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SERI Materials Branch Semiannual Report

**January 1, 1978–
June 30, 1978**

SERI

**Materials Branch Staff
Dr. Barry L. Butler, Chief**

Solar Energy Research Institute

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Golden, Colorado 80401

A Division of Midwest Research Institute

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SERI MATERIALS BRANCH
SEMIANNUAL REPORT

For the Period
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U.S. Department of Energy
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PREFACE

This report was prepared in compliance with Contract Number EG-77-C-01-4042 for the Division of Solar Technology of the U.S. Department of Energy. This report summarizes the progress on Tasks 3102 through 3114 of the Materials Branch of the Research Division of the Solar Energy Research Institute (SERI), a division of Midwest Research Institute.

The purpose of this report is to provide information on the status of materials research activities at SERI. These activities support the Department of Energy (DOE), Energy Technology and Conservation, and Solar Applications programs. The results of preliminary materials program planning activities, laboratory planning, and progress on research projects are included. This report is intended to present the reader with an overview of SERI's materials planning activities in support of DOE and SERI's actual research projects. Detailed information may be obtained by contacting the SERI Materials staff (Appendix I).

This report was prepared by the Materials Branch staff, with the help of many people within the materials community. Special thanks are due to Mr. Michael Lind (Battelle Pacific Northwest Laboratories), Dr. Richard B. Pettit (Sandia Laboratories), Mr. William Carroll and Dr. Marc Adams (Jet Propulsion Laboratory), and Mr. Joseph Richmond (National Bureau of Standards) for aid in preparing and critiquing the national reflector and absorber materials plans.

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ABSTRACT

The Materials Branch has used its resources, now 14 people, to meet the commitments of the FY78 Annual Operating Plan (AOP). Comprehensive program planning, laboratory development, and cooperative research programs with subcontractors are reported. Initial planning has given direction to the materials research activated by SERI. The program planning activities have been consolidated so that the plans for reflector, absorber, and polymer materials research are complementary to each other and support the Branch effort to assess materials limitations in solar energy conversion systems. The planning for a materials laboratory to carry out solar materials research is being guided by both the long-range programs mentioned above and by the programs proposed in the FY79 AOP, which has been prepared and sent to DOE. New equipment and General Services Administration (GSA) surplus equipment have been obtained or ordered. Laboratories for housing the equipment have been specified, laid out, and are under construction. Cooperative research contracts have been placed with Clarkson College (black chrome degradation) and the Colorado School of Mines (corrosion electrode development, black cobalt preparation and properties, sorption by desiccants). Negotiations are nearly complete for contracts to survey the properties of new thermoelectric materials, to study more corrosion resistant silver alloys for second-surface plastic mirrors, and to study the UV degradation of selected polymers.

I. INTRODUCTION

From January 1 to June 30, 1978, the permanent staff of the Materials Branch increased from 5 to 14 people. Branch personnel are listed in Appendix I.

The activities of the Materials Branch have been grouped into three major areas: materials research program planning, materials laboratory development, and materials research. Four areas of materials research activity, polymers, coatings and films, surfaces and interfaces, and reliability and standards, were identified in the SERI FY78 AOP and form the basic program. Growth will be guided by the program planning.

The materials research program planning has evolved to provide (1) the Department of Energy and the materials community with a coherent R&D plan for solar materials research and (2) SERI with guidance for in-house R&D based on national solar program needs. Progress on the national materials program plan is moving forward cautiously because a consensus must be reached by the solar materials community on what materials and processes need basic and applied R&D. A list of SERI/materials community interactions is found in Appendix II. SERI has conducted and participated in national meetings on the interactions of materials and designs of solar energy conversion systems. Materials affect system efficiencies, initial capital costs, and operating and maintenance costs of solar systems, and thereby impact life-cycle costs. SERI has undertaken the task of surveying the solar energy conversion technologies to determine the materials limitations placed on solar energy conversion systems. Progress on this task is highlighted in this report. The internal research programs were initiated in a flexible manner prior to the completion of the

comprehensive planning exercise to permit redirection as more insight is obtained.

The laboratory development supports the broad scope of the materials research planning activity. The SERI laboratories are planned to become a center of excellence for solar materials research, but other materials research activities within the materials community are necessary to provide the depth to build a strong national solar materials R&D capability. The disciplines included in the SERI laboratory plan are metallurgy, polymers, glass/ceramics, composites, optical properties, solar simulation and aging, and surfaces. Details of the laboratory functions and layouts are given in later sections.

Research programs have been activated by SERI in the following areas:

1. silvered plastic mirror development, which includes both plastic and silver alloy development;
2. black chrome and black cobalt selective absorbers;
3. corrosion monitoring methods and equipment development for central receiver boilers and distributed systems;
4. water vapor sorption by desiccant materials for cooling systems;
5. thermoelectric properties of pure SiC;
6. solar degradation of polycarbonate and acrylic materials;
7. reliability and materials standards development.

Progress to date on each project is given as well as the problem definition. Since SERI has not been able to occupy its interim laboratories, all of this work is being carried out under contract to SERI. These contracts have enabled the staff of the Materials

II. MATERIALS R&D PROGRAM PLANNING

Progress on materials limitations in solar conversion systems is summarized in this section. Program plans for absorber materials, reflector materials, and polymeric materials are also included.

