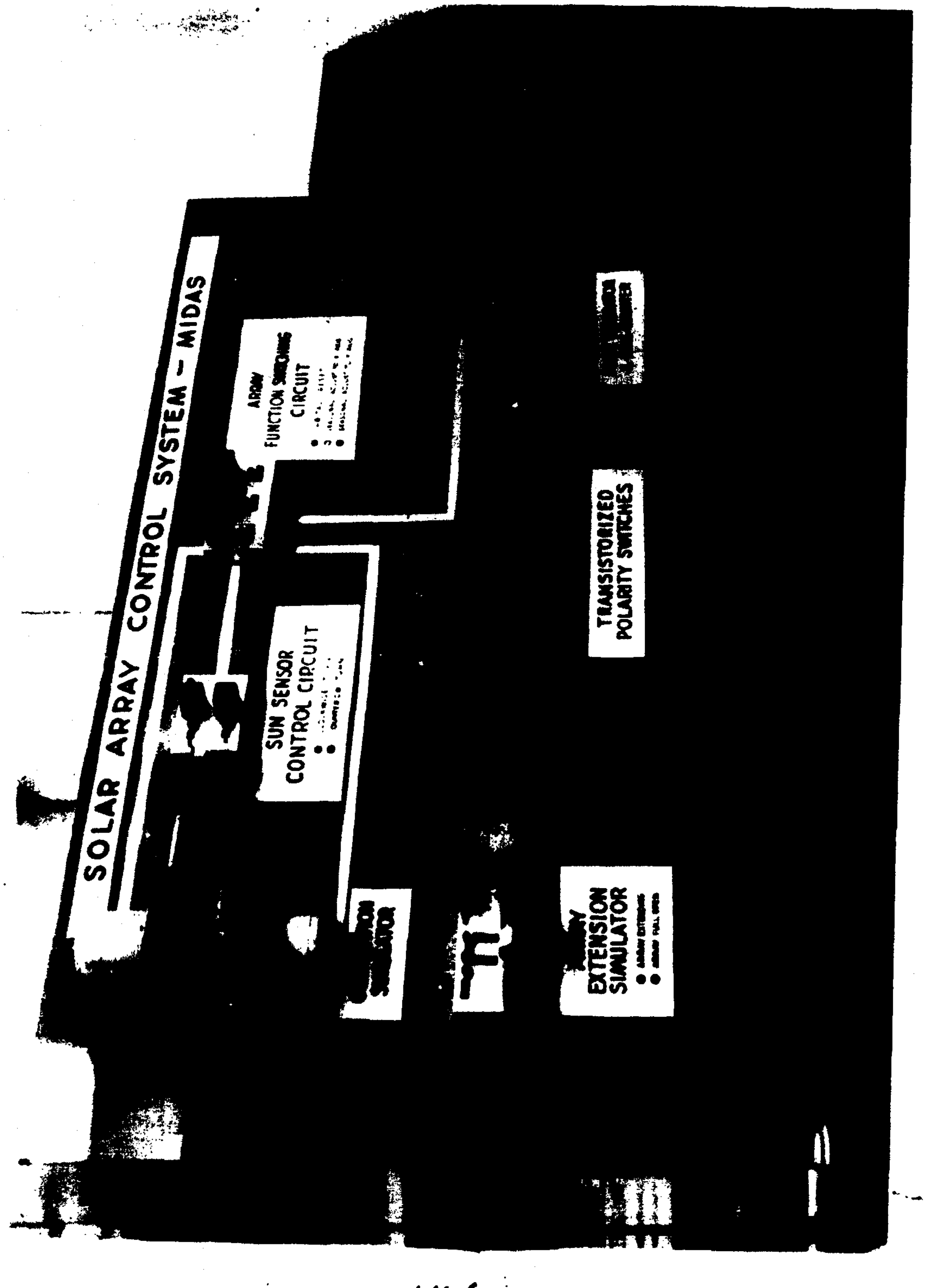
Windows used in first solar cell irradiation with GEL 1 Mev. Electron Accelerator, showing the effect of radiation on quartz. Windows, from top to bottom, are 0.010" 0.040", and 0.070" thick.

