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Solar Energy Systems - Survey of Materials Performance

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Materials and Composites Section
Center for Building Technology
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Final Report

Prepared for
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ABSTRACT

A study was performed to obtain data on the performance of materials in operational solar energy systems, to identify and assess available standards for evaluating materials, to provide recommendations for the development of test method standards for materials and to provide guidelines to aid the selection of materials for use in solar energy systems. During the study, field inspections of twenty-five operational solar energy systems were performed and a questionnaire was sent to 459 manufacturers and installation contractors to obtain materials performance data. This report contains the findings of the study. A primary conclusion is that the process of selecting materials for specific applications within solar energy systems is hindered by the lack of an adequate data base of materials performance under the conditions experienced in solar systems and subsystems. Recommendations are made that would help in establishing an improved data base.

1. INTRODUCTION

1.1 Background

Standards for materials used in solar heating and cooling systems are urgently needed to fulfill the goal of the Energy Research and Development Administration's (ERDA) National Plan for Solar Heating and Cooling (ERDA-76-6) [1][1/]. The goal as stated in the Plan is to "stimulate the creation of a viable industrial and commercial capability to produce and distribute solar heating and cooling systems and thereby reduce the demand on present fuel supplies through widespread applications." The systems which are produced and installed must be capable of meeting the expected heating/cooling requirements for the buildings in which they are used and they must perform their functions for an acceptable period of time. Widespread acceptance of solar heating and cooling systems is unlikely to be achieved until adequate performance standards are established and compliance with these standards is demonstrated. The achievement of the goal therefore hinges upon the development of standards that ensure minimum acceptable levels of performance for solar heating and cooling systems.

1/ Numbers in parentheses refer to references at the end of this report.

The performance standards must establish both measurements of initial properties and measurements of long-term properties (e.g. materials properties after in-service or simulated exposure).

Published information on solar systems generally describes the design and performance of the systems with very little information on the materials problems encountered. Exceptions are a number of National Science Foundation reports that did describe operational and materials problems as well as the methods used to correct some of the problems. Unfortunately, most of the systems discussed had not been in operation for long so that an evaluation of the durability/reliability aspects of material performance for any extended period of time was not possible. For those systems that have performed successfully for an extended period, no recent evaluations of their material performance of system efficiency have been made. Although feedback on materials performance in demonstration systems, sponsored by the Department of Housing and Urban Development (HUD) and ERDA, will aid in developing a data base of materials performance, standards are also needed to ensure adequate performance and help in improving the data base.

There is an urgent need to identify needed standards and to develop priorities for their development. This requires assessment of materials performance in operational systems and assessment of available standards that may be useful for evaluating materials used in solar energy systems.

In addition to standards, there is a need for guidelines to aid the selection of materials for use in solar energy systems. These guidelines should provide for identification of information regarding the ability of materials to perform the intended functions and their durability/reliability, safety, maintainability, cost and compliance with local building codes.

1.2 Objectives

The objectives of this study are 1) to obtain data on the performance of materials in operational solar energy systems, 2) to identify existing standards for evaluating materials and to assess the standards in terms of applicability to materials for use in solar systems, 3) to provide recommendations for the development of test method standards for materials and 4) to provide guidelines to aid the selection of materials for use in solar energy systems.

The project plan included a survey of published literature, field inspections of twenty-five working solar energy systems and the sending of questionnaires to manufacturers and installers of solar energy systems requesting information on materials usage and materials problems encountered. It also included studies to identify and assess currently available materials standards that might apply to solar energy systems, identify areas of need for new standards, recommend priorities for the development of new standards and future laboratory studies, and propose guidelines to aid the selection of materials for use in solar energy systems.

2. MATERIALS PERFORMANCE IN WORKING SOLAR SYSTEMS

The field inspection phase of the project included visits to twenty-five active solar system installations. The period of operation for the systems visited was from a few months to over three years. The inspections revealed that many materials problems had been encountered and that field expedient fixes had had to be made. In some cases, no adequate fixes were possible because of basic design deficiencies. In retrospect, it was obvious that design and materials performance can rarely be separated. In most cases, field expedient fixes for failures were accomplished with readily available materials which were not always the optimum solution to a problem. Unfortunately, some of the projects visited, which were sponsored by the National Science Foundation, were built this way originally, i.e. readily available materials were used which did not always perform satisfactorily.

Field inspections of working solar systems revealed materials problems in all major components of the various subsystems comprising solar systems. The emphasis in this chapter is on the materials problems observed rather than those materials that are performing adequately. The four subsystems into which solar systems can be divided are the collector, transport, storage and control subsystems. Control subsystems will not be discussed in the following evaluation of materials problems but the field study revealed that control problems are numerous and could be the subject for a considerable investigation in itself.

The following discussions of observations made during the field investigation cannot in every case be interpreted as evidence of materials "problems" at this time. Although all problems identified are reported, the extent to which some of them will indeed adversely affect the long-term performance of the systems is not known.