A. MATERIALS LIMITATIONS

The Materials Branch of SERI is conducting an ongoing assessment of materials problems in all solar energy utilization technologies. Each existing solar technology encounters impediments to wider commercialization for a number of reasons, some of which are traceable to limitations of the materials used in the technology. These limitations include not only basic physical limits of strength, conductivity, absorptance, etc., but also limits of durability, reliability, fabricability, environmental safety, and materials costs. Emerging solar technologies such as OTEC and biomass conversion have potential materials problems which have been evaluated in a more preliminary fashion.

The objectives of this task are to generate a continuously updated catalog of materials limitations, to assess the seriousness of these limitations, and to identify materials research options which can most effectively mitigate the important materials problems.

The subtask objectives involved in the materials limitations assessment are listed in Figure 1. Subtask 2 has been completed. The costs and benefits of mitigating a number of important materials problems are now being estimated.

<u>Subtask Objectives</u>	<u>Activities</u>	<u>Inputs</u>
1. Collection of Information	<ul style="list-style-type: none"> ● Catalog and Classify Materials Properties Limitations ● Analyze Patterns ● Rank Potential for Mitigation 	<ul style="list-style-type: none"> ● Published Data ● Technical Conference ● DOE Contractors ● Solar Users
2. Evaluation and Screening (Subjective)	<ul style="list-style-type: none"> ● Select Problem Areas with High Potential Impact on Solar Utilization ● Identify Related Research Activities ● Select Problem Areas Requiring Additional Research Efforts 	<ul style="list-style-type: none"> ● Research Program Summaries--DOE, DOD, NSF, NASA, etc.
3. Analysis of Benefit/Cost Ratios	<ul style="list-style-type: none"> ● Estimate Cost and Duration of Required Research ● Estimate Potential Benefits of Mitigation 	<ul style="list-style-type: none"> ● U.S. Energy Demands Scenarios ● Market Penetration Models
4. Prioritization	<ul style="list-style-type: none"> ● Prioritize and Recommend Research Based on Benefit/Cost Ratios Consistent with National Program Plans and Funding Established by DOE/HQ 	

Figure 1. Process for Prioritizing Materials Limitations of Solar Technologies

The 10 problem areas selected for the first detailed analysis are listed below:

1. reflector durability;
2. photodegradation of polymers;
3. absorber durability;
4. encapsulants for photovoltaic devices;
5. cost-effective reflector structures;
6. outgassing of polymers, insulation, etc.;
7. corrosion of metals;
8. copper ion degradation of polymers;
9. grain boundary and interface effects in photovoltaic semiconductors;
10. stability of working fluids.

A matrix showing the pattern of impacts to be expected from their mitigation is presented in Table 1. Criteria used in selecting these problem areas for earliest consideration were:

- the applicability of the material limitation to several solar technologies,
- the applicability of the material limitation to solar technologies with expected significant market penetrations,
- the specificity of the material limitation to solar technologies, and
- the probable tractability of the material limitation problem.

TABLE 1
IMPACT OF SURMOUNTING MATERIALS LIMITATIONS

Subsystem Function	Solar Energy Conversion Technology							
	<u>WECS</u>	<u>PV</u>	<u>Bio/Chem</u>	<u>SHACOB</u>	<u>Thermal</u>	<u>OTEC</u>	<u>AIPH</u>	<u>SPS</u>
Concentration	--	XO	--	XO	XO	--	XO	XO
Collection	X	--	--	X	X	--	XO	XO
Transfer	--	--	--	X	X	X	X	--
Conversion	--	X	X	--	X	X	X	X
Storage	--	--	--	--	X	--	--	--
Conditioning	--	--	--	--	--	--	--	--
Control	--	--	--	--	X	--	--	--
Transmission	--	--	--	--	--	X	--	--

X = Technical, Materials Property Limitation

O = Economical, Materials Life-Cycle Cost Limitation

(WECS - Wind Energy Conversion Systems, PV - Photovoltaics, SHACOB - Solar Heating and Cooling of Buildings, OTEC - Ocean Thermal Energy Conversion, AIPH - Agricultural and Industrial Process Heat, SPS - Satellite Power Systems.)

The purpose of Subtask 3 is to quantify the benefits as well as the expected costs of research, so that the estimated benefit/cost ratios can be used to rank the priority of materials research options. Additional problem areas will be analyzed in the same manner as part of the ongoing assessment by the Materials Branch.

B. COATING MATERIALS PROGRAM PLAN

Many potential applications for thin films and coatings exist within the solar technologies. Examples include low surface energy coatings for glazings, antibiofouling coatings for OTEC heat exchangers, specialized membranes for battery and photochemical systems, heat mirrors, and absorber materials. To date the largest R&D investment has been made toward the development of candidate absorber surfaces, and the coating R&D planning has addressed this topic first.