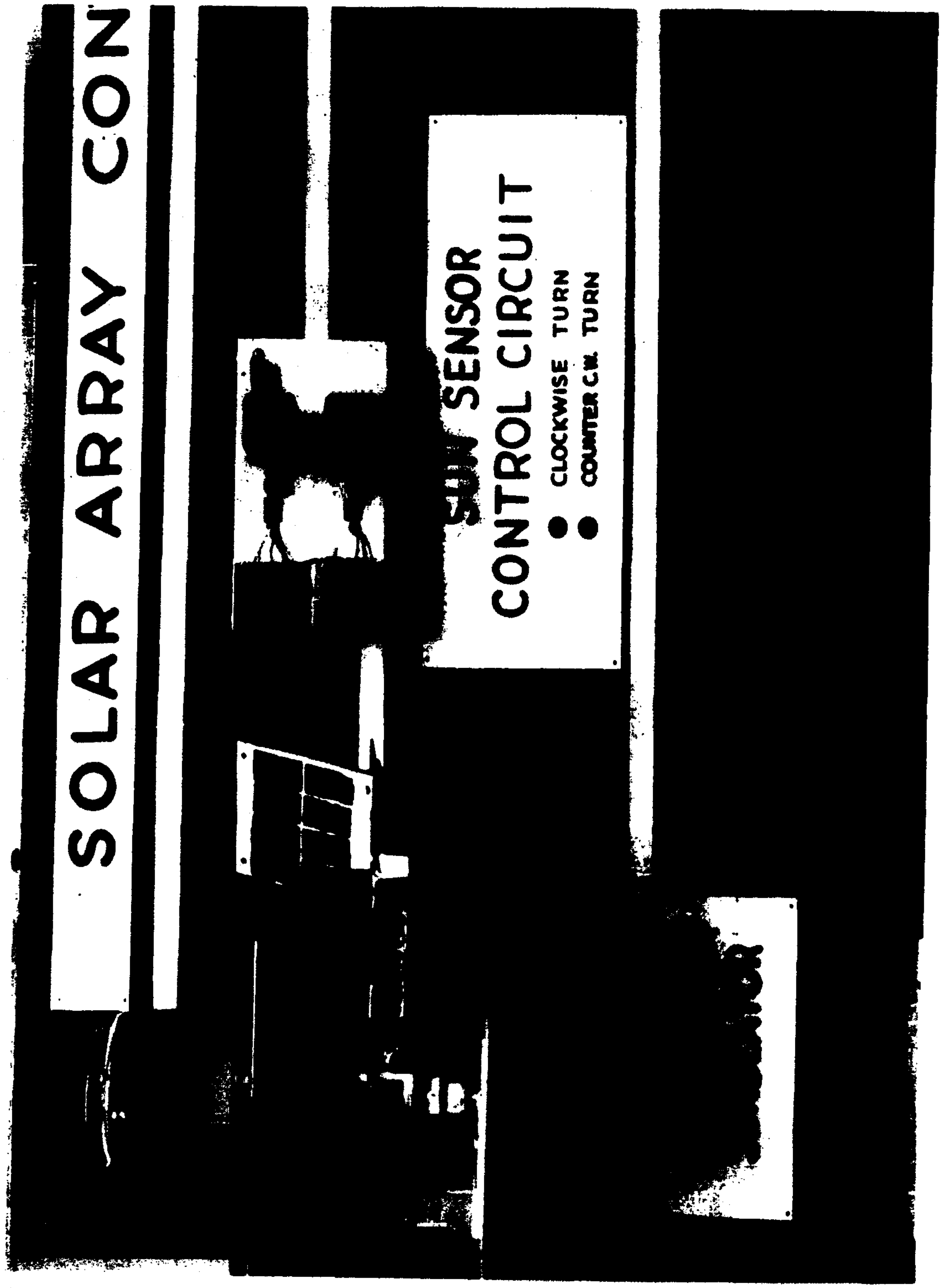


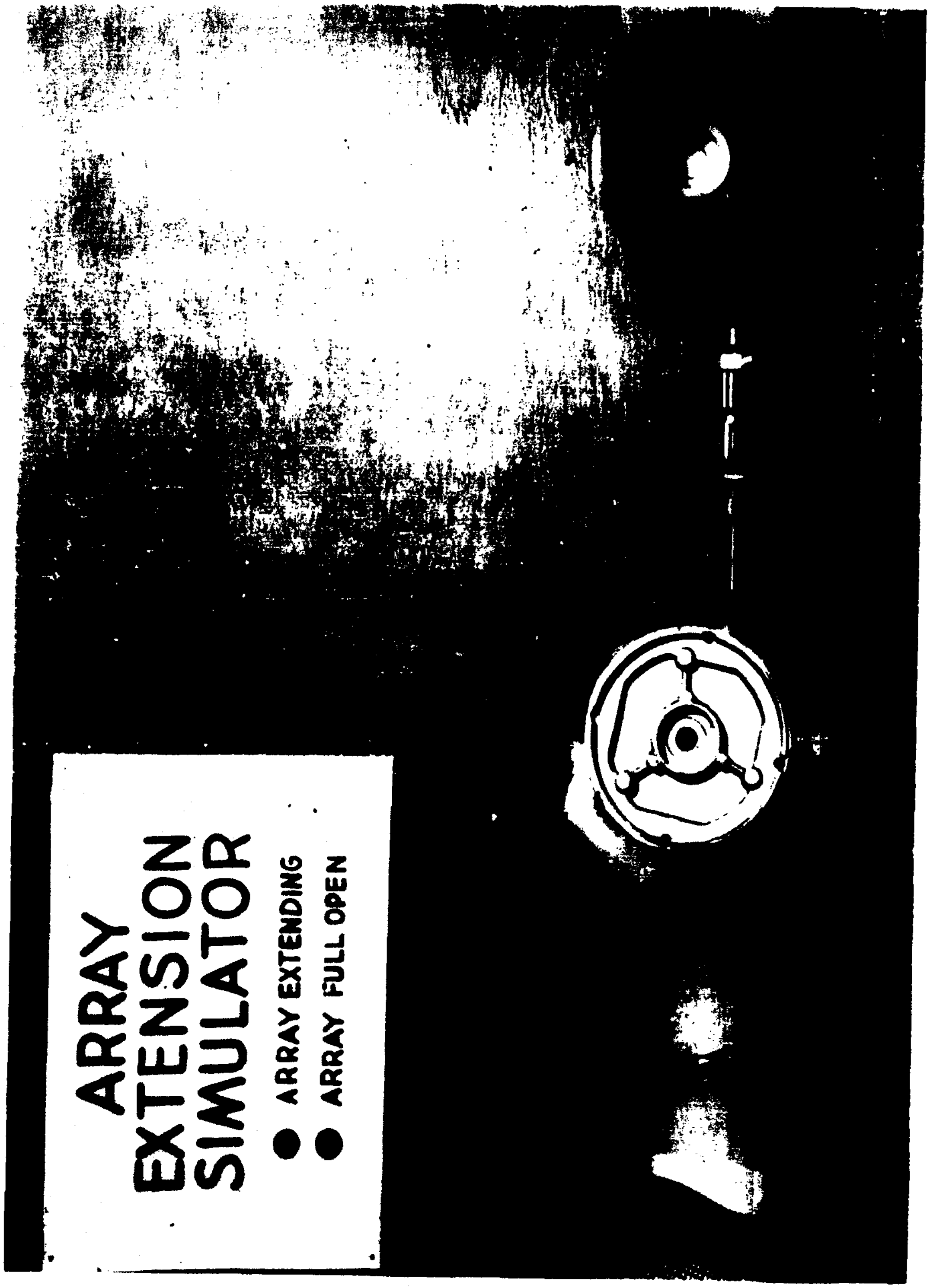
Arrangement of Silicon Solar Cells on Mounting Plate

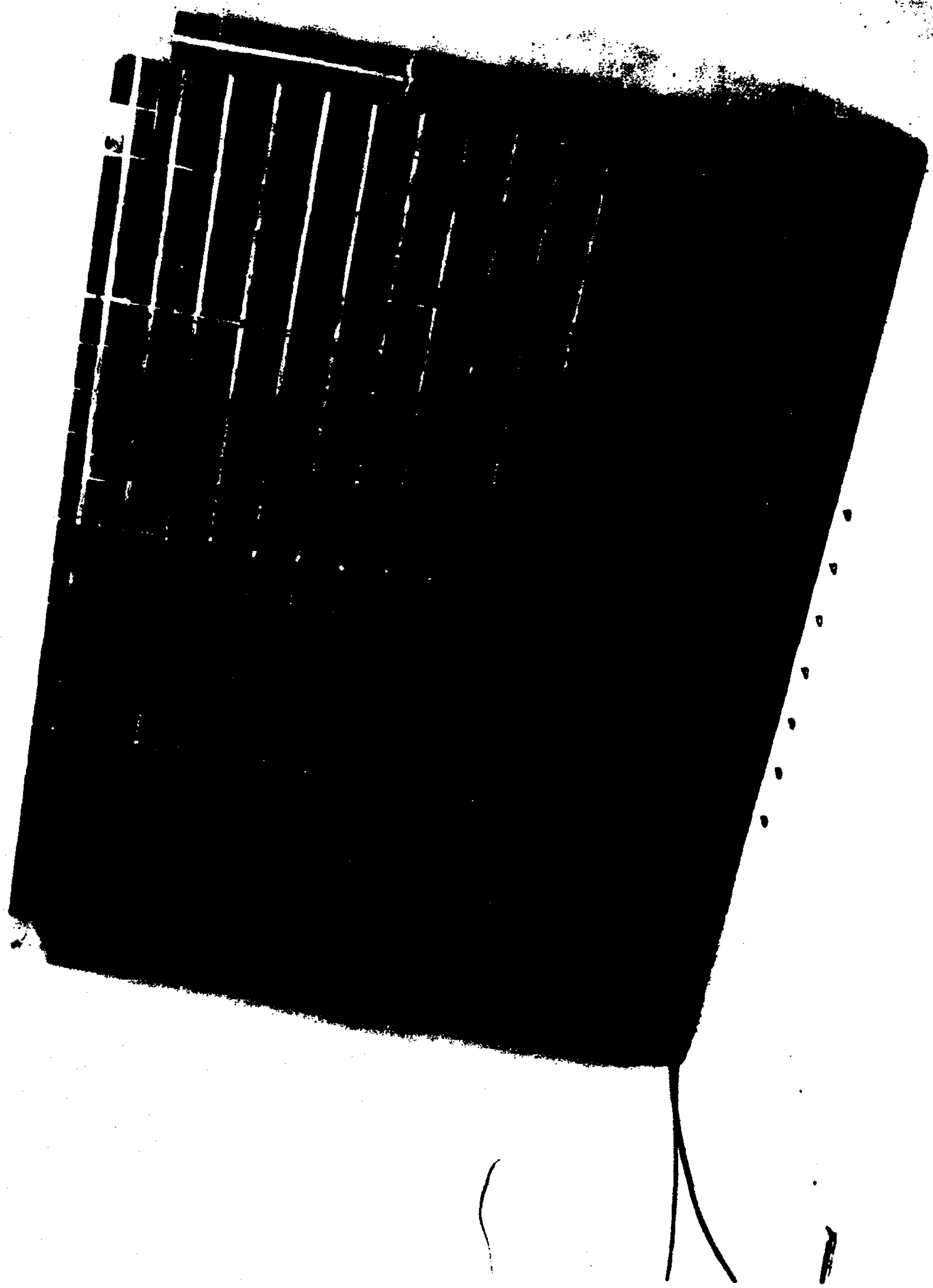
Arrangement of silicon solar cells on mounting plate for irradiation using GEL 1 MEV. Electron Accelerator. View showing, top to bottom four cover conditions -- 0, 0.010", 0.040", and 0.070" quartz windows.

APPENDIX B-2


SOLAR ARRAY CONTROL SYSTEM - MIDAS
FUNCTION SWITCHING
CIRCUIT
SUN SENSOR
CONTROL CIRCUIT
TRANSISTORIZED
POLARITY SWITCHES
EXTENSION
SIMULATOR

