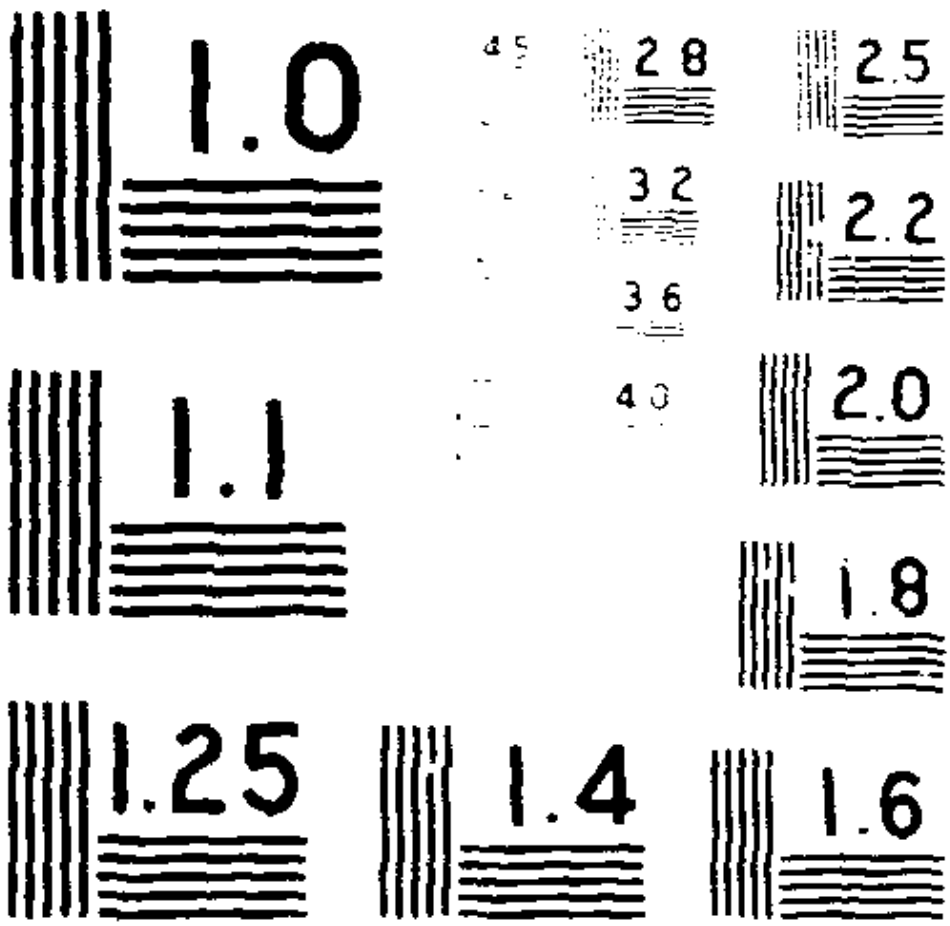

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STUDY TO ESTABLISH CRITERIA FOR A SOLAR CELL ARRAY FOR USE AS A PRIMARY POWER SOURCE FOR A LUNAR-BASED WATER ELECTROLYSIS SYSTEM

MONTHLY PROGRESS REPORT NO. 1
SEPTEMBER 15, 1967

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Prepared for:

National Aeronautics and Space Administration
George C. Marshall Space Flight Center
Huntsville, Alabama
Contract No. NAS8-21189

1. INTRODUCTION

This is the first Progress Report for the "Study to Establish Criteria for a Solar Cell Array for use as a Primary Power Source for a Lunar-Based Water Electrolysis System" and covers activities from July 1, 1967 to August 31, 1967.

2. GENERAL

Contract No. NAS8-21189 was issued by NASA/MSFC (E. Lyons; PR-SS/D) to TRW INC./TRW Systems Group on 29 June 1967. Signators were Lawrence Garrison for NASA/MSFC and John P. Benjamin for TRW INC. This is a 12-month study commencing with the date of contract initiation. It is a Cost-Plus-Fixed-Fee Contract and details are included in NASA Form 437 with Control Number DCN 1-7-40-79268 (IF) and SI (IF) applying.

One (1) copy of NASA 553 Financial Report for the month ending 28 July 1967, was submitted to the NASA/MSFC Contract Office.

TRW Letter SNO 9681.000; 1330.4-7717, of 10 August 1967, was transmitted to Daniel E. Lyons/PR-SS, transmitting one (1) copy of the Technical Plan (TRW Document No. 7440-62) for the contemplated study effort in accordance with contractual requirements. In addition, five (5) copies were submitted to Jim Miller (Principal COR-Astrionics Laboratory) for review and concurrence.

At NASA/MSFC invitation, John Boretz (TRW Systems Study Manager) attended the NASA/MSFC-Astrionics Laboratory Research Achievements Review No. 9 on 27 July 1967. State of the art data on batteries, fuel cells, solar arrays and power conditioning was presented. The results of this meeting are to be compiled and published in September 1967.