A national R&D plan has been generated by SERI for DOE and is in initial draft form at this time. The plan was drafted with the help of representatives from JPL, PNL, Sandia, NASA-Lewis, and other researchers within the field. The plan calls for developmental activities in four areas: low-cost selective surfaces for passive, flat plate, and low concentration ratio evacuated tube systems; black chrome development for selective absorber applications up to 300°C; development of intermediate-temperature selective surfaces (up to 700°C); and development of absorber surfaces for high temperatures (>700°C). The development activities are goal oriented, and funding will be apportioned according to the cost/performance/reliability impact on the affected technologies. A systems benefit analysis to quantify the relative impacts of the development programs initiated by JPL is being refined by JPL and SERI. At high operating system temperatures and concentration ratios, mirror performance, receiver geometry, and working fluid control must be considered

when making an assessment of the value of developing an improved absorber. The system analysis work indicates that highest priorities should be placed on low-temperature (to 300°C) applications, and higher temperature applications should have lower priorities.

A data base in support of the planning activity which consists of a bibliography of 1,000 references, commercial product information, system performance specifications, and current research programs has been compiled. An orderly classification to make this information readily accessible is being developed by SERI; a mechanism for maintaining state-of-the-art data on absorber surface optical performance and durability is currently being explored.

C. REFLECTOR MATERIALS PROGRAM PLAN

A national R&D plan outline for reflector materials has been drafted and is attached as Appendix III. This plan outline was developed by representatives from SERI, Sandia, Battelle PNL, JPL, and other national laboratories following the Solar Reflective Materials Technology workshop sponsored and organized by DOE, PNL, and SERI. The workshop was hosted by SERI, March 28-30, 1978, in Denver. The proceedings of this workshop are being assembled by PNL.

A more detailed program plan will be developed using the outline shown in Appendix III. Clearly, R&D on reflector materials, substrates, protective coatings, structural supports, mirror attachment, and mirror replacement technology is needed. Further, Materials Branch R&D will be required to extend the lifetime of the mirrors by elucidating degradation mechanisms and limiting degradation using various methodologies.

D. POLYMER MATERIALS PROGRAM PLAN

The report providing a national R&D plan for polymeric materials has been delayed because the cognizant senior scientist is no longer with SERI. The plan is being modified and will be issued prior to the end of FY78. Several significant areas of polymer R&D for solar applications will be highlighted in this report. They include:

- a need to understand and control optical and mechanical degradation mechanisms,
- a need to understand and control water vapor and oxygen permeability of films and coatings,
- the need for standardized testing,
- the need to develop structural polymer matrix composites, and
- the need to quantify the environments in which polymers must perform in solar systems.

The polymer R&D plan was presented to the DOE/OER Materials Sciences Workshop on Polymers, June 27-29, 1978. Comments to improve the plan have been incorporated. A summary of the primary thrusts of the preliminary proposed plan is given in Table 2. The polymer problems associated with heat transfer fluids, thermal storage media, and advanced structural composites for solar structures and flywheels were found to be less important than the results of photodegradation, permeation, and surface degradations. A thorough understanding of degradation processes should lead to new or improved polymer materials for solar applications. Applied R&D is also needed to support the empirical route to new materials. SERI will take the lead role in solar/polymer materials research by focusing the interests and activities of the national polymer R&D community on the solar related problems.

TABLE 2
PRIORITY POLYMER R&D ACTIVITIES RECOMMENDED
TO SUPPORT SOLAR TECHNOLOGY DEVELOPMENT

Basic Studies	Applied R&D	Alternate Materials & Processes R&D
A. Thermomechanical Behavior		
1. Model development to relate chemistry and morphology to physical properties.	1. Mechanical and thermo-mechanical stress response ("creep," fatigue).	1. New materials R&D.
2. Basic visco-elastic behavior.	2. Process fluid dynamics.	2. Fabrication process develop.
	3. Process effects and controls.	3. Abrasion-resistant coatings and bulk.
	4. Moisture and thermal induced strains.	4. Tailored Materials--composites, blends, copolymers, etc.
	5. Hardness.	
	6. Interfacial effects.	
B. Permeability		
1. Model transport of O_2 , H_2O , SO_x , etc.	1. Diffusion and interface transport O_2 , H_2O , SO_x .	1. Barrier coatings and laminated film systems.
	2. Corrosion	
C. Photodegradation		
1. Model photon interaction with polymers.	1. Accelerated/real-time correlations.	1. UV screening materials development and immobilization.
	2. UV screening approaches.	2. Antioxidants.
	3. UV and combined environmental effects.	
D. Surface Degradation		
1. Model dust accumulation, retention and removal.	1. Cleaning methods.	1. Self-cleaning materials.
2. Surface and interface physics.	2. Interface chemistry, physics and mechanics.	

III. MATERIALS LABORATORY DEVELOPMENT

A major objective of the Materials Branch is to conduct research on materials problems in solar technologies to improve performance of solar systems. Successful achievement of this goal requires state-of-the-art laboratories equipped to pursue immediate, evolving, and long-term investigative programs. The interim research laboratories, outdoor test facility, and capital equipment are described.

A. LABORATORY FACILITIES

Laboratories to support solar materials research will include corrosion and compatibility; coatings and films; surfaces and interfaces; mechanical, physical, and thermal properties testing; polymers; optical properties; glass, ceramics, and composites; and accelerated life testing. General support laboratories have also been designed which will provide capabilities for electron microscopy, gas/solids studies, metallographic preparation, optical microscopy, analytical chemistry, and x-ray crystallography.