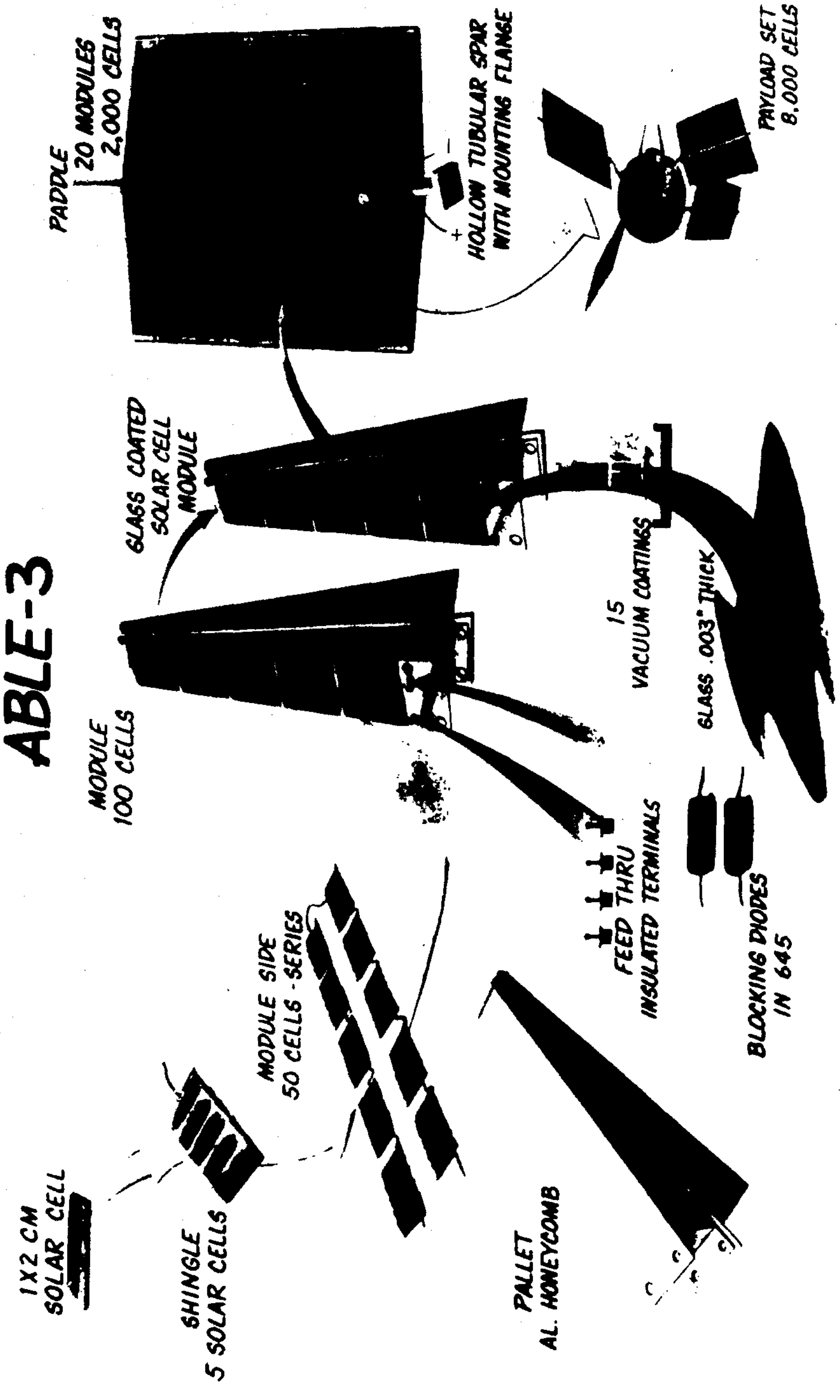

SOLAR ARRAY CON
SENSOR
CONTROL CIRCUIT
CLOCKWISE TURN
COUNTER C.W. TURN

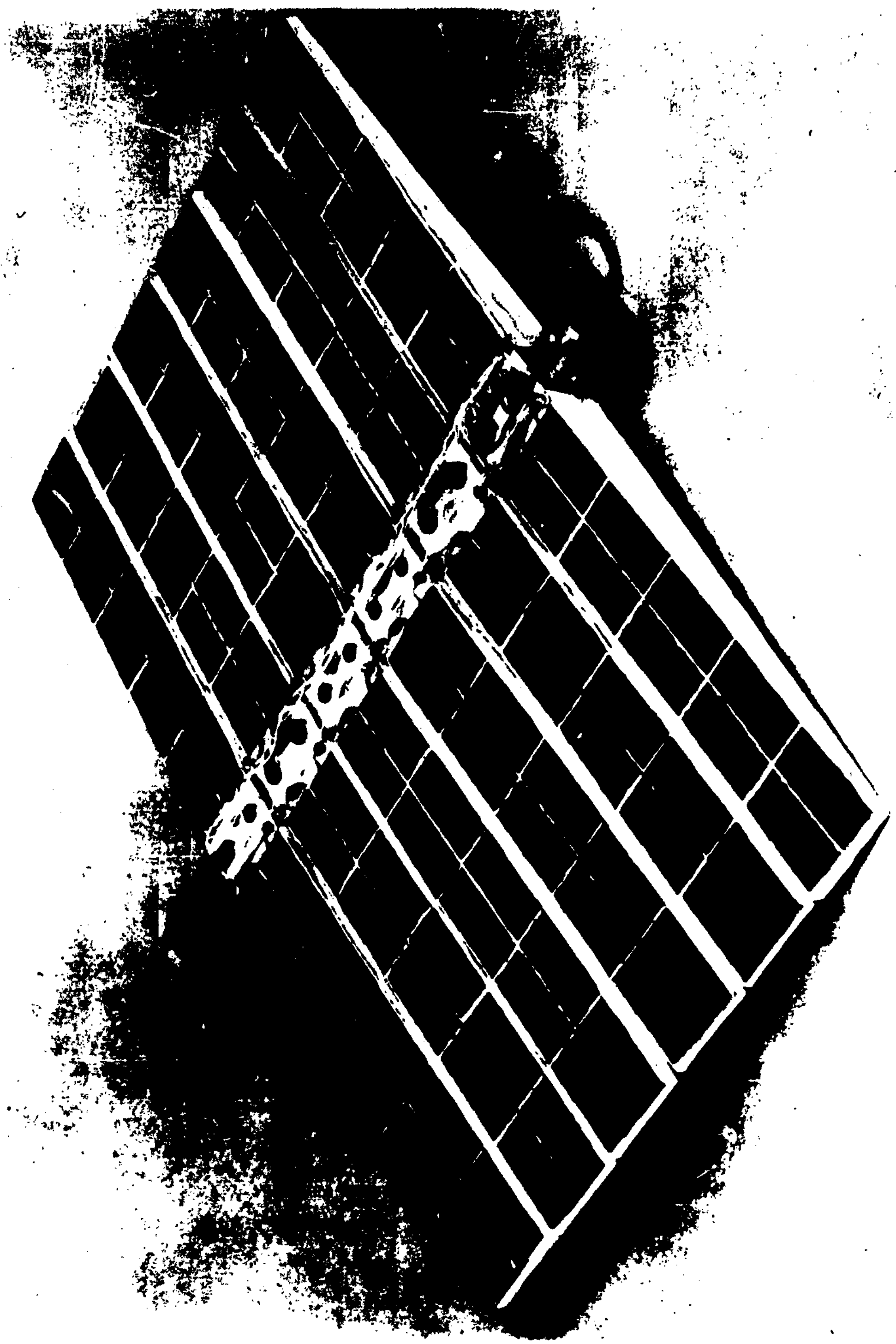

ARRAY
EXTENSION
SIMULATOR
ARRAY EXTENDING
ARRAY FULL OPEN