2.1 Flat Plate Collectors

Collectors used in active (as opposed to passive) solar systems can be divided into three basic types, i.e. flat plate, concentrating and evacuated tube. The majority of collectors inspected were of the flat plate type (both liquid and air). A small number of concentrating and evacuated tube-type collectors were inspected and these problems will be discussed separately. The following is a list of observed problems for each component of collectors.

Cover Plates (General)

1. Condensation was observed on cover plates of 24 out of 25 systems inspected. The amount and degree of condensation appeared to depend on the time of day and the design of the collector (see fig. 2-1.) Condensation, such as that in figure 2-1, may affect the transmittance of the cover.

2. Deposits were observed on the underside of cover plates that resulted either from condensation (contaminant inclusion) or outgassing products from an internal source (see figs. 2-2 and 2-3.) Such deposits may affect the cover plate transmittance.

3. There was a high incidence of dirt retention of the exterior surfaces of cover plates. Dirt retention appears to be dependent on location of collector array and local geographical conditions (see fig. 2-4.)

4. In one system, there was substantial dirt retention on the underside of the cover plate due to improper sealing. The collectors were purposely not sealed to prevent formation of condensation and allow the collectors to breathe (see fig. 2-5.)

Cover Plates (Inorganic)

1. Glass cover plate breakage, ranging from none to approximately 90% in one system, was observed. The breakage that occurred in the system with 90% failure was a double cover system with both covers broken (see fig. 2-6.)

2. There appeared to be a higher incidence of glass cover breakage on a system that used reflectors on a portion of the collector array as compared to those collectors not subjected to added reflector radiation [2].

3. There was a complete adhesion loss in a system utilizing a heat trap adhered between two cover plates (see fig. 2-7.)

4. A polymeric heat trap, under a glass cover plate, exhibited distortion and decomposition manifested in cover plate discoloration on a system exposed to several months of no-flow conditions prior to activation (see figs. 2-1 and 2-8.)

5. Undersize glass, which was improperly bedded and supported, allowed rain leakage into absorber panels (see fig. 2-9). This resulted in degradation of the absorber and the collector enclosure.

Cover Plates (Polymeric)

1. Excessive warpage was observed in several systems using polycarbonate cover plates (see fig. 2-10.) In one system where standoffs were used to prevent contact of covers and absorber plates, incompatibility between the polycarbonate cover and the ethylene propylene diene monomer (EPDM) standoff was noted (see fig. 2-11). In another system, contact between the absorber and cover resulted in cover plate damage (see fig. 2-12).

2. Stress cracking of polycarbonate cover plates that had been designed with indented sections to provide structural rigidity was observed. Approximately 60 to 70% of the indentations exhibited stress cracking to a greater or lesser extent (see fig. 2-13).

3. Embrittlement resulting in complete failure of all covers in a system using a double layer of thin film poly(vinyl fluoride) was observed. Collectors had been subjected to no-flow conditions for several months due to system failure (see fig. 2-14).

Absorber Coatings (Selective)

In a majority of systems where selective coatings had been in service for a year or more color changes were apparent. The range of color change was from minor discoloration to complete changes that gave the appearance of light tan colors (see fig. 2-15). One system that had been subjected to rain leakage as well as transfer fluid leakage exhibited changes from black to light tan (see fig. 2-16). It is not known, at this time, what affect the color change has on the optical properties. Another system had extensive white deposits on the selective coating that was not possible to identify. These deposits may have been coating failures, effects of outgassing or transfer fluid leakage as a result of corrosion (see fig. 2-17).

Absorber Coatings (Nonselective)

Peeling and cracking of nonselective coatings were observed in several cases. The peeling and cracking seemed to be confined to absorber plate edges (within 2 or 3 inches of the edge) and to the lower portions of the absorber plate (see fig. 2-18).

Absorber Plates

1. Leakage resulting from corrosion has been observed in several systems utilizing aluminum absorber plates with integral fluid flow passages. These observed leakages may not be the fault of the absorber plate itself and the cause of the corrosive action may well originate in some other component of the system (see fig. 2-19).

2. The insulation behind the absorber plates was visible through the cover plates in two of the systems inspected. This condition could result in deterioration of the insulation, excessive outgassing, and certainly reduces the absorber plate effective area. The cause may be attributed to either dimensional tolerances of the absorber plate, inadequate support or fastening of the plate to its supporting frame, thermal changes or creep occurring after installation, or poor workmanship during assembly (see fig. 2-20).

3. Separations of as much as 1/4" occurred between the tubing and absorber plates in two systems that depended on intimate contact of tubing to absorber for transfer of heat to the fluid (see fig. 2-21).

4. Extensive weld failures were observed in one system. The system was of aluminum construction with the inlet and outlet tubing being welded to the absorber plate. Threaded connections were then used to connect the inlet to the transport piping. Overstressing of the weldments during the tightening of the threaded tubing to the transport system was a possible cause for the failures (see fig. 2-22).

5. Instances of warped absorber plates were observed in several systems. Warpage was so extensive in several cases that the absorber plates came into physical contact with polymeric cover plates resulting in cover plate fogging (see fig. 2-12).