Staff members responsible for each of the individual laboratories were consulted to determine floor space needs, utility requirements, and special constraints such as vibration isolation, ventilation, temperature control, and water cooling demands. Several meetings were held with the design architect team to convey these requirements and insure their implementation. Representative detailed blueprints which display furniture layout and equipment placement are included in Appendix IV. In total, 21 laboratories (9 research, 12 service) have been planned with the detail shown in Appendix IV. The laboratories provide 7,400 sq ft (60% research, 40% service). Completion of the interim facilities

is scheduled for September 15 through December 15, 1978. In addition to the laboratory space, office space has also been allocated for each of the 24 branch members anticipated by the end of FY79.

B. OUTDOOR TEST FACILITIES

Plans for construction of an interim outdoor field site facility are presently in progress. A proposed solar exposure installation, Figure 2, consisting of three Harrison racks located on a 100 ft x 150 ft lot, will allow life testing, photodegradation, and corrosion studies. Operational readiness is estimated to be September 1978.

To be used in conjunction with outdoor test facilities, on-site indoor laboratory space has also been designed to evaluate electrochemical monitoring systems in steam and/or hot water and to provide a high temperature and pressure environmental corrosion testing facility; see Appendix IV.

C. CAPITAL EQUIPMENT

The Materials Branch capital equipment requirements for FY78 are closely associated with near-term branch R&D tasks, Table 3. At the same time, although each of the requested instruments is deemed necessary for the successful completion of one or more of these projects, all are generally applicable to future research as well.

Operation and performance specifications and price estimates were obtained from appropriate manufacturers to determine which instruments most nearly meet branch research demands. Purchase requests were written on this basis and submitted for approval.

Figure 2. Harrison Solar Exposure Racks (3)--Field on 100 ft x 150 ft Lot

TABLE 3

PRIORITIZED CAPITAL EQUIPMENT

June 12, 1978

<u>Prior- ity</u>	<u>Equipment</u>	<u>Use</u>	<u>Price (\$K)</u>
1	Scanning/Transmission Electron Mic.	Characterization	188.0
2	Gel Permeation Chromatograph	Polymers	24.2
3	Differential Thermal Analyzer	Polymers	13.0
4	UV-VIS-NIR Spectrometer	Optics	35.0
5	Microgravimetric Sorption Apparatus	Surfaces	38.0
6	Potentiostat (2)	Corrosion	18.5
7	Misc, Reliability Program Equip.	Reliability	6.0
8	Salt Spray Cabinet	Corrosion	1.8
9	Controller, Data Processor, X-Y Rec.	Optics	25.2
10	High Temperature Furnace	Absorbers	6.0
11	Machine Shop Hand Tools	Lab Operation	3.4
12	Machine Shop Drill Press	Lab Operation	1.5
13	Machine Shop Grinder	Lab Operation	0.5
14	Machine Shop Disc/Belt Sander	Lab Operation	0.9
15	Monochrometer	Optics	0.5
16	Vacuum Metallizer	Coatings	11.0
17	Accessories for Gotara Apparatus	Surfaces	10.0
18	IR Spectrometer	Polymers	35.6
19	Special Integrating Sphere for 4	Optics	2.0
20	Solar Simulator/Weatherometer	Reliability	<u>14.3</u>
	Total		435.4

To supplement capital equipment purchases, government surplus lists have been surveyed. Several instruments have been secured, Table 4, and are being prepared for utilization. In addition, expendable laboratory items are being ordered in anticipation of completion of the interim facility and the initiation of research activities.

TABLE 4
GOVERNMENT SURPLUS EQUIPMENT

<u>Apparatus</u>	<u>Manufacturer</u>	<u>Activity</u>	<u>Original Acquisition Cost</u>
1. Atomic Absorption Spectrophotometer	Perkin-Elmer	Corrosion	\$10,000
2. IR Spectrophotometer	Perkin-Elmer	Optics	22,600
3. Ultrasonic Cleaner	Acoostica Assoc.	Characterication	600
4. Balance	Mettler Corp.	Characterization	770
5. Tubular Furnace	Lindberg	Coatings	625
6. Potentiometric Voltmeter	Electro-Science	Coatings	750
7. Lab Oven and Associated Equipment, Assorted Glassware, and Electric Motors		Reliability	1,000
8. Optical Microscopes, Monocular, Triple Nose Piece (2)		Characterization	500
9. Tubular Furnaces and Controllers (4)	Heavy-Duty Electric (furnaces), Wheelco (controllers)	Coatings	12,200
10. Metal Shaper	Smith/Mills	Optics Machining	<u>15,000</u>
Total Value			~ \$64,000
SERI Cost			~ \$ 1,000

IV. RESEARCH PROGRAMS

Several contracted research programs have been initiated by the Materials Branch in known problem areas in solar technologies. The programs have been contracted because the laboratory facilities will not be ready for occupancy until early FY79. The need for major equipment acquisitions precludes the possibility of carrying out significant totally in-house research projects until mid- to late-FY79. These contracted research programs are based on interaction between the relevant SERI senior staff and the contractors. A brief description of each problem, its importance and progress is given in this section.