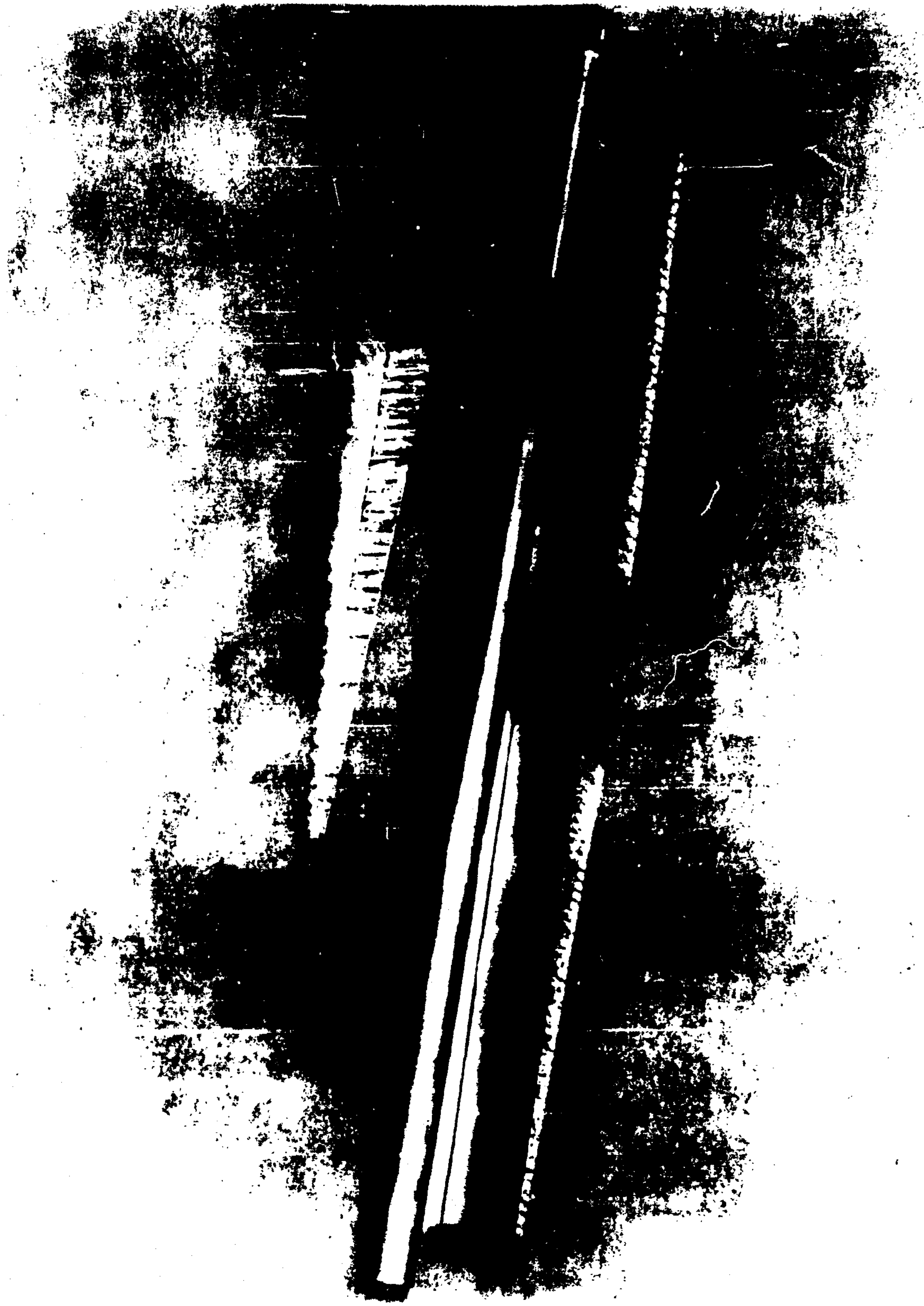


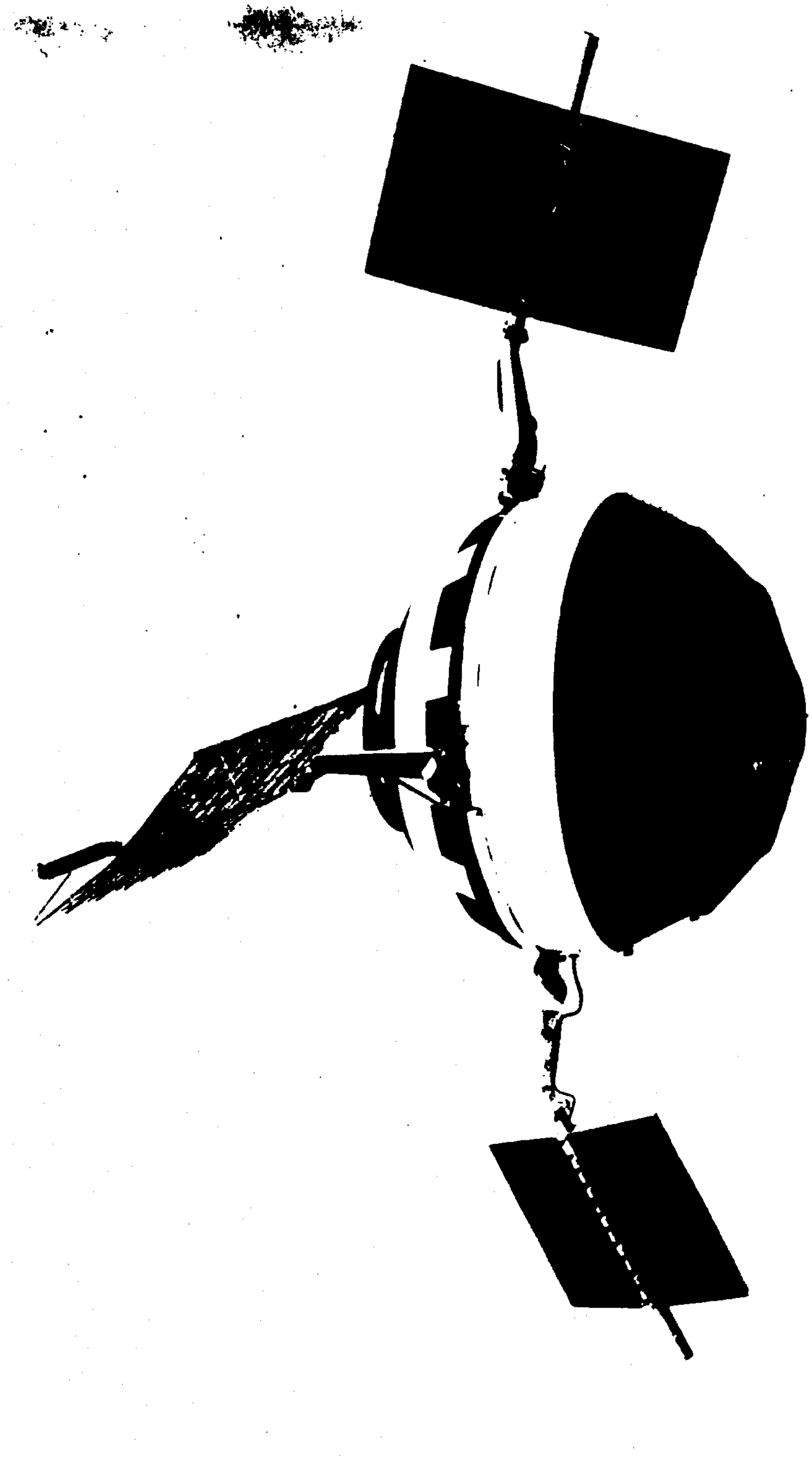
APPENDIX B-3

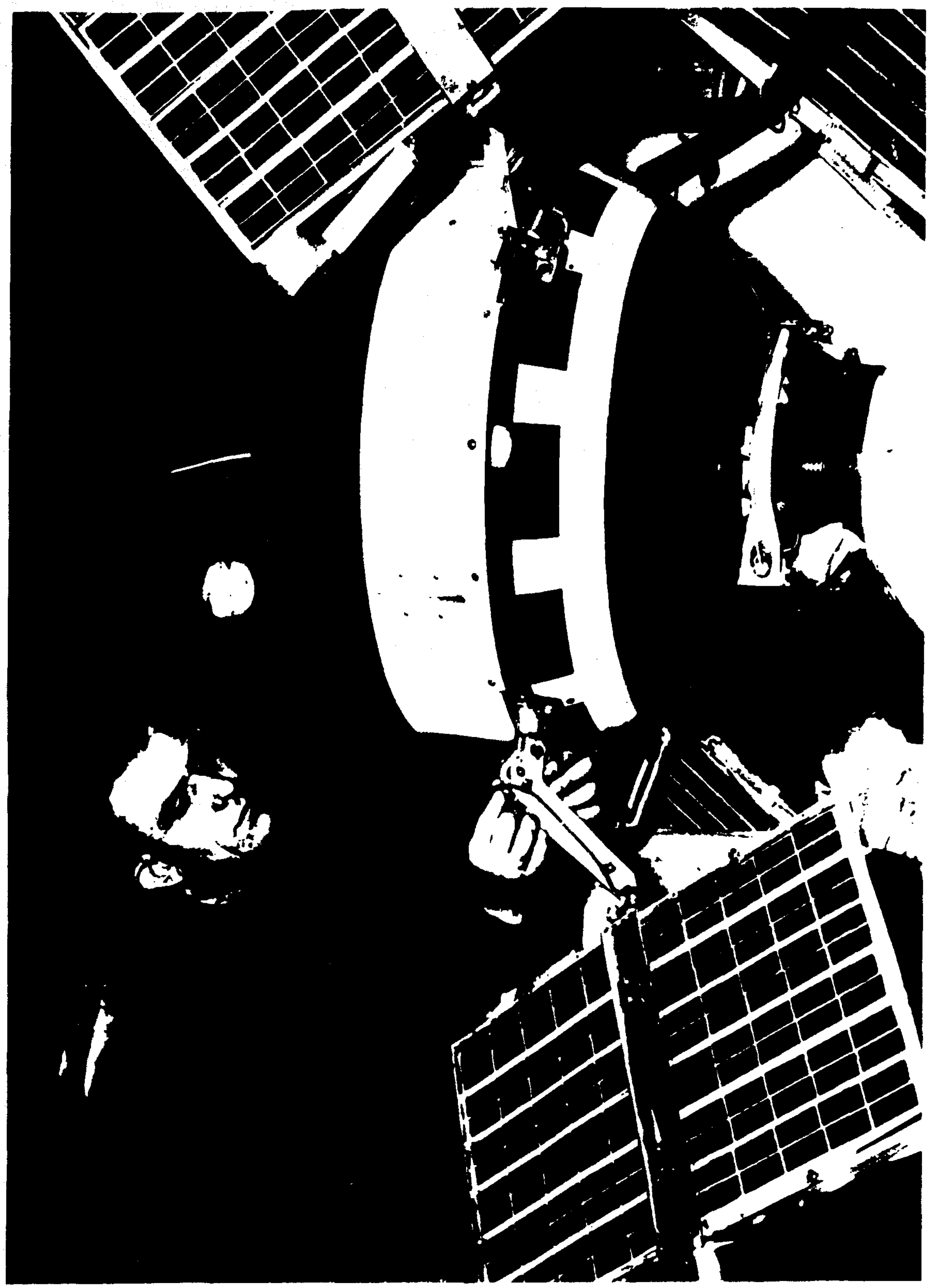
FABRICATION OF SOLAR POWER SUPPLY
ABLE-3

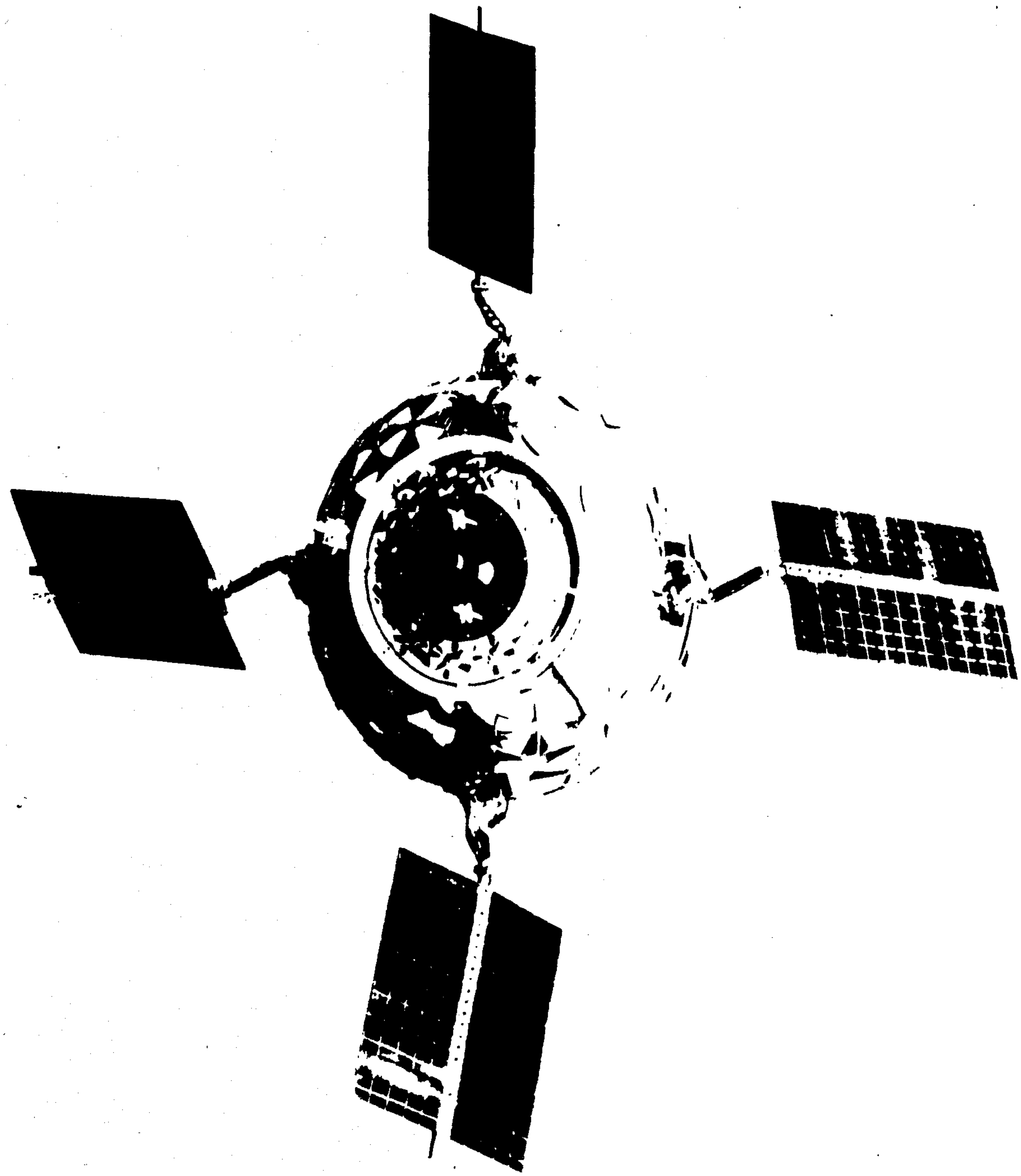