Insulation

It was not possible to inspect the insulation used on all systems because most systems are designed to provide protective covers or containment for insulation, but, several problems were recorded with systems that had exposed insulation.

1. Exposed polyurethane foam was used in three of the systems inspected. In each case, deterioration of the urethane, probably due to ultraviolet radiation, was observed (see fig. 2-23).

2. In one case the system utilized fiberglass insulation on the back of the collector with minimal restraint and no cover system. The insulation had separated and sagged away from the back of the absorber plate so that the back of the absorber was easily visible. This same system did not have any edge insulation (see fig. 2-24).

3. A problem of polyurethane insulation swelling had been reported [3] as having occurred at one of the sites visited. Considerable damage had occurred as a result of elevated temperatures that caused the foam to swell affecting other components of the collectors. At the time of the inspection, the collectors had been rebuilt and no further problems were apparent.

Seals

1. At one installation visited, the sealant used between the glass covers and the wood and aluminum collector enclosure was a major problem. The gray-colored (probably butyl) sealants used originally did not permanently seal the joints. The sealant between the inner cover and the wood enclosure was very brittle and lacked adhesion to the substrate. The sealant between the outer cover and either the wood enclosure or the aluminum cross tee was very brittle and had cracked and shrunk due to weather exposure. A number of the glass covers were undersized which meant that a joint of 3/4" to 1 1/2" had to be sealed. Thus not only was an inadequate sealant used but the joints were often impossible to seal with any sealant. The unsealed joints permitted water to penetrate into the collector interior (see figs. 2-9 and 2-25).

2. In another case, a butyl tape was used between the cover plate and enclosure. This design was not meant to seal the enclosure with the thought that "breathing" of the enclosure would eliminate or substantially reduce condensation formation. This lack of sealing however resulted in the deposition of dust and dirt on the interior of the glass covers and on the surface of the absorber plates (see fig. 2-5).

3. One site visited used a silicone sealant between the outer cover plate and the aluminum retaining frame. Workmanship was excellent but potential problems may occur due to a discoloration of the sealant adjacent to the attachment bolts. The discoloration observed may be an indication of material degradation. Apparently a "hot spot" was created by the attachment bolts which is subjecting the sealant to deteriorating elevated temperatures (see fig. 2-26).

4. Outgassing of improperly cured silicone sealant was observed. The outgassing caused fogging of the cover plates (see fig. 2-3).

Enclosure

1. Of those enclosures constructed of galvanized steel or aluminum no materials problems per se were obvious. Design changes with respect to connections and/or joints in metallic enclosures in some cases however could have improved the collectors ability to perform satisfactorily for a longer period of time.

2. In one case, the collectors were made of wooden restraining frames with plywood backing. The painted wood collector frames had deteriorated because the paint coatings had peeled and cracked exposing the wood to the elements. The surface condition of the painted wood in the interior of the collector was worse than that of the exterior membranes. The plywood backing had not been painted and was deteriorating and delaminating due to moisture penetration even though these collector backs were not subjected to direct weathering. The condition of the wood indicated that it will probably require major repair or replacement within 2-3 years (see fig. 2-27).

Structural Support

Those structural support members made of metallic materials seemed to be performing satisfactorily. Of those structural support members utilizing wood construction it was obvious that more maintenance (frequent repainting) would be required to attain the same expected life as their metallic counterparts. On several systems it seemed as though wood was used for low first cost with no regard to long-time durability/reliability.

Reflective Surfaces

Two flat plate collector systems were inspected which used reflective surfaces. Figure 2-28 shows problems observed on one of the reflective systems. The surface irregularity resulted from difficulties in applying self-adhering aluminized film. Subsequent loss of adhesion required the addition of batten strips.

2.2 Concentrating and Evacuated Tube Collectors

Concentrating and evacuated tube collector systems have unique materials design problems when compared to flat plate collector systems because of the much higher temperatures generated in such systems, particularly during stagnation conditions. Component and materials surface temperatures developed in concentrating and evacuated tube systems are difficult to accurately measure; therefore designs must rely on calculated expected limits of temperature.

Of the two concentrating systems inspected, one contained a bank of small follow-the-sun collectors with the other being an experimental system where the entire roof of the building was designed to focus radiation to a moveable tube that was elevated above the roof. Neither system had been in service long enough to have had durability/reliability problems with materials. In both cases, the primary problems were in the controls and the mechanical system used to track the sun (see figs. 2-29 and 2-30).

Two systems utilizing evacuated tube collectors were visited. Of the problems encountered and those described by the owners, the primary cause of failures can most generally be attributed to over temperature of materials or components during operation or during times of stagnation conditions. Problems encountered include leakage, gasket hardening, dimensional tolerances, tube breakage, tube coating discoloration, dirt accumulation in filter tubes, air entrapment, pump cavitation, manifold insulation discoloration, and system operational control problems (see fig. 2-31).