At NASA/MSFC request, John Boretz attended a kick-off meeting at Chrysler Aerospace Division, Huntsville, on 28 July 1967. In attendance was NASA/MSFC (R. J. Boehme, W. H. Goodhue, J. L. Miller, W. L. Crabtree), Chrysler (G. Offik, D. Ogden) and Allis Chalmers (R. Costa). This was essentially a meeting to become acquainted and define study area responsibilities. The concept of the Electrolytic Reactants Production System (ERPS) was discussed. It was agreed that by 4 September 1967, Chrysler would

supply detailed ERPS requirements to all the attendees as a baseline system for conducting this study.

An additional meeting was held at the NASA/MSFC Astrionics Laboratory on the afternoon of 28 July 1967. Dick Boehme, Jim Miller and Larry Crabtree of this laboratory were present. The approach to the "Lunar Surface Power System" study was discussed briefly. It was agreed that a more detailed discussion must await the publication of the Chrysler ERPS requirements. However, TRW Systems (John Boretz) indicated he would submit his Technical Plan on 15 August 1967, per contractual requirements and would visit NASA/MSFC in Huntsville on 21-22 August, to review this document.

A meeting was held with NASA/MSFC Astrionics Laboratory (Jim Miller, Larry Crabtree, Alton Morgan) on 22 August 1967, to review the Technical Plan. The results of this meeting are described later in this report.

A meeting was held with Chrysler Aerospace Division, Huntsville (George Offik; Dexter Ogden) on 22 August 1967, to exchange information regarding the ERPS requirements. The results of this meeting are outlined later in this report.

A meeting was held with Allis-Chalmers, Milwaukee (Ray Costa, Terrence Davis) on 23 August 1967, to obtain performance information on the 2 kw alkaline fuel cell under development at this company. The results of this meeting are outlined later in this report.

3. PROGRESS DURING CURRENT REPORTING PERIOD

3.1 TECHNICAL PLAN REVIEW

A preliminary review of the study Technical Plan by Jim Miller (Astrionics Laboratory COR) and his staff resulted in the following comments:

(a) The work pertaining to Mission and System Analysis (Work Unit 2.0) should be de-emphasized and not constitute more than 10 percent of the study effort.

(b) The study is to emphasize the design, deployment and orientation of large solar arrays on the lunar surface. Parametric and preliminary design data are to be generated to investigate such aspects as:

- o array configurations
- o type of array (silicon cell and CdS thin films)
- o light weight supporting structures
- o passive versus active thermal control
- o deployment mechanisms
- o sun orientation articulation mechanisms
- o materials technology
- o impact of the lunar environment on performance.

(c) The study is to identify the design and development requirements associated with implementation of large solar arrays. These are to include:

- o Identification of specific development tests needed to establish the adequacy of the solar array design. This could include assessment of temperature effects, radiation damage effects, micrometeorite damage effects, voltage drops, power conditioning requirements, etc.

- o Establish surface finish, friction factor and lubrication requirements for operating deployment and orientation mechanisms on the lunar surface.

- o Determine requirements for solar array material selection and fabrication techniques.

- o Investigate cabling requirements to minimize voltage drops and at the same time not impose excessive torques at deployment hinge points.

(d) The determination of the requirements for the secondary Electric Power System (SEPS) is to be de-emphasized during this fiscal year.

Final comments to the Technical Plan will be provided by Mr. Miller during his planned visit to TRW Systems on 14 September 1967.

3.2 ELECTROLYTIC REACTANTS PRODUCTION SYSTEM (ERPS) COORDINATION

The coordination meeting with Chrysler Aerospace Division consisted of the following:

(a) A preliminary review of typical power profiles for ERPS and their compatibility with non-oriented, flat surface, solar arrays.

(b) A discussion of a tentative new nominal mission (30 day stay time - 3 men) subject to the approval of NASA/MSFC. This mission appeared more consistent with the NASA/MSFC-sponsored MIMOSA study.

(c) A discussion of the Saturn V payload capability with a direct ascent mode logistic payload capability to the lunar surface of 10,600 kg. assumed. This payload would consist of:

- o 2 LEMS
- o 1 ERPS (4000 kg. weight estimated)
- o 1 Trailer (to transport solar array)
- o 1 - 50 kw solar array (2500 kg. weight allowance)

(d) A preliminary discussion on solar array performance and deployment. Various questions posed by Chrysler were answered during the meeting and subsequent telephone conversations following the meeting.

(e) Preliminary life requirements for the solar array were specified as:

- o Standby 4000 hours
- o Operation 6000 hours
- o Total life 10,000 hours

(f) For a 50 kw array supplying power to a 25 percent ERPS cycle efficiency system, Chrysler envisioned a need for 27 kw of dc power for the electrolysis process and approximately 23 kw of ac power for the reactant liquefication and storage process. This size system would be capable of processing 5.18 kg/hr of reactants.