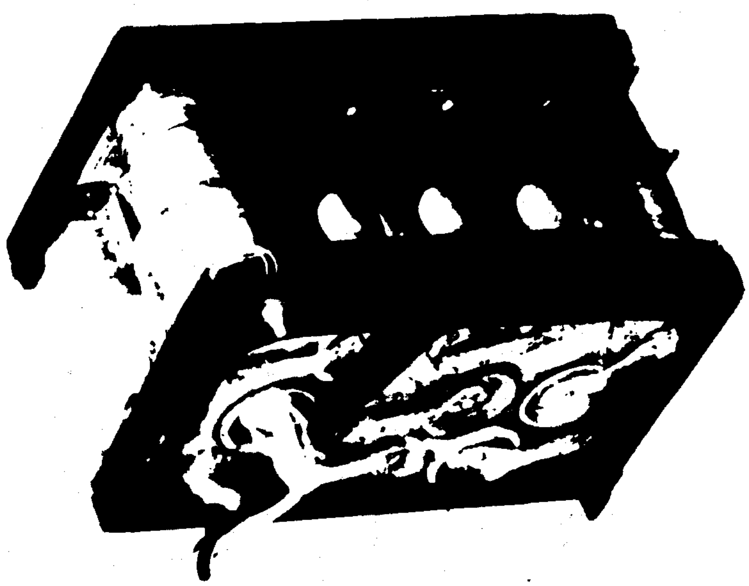




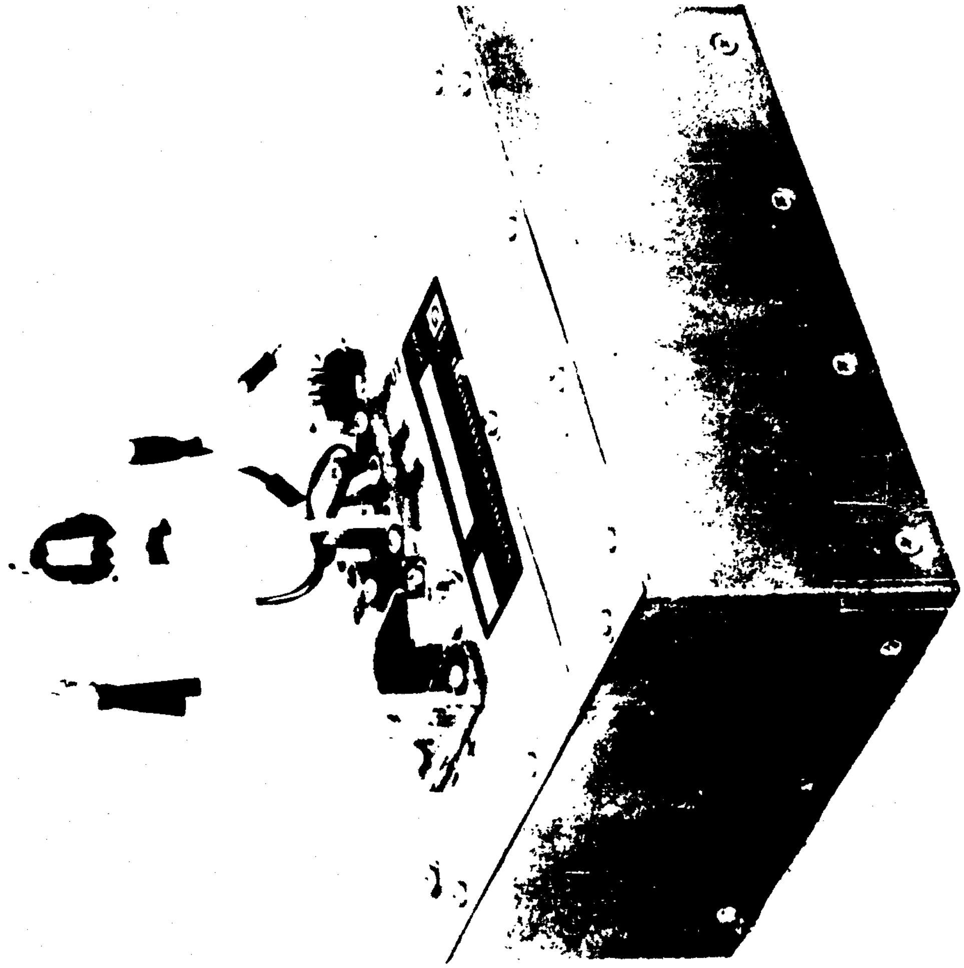


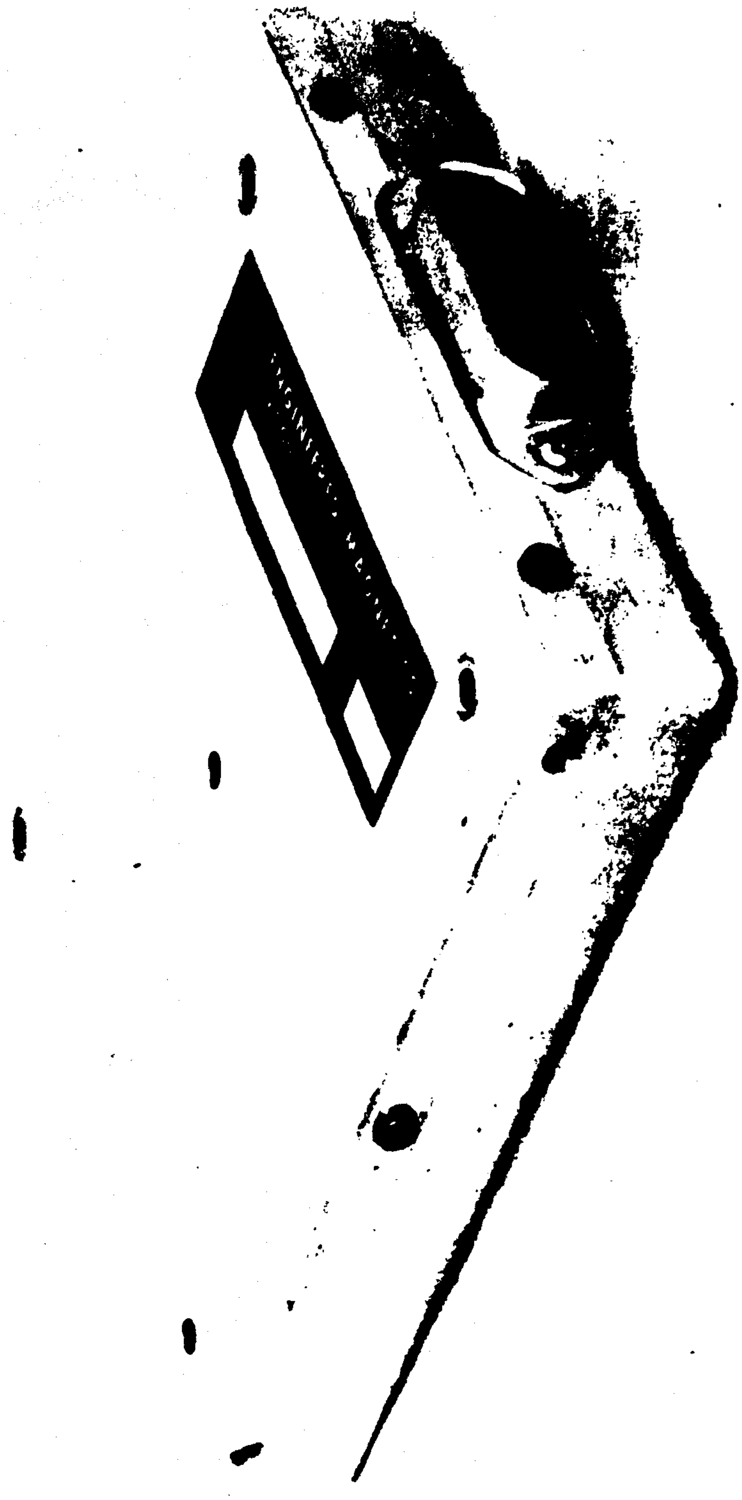


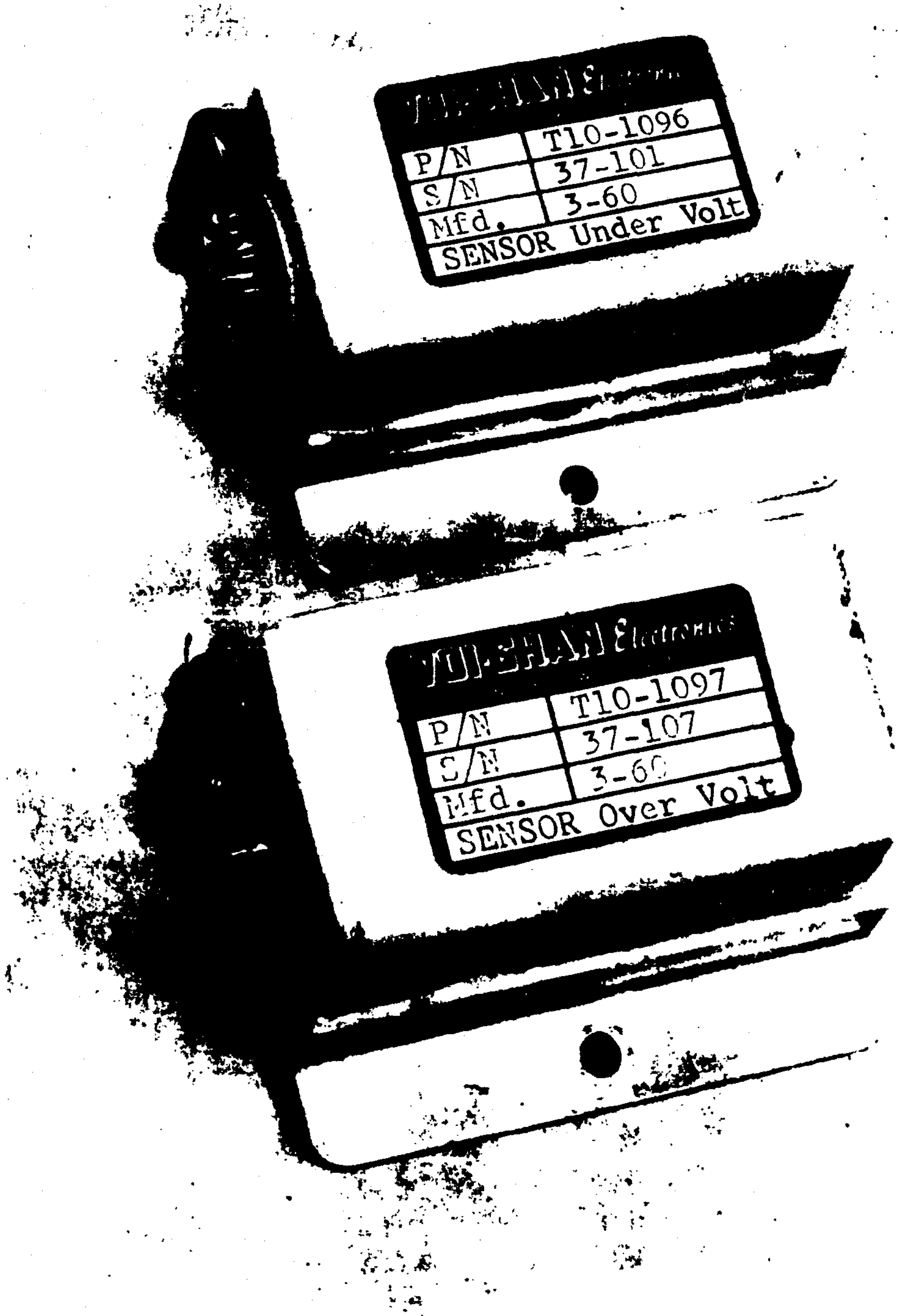


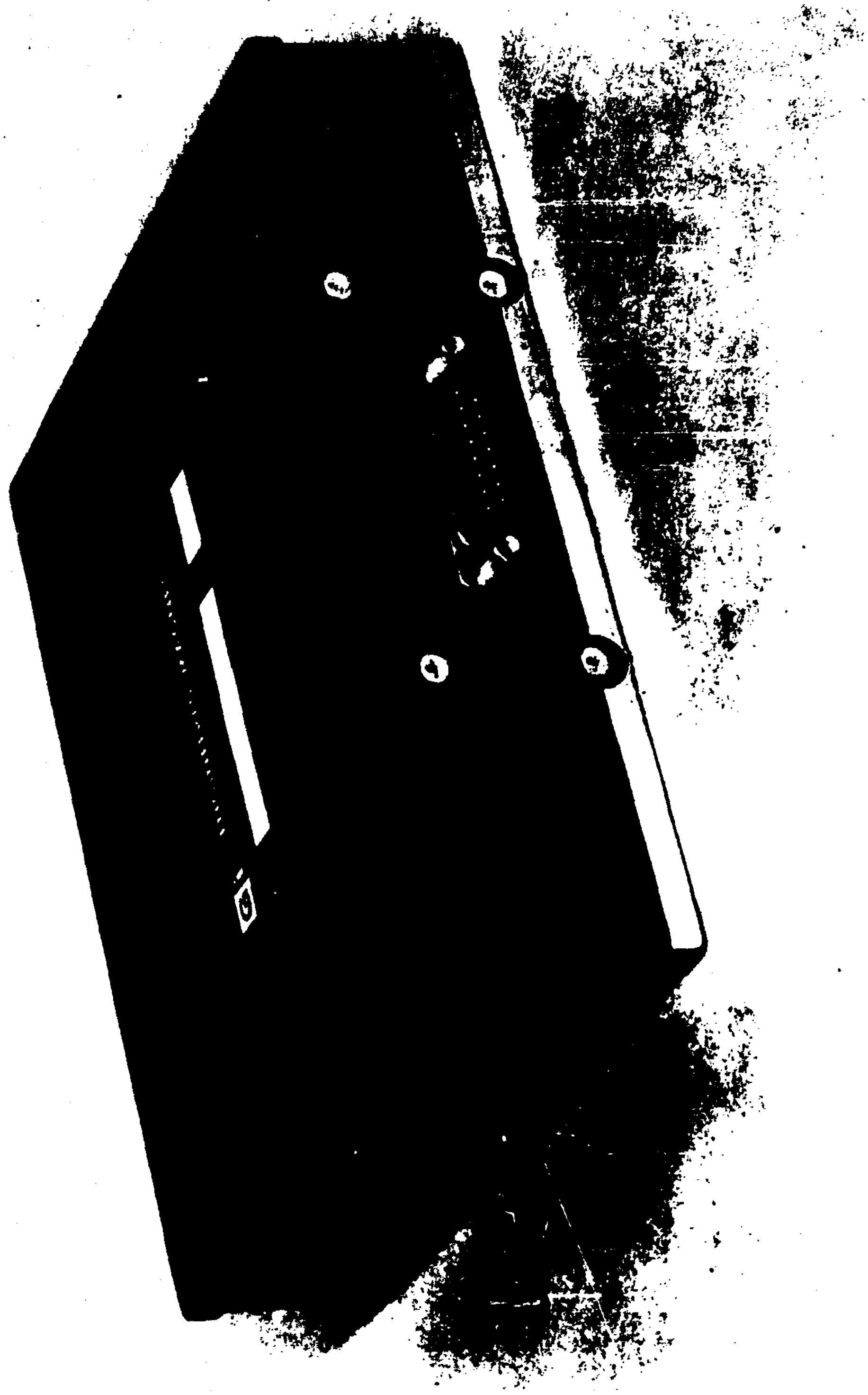