2.3 Transport Subsystems

The greatest single problem encountered in regards to transport piping was the flexible hoses at inlet and outlet couplings of flat plate liquid collectors. At every site visited where flexible coupling hoses were used, leakage problems have occurred to a greater or lesser degree. Causes for leakage have been attributed to age hardening and loss of elasticity, plastic flow of hose materials through slotted holes of gear-type clamps resulting in reduced clamping forces, cumulative slippage of hoses due to thermal movements of collectors and ozone or ultraviolet attack of hoses exposed to weathering. Also, it was reported that it is sometimes difficult to replace collectors that are attached with rubber hoses because of the tightness of the hose/metal bond. Attempts to solve these problems ranged from application of sealants and adhesives to the exterior of leaking hoses to the complete replacement of organic hoses with metallic couplers (see figs. 2-32 and 2-33). Figure 2-34 illustrates a design problem. The hose to collector connection was placed inside the collector enclosure making it difficult to tighten the hose connection or replace the hose.

Several other problems were apparent as regards flexible hose couplings. In many cases the hoses were not insulated resulting in heat losses and weathering deterioration (see fig. 2-35). In one case, where coiled copper connections were used to replace flexible hoses, the insulation at the transport piping was not sealed allowing water to enter the insulation resulting in additional heat losses (see fig. 2-33). At another side, different paint coating systems were used to protect the cellular insulation surrounding the hose connections. In one case, the insulation became embrittled and cracked while the same insulation coated with a different material remained flexible with no damage to the insulation (see figs. 2-36 and 2-37).

On another system (not inspected but described by an installation contractor), a solder joint failure occurred in the transport piping due to poor workmanship. Inclement weather necessitated the system to be drained and secured for several months before repairs could be made. The resulting stagnation conditions caused the cover plate material to fail completely which damaged the absorber plates to the point where the entire collector system had to be replaced.

Another potential problem in piping is the use of dissimilar metals within the system. The use of aluminum, copper and steel pipes in conjunction with galvanized connections, brass and steel valves, and steel or aluminum storage tanks was not unusual. Such conditions can lead to corrosion problems, especially in closed loop systems where metal ions are recirculated. Systems using dissimilar metals must be designed as carefully as possible taking into account the area ratio of one metal to another so that the proper inhibitor materials can be added and periodically adjusted to reduce corrosion to a minimum.

Pump problems were encountered at two of the sites visited. In one case, a substitution was made for the particular pump specified, due to time constraints of the project and lack of availability of the proper pump. The substitute pump used a controlled leakage stuffing box system on the main shaft. Leakage occurred during periods when the pump was not running so that ingested air was present on start up. The air tended to damage the packing and increase the leakage rate resulting in an unusual amount of required maintenance. Replacement of the pump with a sealed shaft system solved the problem.

The other pump problem occurred on a sealed shaft unit. Leakage occurred that was traceable to deterioration of the impeller shaft packing material by the high concentration of chromate inhibitor used in the system. The solution to this problem was to fabricate a system that allowed the material to be washed with untreated water.

2.4 Storage Subsystems

Of the systems inspected, only three storage subsystem problems were encountered. The most serious problem occurred at a site that used two concrete transformer vaults for storage of liquid. In this particular case, project time and financial constraint resulted in the selection of transformer vaults to expedite completion of the project on schedule. Leakage from the two 4,000 gal capacity vaults occurred at varying rates of from 40 to 50 gals a day and appeared to be related to the temperature of the stored liquid. Repairs to the tanks were initiated and the leakage rate was greatly reduced but not eliminated.

The other two storage problems had to do with the tank insulation. In one case a liquid leak from a tank connection resulted in the deterioration of vermiculite plaster insulation used on the ends of the cylindrical roof mounted tank (see fig. 2-38). In the other case, an insufficient amount of insulation was used on three buried tanks resulting in excessive heat losses. This was evidenced by the fact that the earth cover did not support the growth of vegetation. This heat loss was also substantiated by the rapid drying of the area above the buried tanks after a rain storm when compared to adjacent areas.

2.5 Conclusions from Field Inspections

The observations made during the field inspections illustrate that numerous material related problems have occurred in operational solar energy systems. Field problems were identified in each of the major subsystems, collector, transport and storage, of one or more of the solar energy systems surveyed. Also materials problems were identified for most components within the subsystems. For example, problems were identified in one or more collector subsystems with materials used for cover plates, absorptive coatings, absorber plates, insulation, seals, enclosures and structural supports.

Although some of the observed problems result from improper design considerations, most result from inadequate resistance of materials to the exposure conditions experienced in the solar systems. Recommendations to reduce the extensive field problems reported in this chapter are provided in Chapter 5 of this report.

3. RESULTS OF LETTER SURVEY AND QUESTIONNAIRE

A questionnaire accompanied by appropriate instructions and an explanatory letter describing the scope of the project was sent to the 459 manufacturers and installers of solar equipment. The primary purpose of the questionnaire was to obtain data on materials performance in operational systems. A questionnaire, instructions and sample letter are included in Appendix A. The mailing list is included in Appendix B. The questionnaire, titled "Data Sheet for Operational Solar Energy Systems" is divided into five parts. Part I identifies the respondent, Part II identifies the location, age and function of the solar systems, Parts III, IV and V deal with the materials used in the collector, thermal storage and energy transport subsystems, respectively.