Finally, Chrysler advised TRW Systems that the overall ERPS requirements would be submitted to NASA/MSFC on 4 September 1967, and after their

review and approval, would be sent to us for use as a baseline system for our solar array concepts.

3.3 FUEL CELL PERFORMANCE COORDINATION

The coordination meeting with Allis-Chalmers consisted of a review of the performance and development status of their 2 kw alkaline fuel cell. Basic data supplied was as follows:

o System rating	2 kw (continuous)
o Overload capacity	3 kw (up to 1 hour)
o Current density	200 amps/sq. ft. (@ 2 kw)
o Weight (with inverter)	169 pounds
o Weight (without inverter)	161 pounds
o Envelope dimensions	21"w x 32"l x 14"h
o Specific weight (dry)	approx. 80 lbs/kw
o Energy to warm up from 0°F	1 kw-hr
o Nominal Operating Temperature	200°F
o Voltage output	28 vdc $\pm$ 1 volt
o Specific reactant consumption	approx. 0.84 lb/kw-hr
o Operation in zero-g environment	no problem
o Acceleration load capability	3g (with higher loads possible if required)

Since Allis-Chalmers is a subcontractor to Chrysler on the ERPS, discussions on the electrolysis process were deferred at this time, pending Chrysler's evaluation and approval of Allis-Chalmers recommendations.

3.4 MISSION AND SYSTEMS ANALYSIS (Task 2.0)

Several analyses were conducted during this reporting period to provide support data for solar array configuration selection and preliminary design. These consisted of the following:

(a) A trade-off analysis was conducted for eight (8) solar array configurations. For each configuration the following was determined:

- o diurnal power profile
- o Total integrated power (for one lunar day)
- o relative array weight (fixed flat surface = 1.0)
- o relative solar cell area (fixed flat surface = 1.0)

(b) An analysis was made to evaluate the merits of various power systems to perform the missions specified. (Paragraph 2.4.7 of Appendix B of PR-DCN 1-7-40-79268) Specific systems compared were:

- o Solar Array and Secondary Batteries (without ERPS)
- o Solar Array, Fuel Cells and Initial Reactants (with ERPS)
- o Fuel Cells and Transported Reactants (without ERPS)
- o Solar Array (Base Power only), Fuel Cells and Transported Reactants (without ERPS).

Primary batteries and solar dynamic systems were investigated also, but found not to be competitive with solar arrays in the power levels of interest.

(c) An analysis was made to evaluate the use of solar arrays in conjunction with fuel cell powered lunar surface vehicles to determine potential reduced reactant consumption requirements. Equations were derived to show the range of applicability of this concept for lunar surface exploration with and without ERPS. The results were plotted in non-dimensional form.

(d) Because the fixed lean-to solar array configurations looked attractive from a relative weight standpoint, an analysis was made to determine if it was practical to consider manual deployment of these arrays (up to 50 kw) without exceeding the "moderate work" level (approximately 1500 Btu/hour) permissable for astronauts working in space suits. Results indicated that 4 astronauts could erect a 10 kw array in approximately 2 hours. Approximately 3 hours would be required for a 50 kw array.

3.5 POWER SYSTEM SYNTHESIS AND DESIGN (Task 3.0)

The main activity during this reporting period for this task has been the compiling of the latest state-of-the-art (SOA) data regarding high energy batteries, fuel cells and RTG's. This data is being organized in both tabular and graphical form. Extrapolations for improvements in the SOA as a function of calendar time is also being carried out. Upon receipt of the Chrysler ERPS power profile and other related mission data, an evaluation will be made as to the best approach to be taken for providing power for the Energy Depot during the lunar night.

Data is also being obtained from Atomics International concerning the performance and development status on their 20 to 30 kw nuclear thermionic

system. This information will be compared with current and projected performance on solar arrays.

3.6 SOLAR ARRAY SYSTEM REQUIREMENTS (Task 4.0)

Several investigations have been conducted during this reporting period to provide a basis for establishing solar array requirements. These consisted of the following:

(a) A survey was conducted to obtain the latest data available pertaining to the lunar surface environment. This information has been compiled to provide a baseline lunar environmental model for this study. Parameters encompassed by this survey include:

- micrometeorites (Surveyor data)
- radiation (particle)
- solar radiation
- solar wind
- temperature
- pressure
- ultraviolet levels
- vacuum level
- atmospheric constituents
- lunar surface allowable bearing pressures
- erosion rate.

(b) A survey was conducted to obtain the latest state-of-the-art information pertaining to solar array materials. This information included:

- solar cells (single crystal silicon and thin films)
- cell covers (α, ε)
- cover adhesives
- interconnections
- dielectric insulations
- cell adhesives
- array support structures
- wiring
- thermal coatings (α, ε)
- mechanism lubricants
- miscellaneous applicable materials

Utilizing the data obtained above, an analysis was made of the effects of the lunar environment on selected array materials. Significant changes in material properties as well as degradation as a function of time were identified. An interim preliminary report was prepared and is to be used as a guide in the conceptual design of the selected solar array design.