SPACE TECHNOLOGY LABORATORIES
S/N
S/N
P/N
P/N

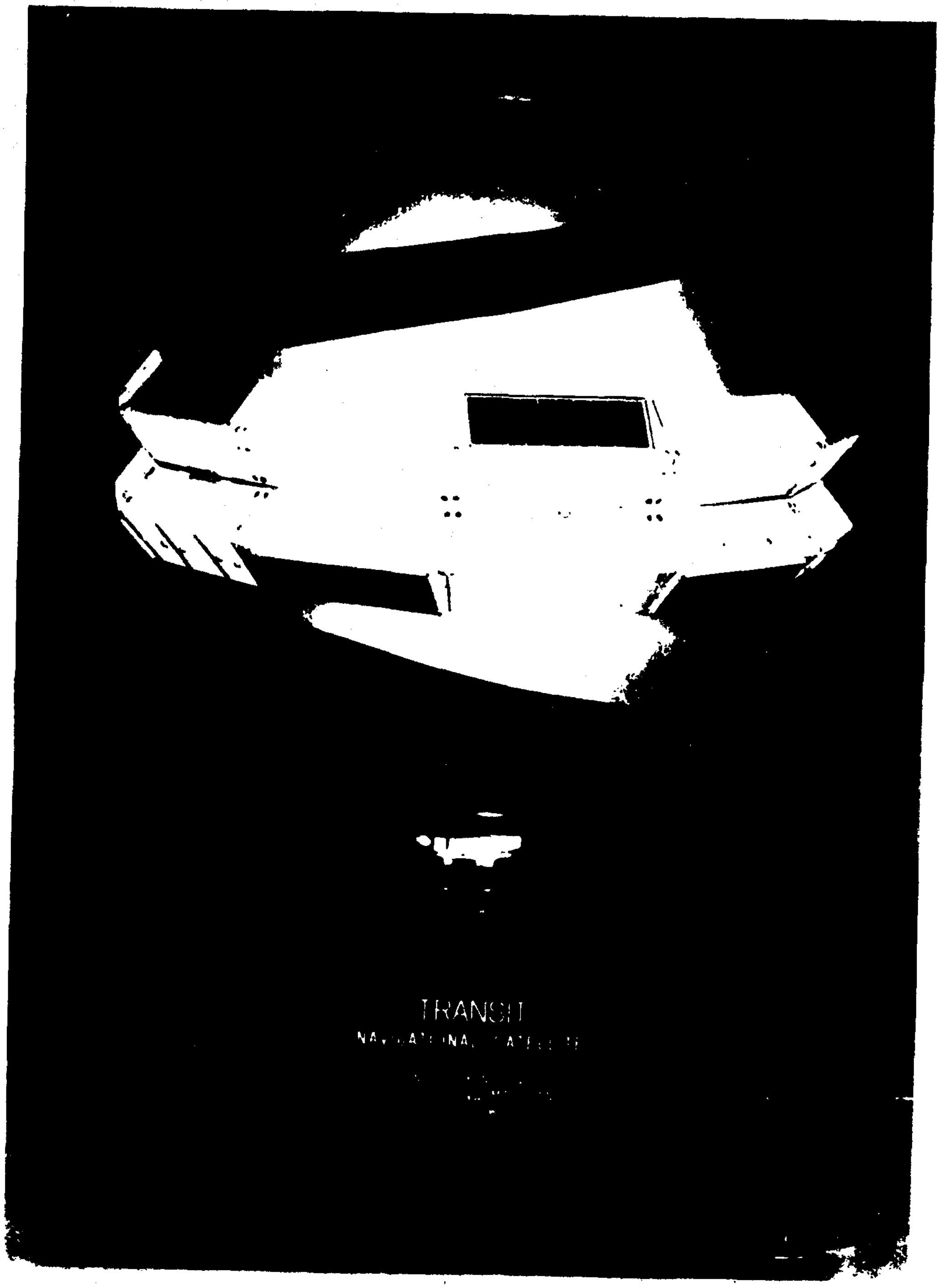





TUI-SHAN Electronics
P/N T10-1096
S/N 37-101
Mfd. 3-60
SENSOR Under Volt
TUI-SHAN Electronics