A. SILVER ALLOY COATINGS FOR POLYMER SUPPORTED REFLECTORS

Many potential applications of solar energy require high temperatures that are only obtainable by using concentrating collectors. High specular reflectance with good durability is desirable in order to maintain high system efficiency. In addition, a low system capital cost also enhances economic viability. Thin film plastic reflectors have high initial reflectance but to date have shown inadequate durability against environmental degradation. A research project to seek more durable metallized plastic reflectors has been initiated by SERI.

A survey of literature revealed that only silver and aluminum had high reflectance across the solar spectrum. Fresh silver coatings have the highest reflectance (0.98) but are environmentally unstable. Aluminum is more stable due to the rapid formation of an Al_2O_3 skin but has a considerably lower reflectance (0.92).

Therefore, in the first phase of this project, the two metals will be alloyed in an effort to maintain, simultaneously, the superior reflectance of silver and the better durability of aluminum.

The initiation of this phase of the research is pending the placement of a contract. The contractor will produce the alloys by cosputtering aluminum and silver in a very clean vacuum system to produce a film with a well-defined gradient in the Ag/Al ratio across the surface of a 25 mm by 75 mm sample. The contractor will also provide metallurgical characterization of the films, and SERI will measure their specular reflectance using a spectrophotometer scheduled for acquisition in FY78. Degradation tests in a weatherometer and subsequent film analysis should enable SERI to determine the optimum alloy composition and preparation that exhibit the best reflectance and durability.

A second phase of this project will be a cooperative effort with the polymer research task to provide more stable and impervious polymer films used both as substrates and protective overlayers for the metal films. In partial support of this phase a Perkin-Elmer Model 521 infrared spectrophotometer was acquired through GSA surplus. The condition of the instrument is presently being assessed to determine what repairs are warranted. Other aspects of the second phase are described in the polymer research sections of this report. Dr. Keith Masterson is the SERI contract collaborator on alloy reflector projects.

B. BLACK CHROME AND BLACK COBALT SELECTIVE ABSORBERS

Black Chrome

Black chrome has the most desirable optical properties as a selective absorber coating for flat plate and linear concentrator systems. Unfortunately, the optical properties degrade in

terrestrial environments at temperatures in excess of 250°C to 300°C. The contract placed at Clarkson College is a first step toward elucidating the degradation mechanism of reactively evaporated black chrome. This program complements the black chrome process development work being carried out by Honeywell and Sandia.

Personnel at Clarkson have invested nearly two years (prior to the contract period) to place the apparatus shown in Figure 3 into operation. With this apparatus, it is possible to reactively evaporate a black chrome film of known thickness onto a substrate, A; to introduce degrading atmospheres to the film from a gas handling station, II; and to heat the film with a furnace, EE. The mass gain by the film is monitored with an inert Czanderna-type microbalance and, simultaneously, the optical transmittance and reflectance are measured as the reaction proceeds.

The apparatus is now being used to study the preparation and degradation of Cu_2S , a photovoltaic material of interest, while several items of equipment are made to adapt the apparatus for black chrome studies. $\text{Cu}_{1.4}\text{S}$ and $\text{Cu}_{1.8}\text{S}$ films have been formed in $\text{H}_2\text{S}/\text{H}_2$ mixtures at surprisingly low temperatures compared with other work; SEM photographs show that the films are sufficiently uniform to provide interpretable optical data.

A standard bell jar vacuum station has been modified to permit black chrome films to be reactively evaporated in oxygen-18 for isotopic labeling. The exploratory depositions of chromium and black chrome have been recently begun. The contract was placed May 1978; the technical collaborator for SERI is Dr. A. W. Czanderna.

A-Substrate, B-Microbalance Beam, C-Field Lens, D-Quartz Disc, E-Transducer, F-Magnetic Compensation Solenoid, G-Piano Wire Probe, H-Translator, I-Amp-
 lifier, J-Servo Motor, K-Helipot, L-Standard Resistor, M-Bucking Voltage
 Source and Recorder, N-Cunife Comp-
 ensation Magnet, O1,O2-Quartz Win-
 dows, P1-P5-Full Silvered Mirrors, Q1-Q3-
 Beam Splitters, R-Beam Chopper, S-Light
 Source, T-Monochromator, U-Motor Drive
 (Wavelength Adjust), V-Polyimide Valve,
 W-Ion Pump, X-PMT Tube Selector, Y-
 Photometer, Z1-Z3-PMT Tubes, AA-Pyrex
 Optical Window, BB-Access Port, CC-
 Push-Pull Deposition Boat Assembly,
 DD-Push-Pull Boat Shield Assembly,
 EE-Furnace, FF-Stainless Steel Bellows,
 GG-Glass Balance Housing, HH-Stainless
 Steel Hangdown Tube, II-Input From Gas
 Handling Station, JJ-DVM Input Selector,
 KK-EVM, LL-Computer, MM-Input/Output
 Terminal.