Of the 459 questionnaires sent out, 136 responses were received. Sixty-five responses did not contain usable information on materials performance. Twenty-one questionnaires were returned as not deliverable due to either change in address or the fact that the company was out of business. Fifty responses contained usable materials performance information and of those fifty, twenty-one were from installation contractors, eighteen were from manufacturers, and eight responses were from companies that both manufactured and installed solar equipment. Three respondents failed to indicate whether they were manufacturers or installers.

Part II of the questionnaire was to identify the location, age and function of the solar systems reported. Table 3-1 is a resume of the responses to Part II by the fifty respondents that presented usable information. The questionnaire did not specify solar swimming pool heaters but information on such heaters was included in a number of questionnaires. One manufacturer indicated that his company had installed over 200 swimming pool heaters but did not indicate the age of any of them. Another manufacturer indicated that approximately 30 swimming pool heaters were installed that had been in service for one to two

Table 3-1. Summary of Responses to Questionnaire -- System Function and Time in Operation

Operation Time (Years) \ Function	Domestic Hot Water	Heating	Cooling	Swimming Pool Heat	Total
0 - 1	86	33	7	8	134
1 - 2	17	10	1	30	58
2 - 3	12	7	2	0	21
3 - 4	1	1	0	0	2
Undated	6	6	1	201	214
Total	122	57	11	239	429

years. Except for pool heaters, the greatest number of solar devices reported on were domestic hot water heaters that are less than one year old. The next most common solar device reported were home heating systems with the least information beingreceived on home cooling systems.

Table 3-2 lists the types of collectors reported on and the materials that were used in the collectors as reported in Part III of the questionnaire. The dominant collector system was the flat plate, liquid type, which comprised 134 systems. Seventeen flat plate air systems were reported on with only three concentrating collector systems reported.

The listings in table 3-2 include the liquid transfer medium used, cover plate materials, cover plate reflective coatings, absorber coatings and substrate, fluid passages that differed from the absorber substrate, gaskets and sealants, insulation, enclosure materials, reflector materials and the dessicants used.

Table 3-3 lists the types of thermal storage units reported on and the materials used in the thermal storage units as reported in Part IV of the questionnaire. Table 3-3 also includes the use conditions, storage medium, insulation, gaskets and sealants and those storage units that were designed with integral heat exchangers. The predominant system was steel tanks for the storage of liquid, insulated with glass fibers and located in a shelter above ground. Since 75% of the storage systems reported were steel tanks, table 3-4 is a resume of the location, interior lining and insulation used in these systems.

Table 3-5 lists the materials used in the transport subsystems reported on in Part V of the questionnaire. Copper piping was used in 68 of the 113 systems reported. The connections were predominantly rigid and the insulation material used most often was foam rubber. Of all the systems reported on, 14 included filters or getter columns.

The data presented in tables 3-1 through 3-5 do not reflect all questions asked in the questionnaire. The last three questions in Parts III, IV and V are directed toward any problems that may have been encountered during the operation of the solar systems. Of the fifty questionnaires used in the compilation of data, positive responses to these questions were received in thirteen cases. Six manufacturers, five installation contractors and two respondents that are both manufacturers and installation contractors indicated some problems. Ten problems that required repair or replacement of collectors were reported, corrosion was reported in four cases, transport system repairs were required in four cases and only one storage problem was reported.

Table 3-2. Summary of Responses to Questionnaire -- Collector Information

Type			
Flat plate	134		
Liquid, open	28		
Liquid, closed	94		
Air	12		
Concentrating	3		

Liquid Transfer Medium

Type	Total	With Additives
Water	70	7
Ethylene glycol/water	26	14
Propylene glycol/water	10	0
Other	6	4

Cover Plates

	Primary	Secondary
Glass	45	14
Tempered glass	30	9
Poly(vinyl fluoride)	4	4
Vinyl tube	4	0
Fiber reinforced polyester	22	1
Polycarbonate	1	0
Acrylic	15	0
Fluorinated ethylene propylene	0	3
Poly(ethylene terephthalate)	0	4
Poly(ethylene) heat trap	0	5
Cellulose acetate butyrate	1	0

Reflective Coatings

Aluminum	3
Acid etch	4

Absorber Coating/Substrate

	Selective	Nonselective	Dye in Fluid
Aluminum	8	46	0
Copper	7	32	0
Steel	9	6	0
Plastic	0	1	0
Unknown	0	5	4

Table 3-2. (continued)

Fluid Passages Different Than Absorber Substrate		(Passage/Substrate)
Copper/aluminum	23	
Copper/steel	2	
Gaskets/Sealants		
Silicone	60	
Neoprene	13	
Butyl	8	
Polysulfide	4	
EPDM	6	
RTV	2	
Cork	1	
Insulation		
Glass fiber	72	
Urethane	23	
Cellulosic	8	
Mineral wool	7	
Isocyanurate	7	
Polystyrene	5	
Enclosure		
Metal		
Aluminum	52	
Galv. steel	21	
Steel	9	
Stainless steel	2	
Copper	3	
Plastic	2	
Wood	26	
Reflectors		
Aluminum	7	
Dessicants		
Silica gel	9	