P/N T10-1097
S/N 37-107
Mfd. 3-60
SENSOR Over Volt



APPENDIX B-4



TRANSIT SATELLITE ON VIBRATION TABLE

FIGURE 1

Pg.4
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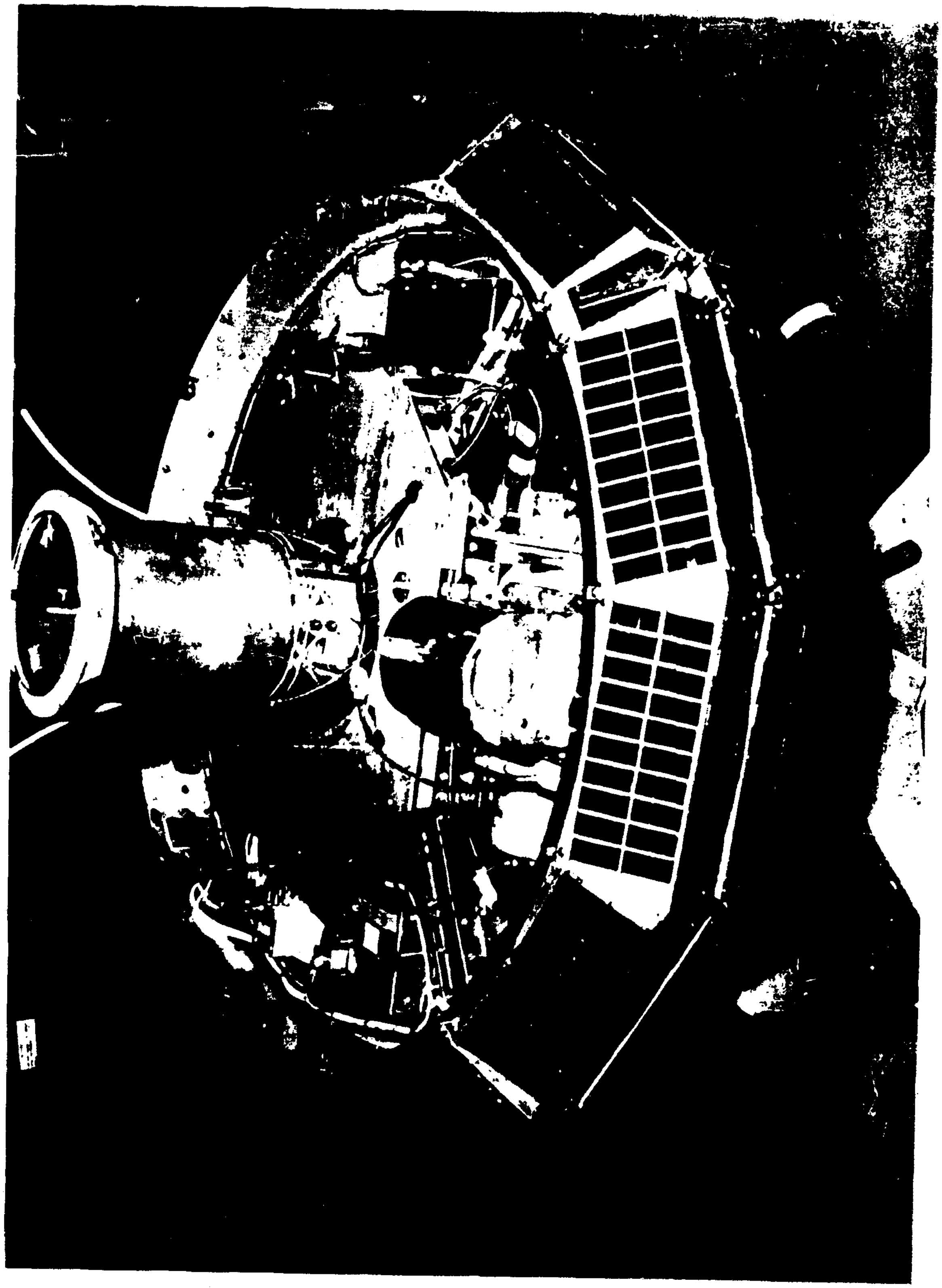