Figure 3A. Apparatus for Simultaneous Measurement of Mass Change, Optical Transmittance and Reflectance

Figure 3B. Photograph of Apparatus Shown in Figure 3A

Black Cobalt

Black cobalt has potential as a high-temperature ($>650^{\circ}\text{C}$) electrodeposited absorber coating, but insufficient data exist to determine the behavior of black cobalt prepared with optimal characteristics. A contract placed with the Colorado School of Mines (CSM) is designed to explore thoroughly the electrodeposition of black cobalt with a goal of achieving $\alpha_s > 0.95$ and $\epsilon_t < 0.20$ at 650°C . Once this goal is reached the thermal stability and degradation mechanisms of the films will be investigated. Kokoropoulos, et al., [1960] reported no loss in blackness after 26 hours in air at 1100°C . At the present time, no other selective absorber coating has demonstrated suitable characteristics for high-temperature application to external receiver power towers and parabolic dish receivers. Experimental facilities and personnel at CSM are being utilized as well as G. McDonald of NASA. Initial work on the contract, placed in June 1978, is now underway. Dr. P. Call is the technical collaborator for SERI.

C. CORROSION MONITORING METHODS AND EQUIPMENT DEVELOPMENT

Electrochemical evaluation of corrosion parameters within a solar energy system requires stable reference electrodes and reliable monitoring techniques. Suitable electrodes exist for low-temperature, low-pressure (150°C , five bars) applications but stable high-temperature and high-pressure electrodes must be developed. Monitoring systems for flat plate collectors and central power systems are being sought. The use of AC and DC techniques combined with water chemistry and coupon evaluation will be studied. An atomic absorption spectrophotometer has been obtained from GSA to support this work.

To electrochemically determine the corrosion activity within a solar thermal system, a reference electrode capable of providing a reliable output at extreme temperatures and pressures expected in solar heat exchange circuits is required. The Colorado School of Mines, under contract to SERI, is presently evaluating reference electrode systems to determine their temperature and pressure limits of reliability. The contract, to date, has provided SERI with a literature survey in the areas of (1) conventional and solid state reference electrodes for high-temperature/pressure application and (2) autoclave designs for high-temperature/pressure reference electrode testing. Review of the literature has identified the following reference electrode systems as potential candidates: hydrogen electrode, silver/silver chloride electrode, thallium amalgam/thallium chloride electrode, copper/copper oxide electrode, and a doped p type silicon electrode.

Initial electrode evaluation will be conducted in a 1 liter, glass-lined 304 stainless steel autoclave with gas flow-through capabilities. Autoclaves that will allow rapid removal and replacement of the test electrodes are presently being designed and will be employed in the future. Test procedures for each electrode system, starting with hydrogen and silver/silver chloride, will allow for initial monitoring of output signals at ambient temperature and incremental pressures up to 3,000 psi. A pressure of 1,000 psi will then be maintained, and stability of output signals will be monitored up to a maximum of 300°C. Output magnitude and stability for each reference electrode will be compared to those of the hydrogen electrode.

The sponsored research will provide SERI with several calibrated reference electrode systems, with respect to temperature and pressure under static conditions, that will then be evaluated under dynamic conditions using SERI's steam and high-temperature

test loop. The expected goal of the program is to develop and characterize a reference electrode(s) that can be employed for high-temperature/pressure corrosion parameter determination and eventual incorporation into an electrochemical monitoring system.

In conjunction with the desired goal of developing a rapid and accurate monitoring system, Dr. Donald Smith, a consultant from Northwestern University, will work with SERI to determine the potential of digital AC impedance techniques for corrosion monitoring in solar energy systems.

An active interaction has developed between SERI and Sandia Laboratories to investigate and provide materials support for the receiver loop of the 10 MW solar thermal test facilities at Barstow, Calif. Sandia will provide the required material support and proper evaluation of the Incoloy 800 receiver tubes. SERI has been asked to provide materials evaluation of one or more of the preferred backup materials for the receiver tubes. Communications with various private and national laboratories concerning mechanical, environmental, and mechanical/environmental testing of type 625 and 617/Inconel, type 800/Incoloy and type 321 stainless steel have been initiated. Dr. Steven L. Pohlman is the technical collaborator on this program.

D. SORPTION BY DESICCANTS

Desiccants have potential application for solar cooling of buildings, but cheap materials with desirable sorption capacity and absorption and desorption kinetics must be found to permit solar based cooling systems to be cost-effective. A state-of-the-art sorption chromatograph for in-house research at SERI in FY79 is being designed; the necessary capital equipment acquisitions are planned for late FY78. It is anticipated that several months will be required to assemble, calibrate, and learn to use the new

equipment reliably. To secure data immediately, a contract has been placed with Colorado School of Mines (CSM) to study the adsorption and desorption of water vapor by silica gel and zeolites using chromatographic and gravimetric techniques. The exploratory work will provide greatly needed data on the temperature dependence of the kinetics of adsorption and desorption of water vapor from the desiccants selected. The contract is in the final stages of negotiation with CSM; Dr. A. W. Czanderna will be the SERI technical collaborator.