Table 3-3. Summary of Responses to Questionnaire -- Thermal Storage Information

<u>Tank or Container</u>	
Composition	
Steel	82
Concrete	23
Wood	2
Fiber reinforced polyester	3
Use	
Buried	17
Above ground sheltered	55
Above ground unsheltered	9
In basement	22
<u>Storage Medium</u>	
Liquid	98
Aggregates	12
<u>Insulation</u>	
Glass fiber	63
Urethane	17
Polystyrene	11
Cellulosic	1
Mineral wool	1
Foamed glass	1
Foamed rubber	1
Isocyanurate	1
<u>Gaskets/Sealants</u>	
Silicone	1
Rubber	1
<u>Storage Units with Heat Exchangers</u>	43

Table 3-4. Summary of Responses to Questionnaire -- Steel Tanks for Liquid Storage: Location, Interior Lining, Insulation

Type of Insulation	Glass Fiber			Urethane			Polystyrene			Mineral Wool			Isocyanurate			Other or Unknown		
Location \ Type of Interior Lining	Glass Lined	Coated	Not Specified	Glass Lined	Coated	Not Specified	Glass Lined	Coated	Not Specified	Glass Lined	Coated	Not Specified	Glass Lined	Coated	Not Specified	Glass Lined	Coated	Not Specified
Buried	0	0	0	0	1	0	0	1	0	0	0	0	0	1	0	0	0	0
Above ground (sheltered)	28	11	1	4	1	0	0	2	1	0	0	0	0	0	0	1	1	0
Above ground (unsheltered)	3	0	0	0	3	1	0	0	1	0	0	1	0	0	0	0	0	1
In basement	11	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1

Table 3-5. Summary of Responses to Questionnaire -- Transport Subsystem Information

Piping/Ducting	
Copper	68
CPVC	19
Sheet metal (air)	8
Poly(ethylene)	4
Steel	4
Aluminum	4
Poly(vinyl chloride)	4
Neoprene	1
Aluminum faced fiber glass (air)	1
Connections	
Rigid	
Soldered	57
Bonded	27
Threaded	15
Bolted	5
Flexible	
Metal	15
Rubber	9
Insulation	
Foam rubber	68
Glass fiber	16
Urethane	6
Neoprene	2
Isocyanurate	4
Gasket/Sealants	
Neoprene	4
Silicone	4
Teflon tape	2
Epoxy adhesive	1
Transport with filters or getters	14

The number of reported problems seems to be small when compared to those observed in the field inspection phase of this study. There are several possible explanations for this inconsistency: 1) neglecting swimming pool heaters and undated responses, over 85% of the systems reported on were less than two years old and problems may not occur in such short times on many systems, 2) problems may have been considered insignificant and not worthy of reporting unless a considerable reduction in efficiency was reported by the user, 3) the materials used in systems reported on in the questionnaire may have been much better performers than those in systems actually inspected, 4) problems may have occurred but went undetected by those responding to the questionnaire and 5) respondents to the questionnaire may not have reported all known problems. In summary, the questionnaire results did not yield the materials performance data which had been anticipated. The data obtained, however, are useful in identifying the types of materials that are currently being used in operational systems.

4. TEST METHOD STANDARDS FOR MATERIALS

Numerous standard methods of test for materials have been developed by standards setting organizations such as ASTM (American Society for Testing and Materials), ANSI (American National Standards Institute) and ISO (International Organization for Standardization). Also test methods are available in trade association specifications and guidelines and in Federal and military specifications and standards.

The purposes of this chapter are to identify available standards for materials commonly used in solar energy systems and to assess the standards in terms of their applicability to materials used in solar energy systems.

4.1 Identification of Standards

Tables 4.1 through 4.7 include test methods for materials commonly used in solar energy systems: coatings, fluids, glass, insulation, metals, plastics and rubbers. The tables divide test methods according to the type of test. Reference [4] also identifies numerous standard test methods for building materials.

Each of the types of materials may be used in many ways within solar energy systems. For example, coatings may be used as absorbers of solar energy, as reflective or anti-reflective surfaces and as protective coatings for system components. Fluids may be used for transporting and storing energy. Typical applications of glass include cover plates, absorber substrates and fluid conduits and containers. Insulation materials are used in collectors as well as with transport and storage subsystems. Metals may be used in collectors as absorber plates, enclosures and structural supports, in transport subsystems as piping and connections and in storage subsystems as heat exchangers, connections and tank materials. Metallic solders may also be used to join metallic components. Plastics may be used in collectors as cover plates, absorbers and enclosures, in transport subsystems as piping and connections and in storage subsystems as heat exchangers, connections and tank materials and liners. Rubbers may be used as seals, adhesives and flexible couplings throughout solar energy systems.