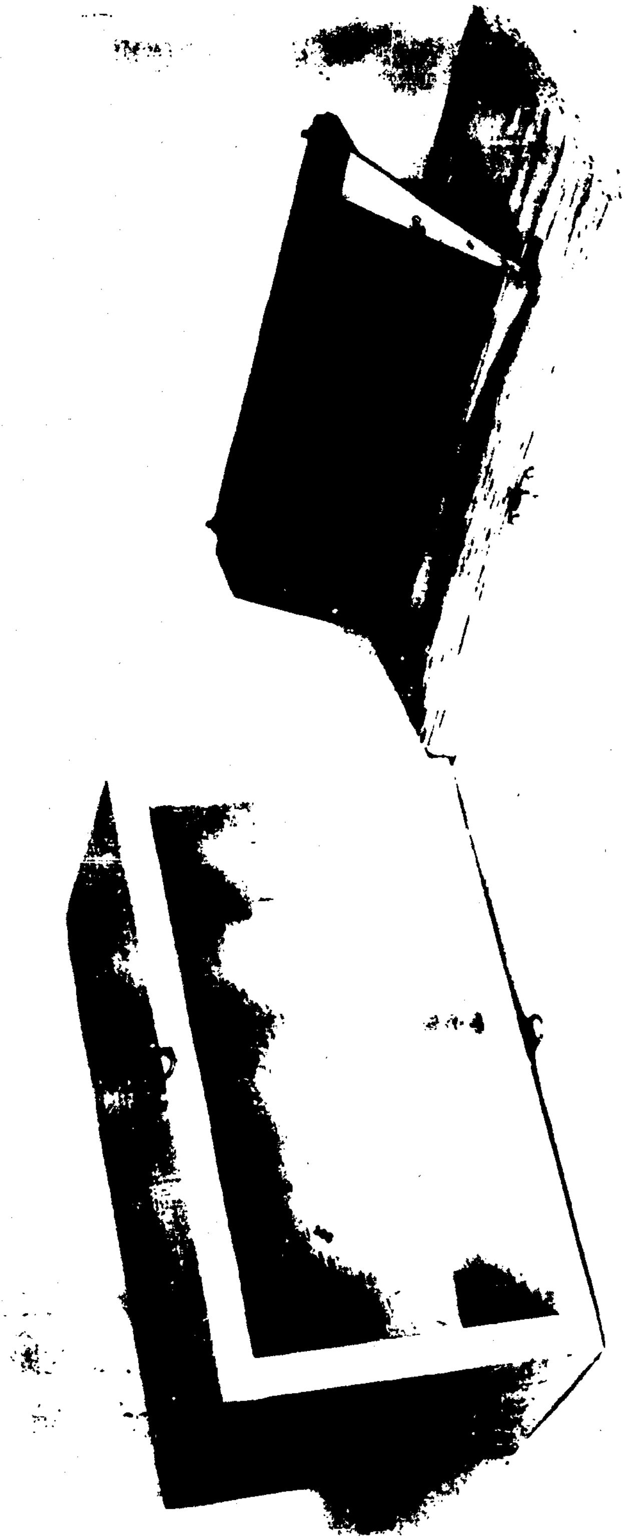

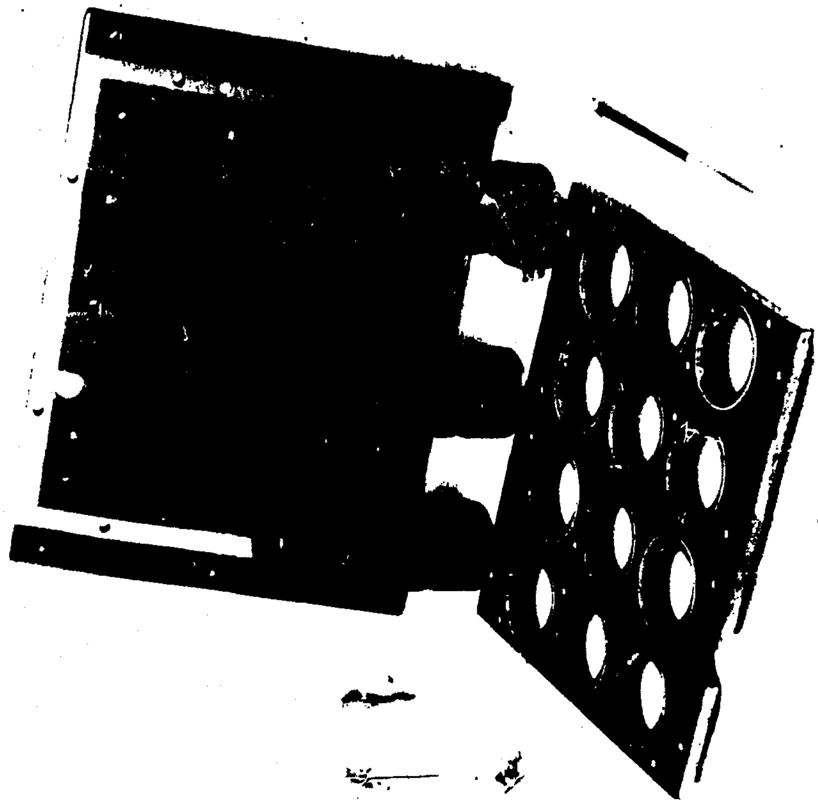

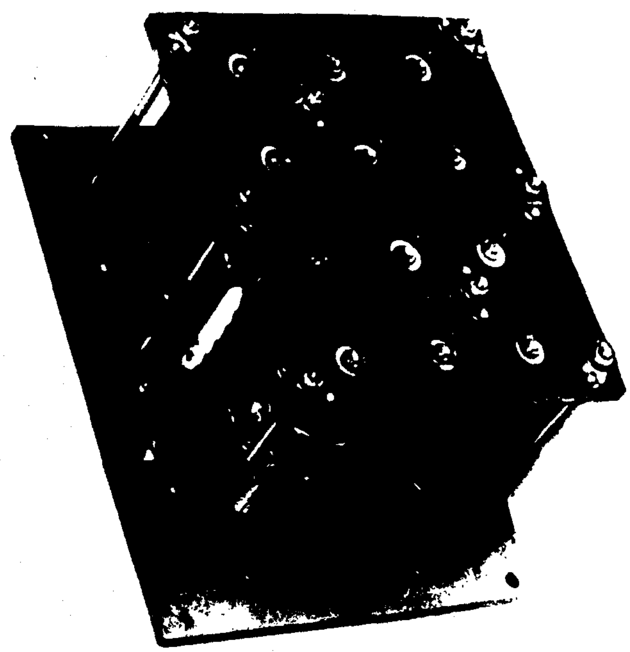

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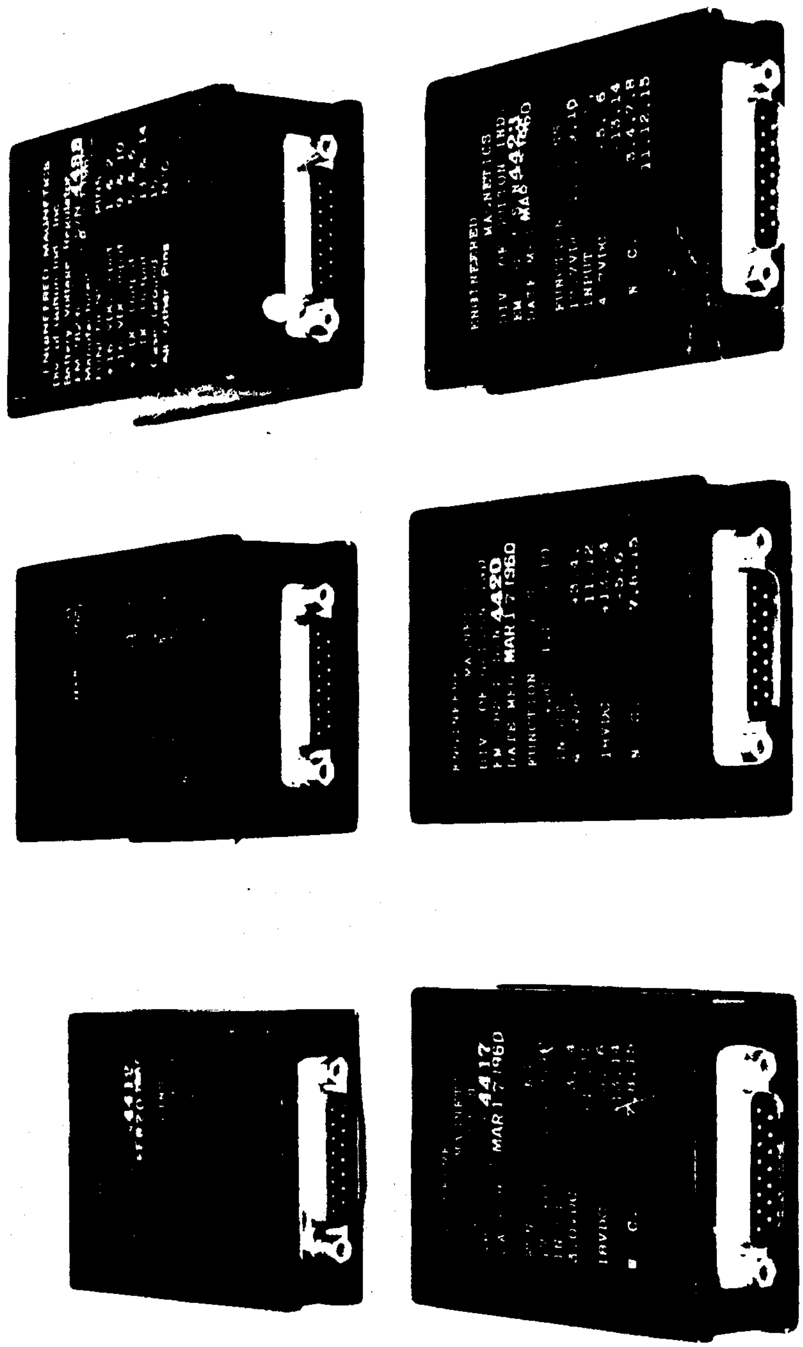

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