E. SOLAR THERMOELECTRIC CONVERSION

Recent developments in materials have significantly increased the efficiency and durability of thermoelectric generators. The SERI Systems Analysis Branch has assessed potential solar applications of thermoelectric converters and has identified areas of considerable promise. In low-temperature applications, the low cost solar collectors and readily available thermal storage more than compensate for the relatively low conversion efficiency (typically 20% of Carnot). Higher temperature solar applications of thermoelectric converters would be advantageous if a sufficiently durable high-temperature thermoelectric material were available. Silicon carbide has the potential for meeting this requirement.

A contract is being negotiated to assess the potential of SiC for high-temperature solar thermoelectric conversion. The assessment will be based on a unique computer modeling code developed at Naval Surface Weapons Laboratory. It is anticipated that the contract will be placed by the end of FY78 or early in FY79 with Mr. D. Benson as the SERI technical collaborator.

F. UV DEGRADATION OF POLYMERIC MATERIALS

Polymeric materials are widely used as protective coatings or encapsulants for solar devices, but they are susceptible to degradation by the UV component of solar radiation. The purpose of the planned project is to detect the onset of time and temperature dependent UV degradation of polycarbonates and acrylics using the Fourier Transform Infrared Spectrometer (FTIR). A special cell to measure polycarbonate degradation rates under xenon arc exposure at various intensities and times has been designed. This cell can also be placed in the FTIR for polymer surface degradation studies. Dr. A. W. Czanderna will serve as the SERI collaborator.

G. RELIABILITY AND STANDARDS

The reliability and standards task has four major areas of activity. They are:

- develop a national program for corrosion and performance reliability,
- develop a comprehensive materials testing program,
- develop on-line monitoring capabilities,
- develop models for life prediction of components and systems.

The preliminary program plan is outlined in Appendix V. The program stresses system reliability and how materials interact with systems. Failure analysis and preventive monitoring will be used to assess reliability. Principal investigators for this program are Gordon Gross, PE, and Dr. Steve Pohlman.

V. ASSISTANCE TO DOE

Materials Branch personnel have provided assistance to DOE in technical monitoring with consultation in workshops and in planning for standards guidelines.

Technical monitoring support of ongoing DOE contracts in the absorber materials activity within the Advanced Solar Thermal Technology Branch has been provided. This work has consisted of review of progress reports from the seven current contractors and review and recommendation on funding of renewal proposals.

SERI is assisting DOE in establishing optical measurement standards, performance specifications, and process guidelines. Specifically, a review of the electroplating of black chrome on aluminum substrates has been conducted at the request of SHAC R&D at DOE/CS. Two recommendations emerged from this industry-wide review. First, a project is needed to assess directly the durability of such films under accelerated operating conditions and to relate the durability to the process parameters. Secondly, the producer/customer dialogue as to the appropriate coating parameters for a particular application can be assisted by reference to ASTM 456 until the detailed study can be completed.

The Proceedings of the DOE Absorber Coatings workshop, hosted by SERI from December 6-8, 1977, were collected, assembled, printed, and distributed by Dr. P. Call. This 481-page document is serving as a valuable guide for developing the absorber coatings program. Materials Branch personnel also assisted significantly in the Solar Reflective Materials Technology Workshop sponsored and organized by DOE, SERI, and PNL.

Consultation services have been provided directly to DOE or to DOE laboratories on desiccant materials, surface studies, absorber coatings, reflector materials, and in solar technologies.

Although not directly related to assisting DOE, Materials Branch personnel have presented numerous talks on solar energy and in their research specialities and are serving on various international and national committees of professional importance; see Appendix II.

APPENDIX I

MATERIALS BRANCH STAFF, FY78

<u>Position</u>	<u>Person</u>	<u>Background</u>	<u>Active Month</u>
Branch Chief	Dr. Barry L. Butler	Composites, Ceramics, Metals	1/78
Staff	Mr. David K. Benson	Physics, Metals, Materials	8/77
	Dr. Patrick J. Call	Thin Films, Coatings	5/77
	Dr. R. Thomas Coyle	Ceramist	7/78
	Dr. Alvin W. Czanderna	Surfaces and Interfaces	2/78
	Mr. Gordon E. Gross, PE	Math, Physics, Ceramics	8/77
	Dr. Steven L. Pohlman	Corrosion, Electrochemistry	4/78
	Dr. Keith D. Masterson	Optics, Materials	8/78
	Mr. Gary J. Jorgensen	Computer Systems, Programming	1/78
Associate Staff	Mr. Manuel M. Gutierrez	Electron/Optical Microscopy	6/78
	Ms. Teresa A. Fryberger	Chemistry, Corrosion	6/78
	Mr. J. Roland Pitts	Physics, Electronics	6/78
	Mr. John D. Webb	Chemistry, Engineering	5/78
Technicians	Ms. Rita M. Goggin	Polymers	6/78

APPENDIX II

SERI/MATERIALS COMMUNITY INTERACTIONS

National Committees

Material Properties Council (ASM, AWS, ASTM, AIME)

Solar Material Technical Advisory Committee
Chairman - Gerry Slaughter, ORNL
Vice-Chairman - Dave Benson, SERI

ASM Technical Council

Solar Energy Subcommittee
Co-Chairman - Dave Benson, SERI
Pesho Kotval, Union Carbide