4.2 Assessment of Standards

Test methods for evaluating materials used in solar energy systems must be based upon the properties that are important and the exposures expected in service. In order to assess the applicability of existing standards to materials used in solar energy systems, the use of the material must be considered. For example, test conditions for evaluating the thermal stability of absorber coatings will be different from test conditions for evaluating exterior protective coatings.

The remainder of this chapter will consider the applicability of existing materials standards to specific applications of materials in solar energy systems. Test methods relative to the primary performance requirements will be included. The test methods will be classified either as property measurement tests or aging tests. Property measurement tests provide a means of measuring specific properties of materials, such as adhesion, impact resistance, strength, color, etc. Aging tests are tests which provide for exposure of materials to environments which may change their initial properties. By measuring a property or group of properties before and after aging, the effect of the aging test can be determined.

4.2.1 Coatings

The key properties of absorber coatings are absorptance, emittance and adhesion. Test methods for measuring optical properties are listed in table 4.1 and are judged to be applicable to solar absorber coatings. However, the standard method for measuring reflectance (ASTM E424), which is used to calculate absorptance, involves costly instrumentation and the lack of a suitable standard coating has led to questions regarding the comparison of values obtained using different instruments. For absorber coatings which are protected from the exterior atmosphere by cover plates, the primary factors that should be included in aging tests are elevated temperature, temperature cycles, weathering (particularly ultraviolet radiation) and humidity. Existing accelerated methods for these factors, as listed in table 4.1 under moisture, thermal aging and weathering, have been developed for coatings other than absorber coatings. Methods for determining the effects of moisture, such as ASTM D1735 and D2247 and Mil. Std. 810C are probably useful in evaluating absorber coatings. However, the effects of moisture in combination with elevated temperature should be considered. Energy methods for thermal aging and ultraviolet stability are not directly applicable to absorber coatings. Thermal aging tests do not include temperatures as high or as low as those observed in service. One problem which can result from thermal instability is called outgassing in which degradation products affect the performance of other components. Accelerated methods for radiation exposure using carbon or xenon arc exposure do not include a simulated cover plate and do not include temperatures to simulate those obtained on absorber coatings. For coatings designed to be in direct contact with heat transfer liquids, a test is needed for compatibility of the coating and liquid. Also outdoor exposure tests do not simulate in-service exposure of absorber coatings. One additional consideration is that many of the existing test methods are designed for either specific coatings or specific substrates. It is not known if these methods are applicable to other coatings or substrates.

The key properties of reflective or anti-reflective coatings are optical properties and adhesion. Optical properties may be measured by the methods listed in table 4.1. Adhesion test methods are seldom completely satisfactory but can be used for comparing the relative adhesion of various coatings. The primary factors which could affect the properties of reflective or anti-reflective properties are the same as those for absorber coatings. As with absorber coatings, the existing test methods do not include temperatures which simulate in-service exposure. This leads to questions regarding the applicability of the methods in evaluating the effect of temperature and ultraviolet radiation. The resistance to humidity can probably be determined using the same methods mentioned for absorber coatings.

Protective coatings for collector components can be evaluated as exterior coatings for buildings would be. The aging tests for resistance to atmospheric pollutants, impact, moisture, thermal aging and exterior weathering may be useful. Protective coatings for use in direct contact with transfer or storage liquids must be tested for compatibility. A standard test method for this is not available.

4.2.2 Fluids

A number of properties of liquid transport or storage fluids may be evaluated using the methods in table 4.2. Aging tests for fluids should include the effect of elevated temperature and temperature cycles and compatibility with adjoining materials. Standard test methods for thermal stability of fluids are not available. Compatibility of fluids with metals is discussed in 4.2.5 and with rubbers in 4.2.7.

4.2.3 Glasses

Table 4.3 lists test methods for glass. As indicated in Chapter 2, the differential coefficients of expansion between glass covers on flat plate collectors and the collector enclosure can lead to glass breakage. Assuming this problem has been overcome through design considerations, a primary concern with glass covers is impact resistance, particularly hail impact. The impact tests listed in table 4.3 may be useful for comparing the relative impact resistance of various types of glass. These methods, however, have not been shown to relate to hail impact. Another concern, particularly with evacuated tube collectors, is burst strength or shattering initiated near defects.

4.2.4 Insulation

Table 4.4 lists test methods for insulation. The key thermal property of insulation is thermal conductivity, which indicates the ability of the insulation to prevent heat losses. It can be measured by the methods shown in table 4.4.

In addition to thermal properties, insulation for use in solar collectors must be highly resistant to changes in chemical composition and physical dimensions. Chemical stability ensures functional performance and compatibility with surrounding components over an extended service life. Physical (dimensional) stability is essential to ensure that a physical barrier of constant volume is maintained between two substrates which are thermally different, and also, to ensure that the enclosure is not subjected to excessive pressures. For insulation not exposed to the exterior atmosphere, moisture and elevated temperature are the primary factors that should be included in aging tests. The procedures outlined in Mil. Std. 810C should be useful if the test temperature is altered to reflect that obtained in solar applications. A test method is needed to determine the effect of degradation products at elevated temperature on other components.