ASTM E-44 Committee

Solar Material Standards and Performance
Gordon Gross
Dave Benson

ASHRAE - TC6.7 Technical Committee

Solar Engineering and Applications
Committee Member - Gordon Gross

IITRI - Solar Materials Testing and Reliability Handbook

Review and Evaluation Committee
Chairman - Steve Sargent, DOE
Member - Gordon Gross

Domestic Policy Review

Solar Energy
RD&D Panel Member - Patrick Call

NACE - T-5F Technical Committee

Solar Material Compatibility
Chairman - Steven Pohlman

ASTM E-42 Committee

Ion Scattering Spectrometry
Member - Alvin Czanderna

DOE Conferences on Surface Materials

Steering Committee
Member - Alvin Czanderna

Conferences on Vacuum Microbalance Techniques

Steering Committee
Co-Chairman - Alvin Czanderna

Conferences on Ion Beam Surface Analysis

Steering Committee
Member - Alvin Czanderna

NACE - T-5 Corrosion Problems in the Process Industries

Steering Committee
Member - Steven Pohlman

NACE - T-3L - Technical Committee

Electrochemical Techniques for Corrosion Control
Member - Steven Pohlman

NACE - T-7H - Technical Committee

Corrosion in Boilers
Member - Steven Pohlman

EMACC - Energy Materials Coordinating Committee

Chairman - Robert Reeber, DOE/Geothermal Division
Member - Martin Gutstein, DOE/Solar Division
SERI Support to Solar Division - Barry Butler

DOE Contract Review

Optical Materials and Instrumentation
Reviewer - Keith Masterson

Symposia and Workshop Chairmanships

Coatings Workshop (Patrick Call)

SHACOB - Black Chrome Electroplating on Aluminum - Symposium
(Patrick Call)

Solar Thermal Concentrating Collector Tech. - Symposium
Absorber Materials Workshop (Patrick Call)

Solar Thermal Concentrating Collector Tech. - Symposium
Concentrating Collector Workshop (Keith Masterson)

Metal and Welding Conference (ASM, AWS, ASTM, AIME, NACE)
Solar Energy Materials Symposium (Steven Pohlman)

Solar Thermal Concentrating Collector Technical Symposium
Materials - Fluid Compatibility Workshop (Steven Pohlman)

APPENDIX III

DRAFT OUTLINE OF PRELIMINARY PLAN FOR THE NATIONAL REFLECTOR MATERIALS PROGRAM

I. Management

1. Program Planning
2. Coordination
3. Data Base
4. Information Dissemination

II. Materials R&D

1. Reflector Materials
2. Reflector Substrate Materials
3. Protective Coatings (Front and/or Back)
4. Mirror Support Materials and Structures
5. Mirror Attachment Technology
6. Mirror Refurbishment/Replacement Technology

III. Large Scale Manufacturing Technology

1. Reflector Materials
2. Substrate Materials
3. Protective Coatings
4. Mirror Support Materials
5. Mirror Attachment Technology
6. Mirror Refurbishment/Replacement Technology

IV. Measurement and Standards

1. Intrinsic Mirror Quality
2. Configurational Accuracy
3. Design and Engineering Data
4. Instrument Development and Commercialization

V. Long-Term Performance

1. Performance Prediction Modeling
2. Test Development (Real Time and Accelerated)
3. Degradation Mechanisms
4. Degradation Control
5. Economic Strategy

VI. Other (e.g., Fresnel Lenses, Secondary Concentrator Mirrors, etc.)

APPENDIX IV
TYPICAL LABORATORY LAYOUTS

Figure IV-1. Electron Microscopy Laboratory.

Lab 30'x20'

Figure IV-2. Corrosion and Steam Loop Laboratory

APPENDIX V

PROPOSED OUTLINE FOR RELIABILITY AND STANDARDS PROGRAM SUMMARY

I. PROGRAM DEVELOPMENT

- A. INTERACTION WITH NATIONAL ORGANIZATIONS AND COMMITTEES
- B. IDENTIFY AND PRIORITIZE BASIC MATERIAL PROBLEMS
- C. ORGANIZE MATERIALS COMPATIBILITY AND PERFORMANCE RELIABILITY WORKSHOP
- D. CREATE NEW CODES FOR RELIABILITY AND PERFORMANCE STANDARDS

II. MATERIAL TESTING PROGRAM

- A. ENVIRONMENTAL TEST CAPABILITIES
 - 1. Coupon Exposure Racks
 - 2. Hot Water/Steam Test Loop
 - 3. Weatherometer
 - 4. Salt Spray Chamber
 - 5. Alternate Immersion
 - 6. Commercial Test Facilities

- B. FAILURE ANALYSIS
- C. SURFACE AND BULK SAMPLE ANALYSIS

III. ON-LINE MONITORING

- A. ELECTROCHEMICAL MONITORING
 - 1. Review of Present Techniques
 - 2. Development of AC Techniques
- B. SAMPLING AND/OR INTERNAL COUPON TECHNIQUES

IV. DEVELOPMENT OF MODELS

- A. CORRELATE RESULTS FROM ENVIRONMENTAL, ELECTROCHEMICAL, AND ON-LINE MONITORING
- B. DEVELOP MODELS FOR LIFE PREDICTION OF COMPONENTS AND SYSTEMS

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