For insulation exposed to the exterior environment, aging tests should include ultraviolet radiation and possibly atmospheric pollutants in addition to those factors mentioned above. The test methods listed under resistance to weathering may be useful for exterior exposures.

Insulation buried in soil must be compatible with constituents of the soil. A test to determine this compatibility is needed.

4.2.5 Metals

Table 4.5 lists test methods for metals. The primary concern regarding the use of metals is corrosion. This is particularly true for collector, transport and storage subsystems in which metals are in direct contact with heat transport or storage liquids. Although numerous test methods for corrosion are included in table 4.5, none are completely adequate for ensuring long-term corrosion-free performance. The corrosion tests listed in table 4.5 may be useful for comparing the relative corrosion resistance of various metals. To obtain accurate predictions of long-term performance, however, tests should include temperature, flow rates and additives to more closely simulate service conditions.

The extent of corrosion is often evaluated by visually examining the metals before and after aging tests. In a laboratory test or in an actual solar energy system, visual inspections are often difficult or impossible to perform. Often corrosion is not obvious until leaks occur. A nondestructive test method other than visual inspection is needed for determining if corrosion is occurring on the interior of enclosed metallic components.

4.2.6 Plastics

Table 4.6 lists test methods for plastics. The key property of plastics for use as cover plates is transmittance. However, other properties such as abrasion resistance, embrittlement, impact strength and warping may be important for some materials. Property measurement tests in table 4.6 should be useful with the possible exception of abrasion resistance. Most plastics would be expected to perform poorly with existing abrasion tests and the results may not adequately reflect performance in service. The primary factors that should be included in aging tests of plastic covers are elevated temperature, temperature cycles and weathering resistance (particularly ultraviolet radiation exposure). Existing tests for thermal aging of plastics do not include temperatures that simulate in-service solar exposure. Thus, they are not directly applicable to plastic covers. Accelerated radiation exposures using carbon or xenon-arcs likewise, do not include temperatures experienced in service. Outdoor exposure tests provide for exposure of plastics but not in the configuration used in solar collectors. This results in lower exposure temperatures than would be experienced in service.

Plastics are used as absorbers or absorber substrates in some commercial collectors. The key to the long-term performance of plastics in these applications is thermal stability. Existing tests for thermal stability are not directly applicable unless the maximum in-service temperature is less than that specified in the tests. In addition to thermal stability, weathering resistance (particularly ultraviolet radiation exposure) may be important. Applicability of tests for weathering resistance is also dependent upon the relationship between the maximum service temperature and the test temperature.

Plastics for use in exterior applications, such as collector enclosures may be evaluated by existing tests. As with most materials, however, there is seldom a satisfactory relationship between accelerated tests and in-service exposure. These tests may be useful for comparing the relative performance of plastics under identical exposure conditions.

For plastics used in direct contact with transport or storage liquids, the key aging test involves determining the compatibility between the plastic and the liquid under service conditions. Tests are needed in this regard.

4.2.7 Rubbers

Table 4.7 lists test methods for rubbers. Rubber materials are typically used as seals, flexible coupling hoses and adhesives. For sealing, properties such as adhesion, compression set, hardness, tensile strength and ultimate elongation are particularly important. These properties may be measured by existing tests. Primary factors which should be included in aging tests include atmospheric pollutants (particularly ozone), moisture or liquid immersion (particularly for hydraulic seals), elevated and depressed temperature, temperature cycles and weathering resistance (particularly ultraviolet radiation). Existing tests as outlined in table 4.7 may be useful providing the test temperature is modified to reflect the temperatures experienced in service. A test method is needed to determine the effect of degradation products at elevated temperature on other components.

Important properties of flexible coupling hoses include compression set, creep, extension-recovery, strength, hardness, tear resistance and ultimate elongation. These properties may be measured by existing tests. Primary factors which should be included in aging tests include atmospheric pollutants (particularly ozone), liquid immersion with transfer fluids, elevated and depressed temperature, temperature cycles and weathering resistance (particularly ultraviolet radiation). The types of aging tests listed in table 4.7 may be useful provided the test temperature is modified to simulate in-service exposure. In addition to the factors listed above, the clamping mechanism used on rubber hoses can affect their long-term performance. The use of clamps needs to be addressed in standards in such a way that field problems can be avoided.

Properties of adhesive bonds which are particularly important are flexural, shear and tensile strengths. These may be measured with existing tests. The key factors which should be included in aging tests are moisture resistance, elevated temperature, temperature cycles and possibly creep, if sustained loads are applied. Existing aging tests may be useful if test temperatures are modified to reflect service conditions.

4.3 Conclusions Regarding Existing Test Method Standards

It is obvious from the lists in tables 4.1 through 4.7 that many test method standards for materials are available. Although many of the property measurement tests are apparently applicable to materials used in solar energy systems, most aging tests are not directly applicable. In some cases, modification of the exposure conditions may result in acceptable aging tests but laboratory verification is needed of the modified tests. A number of new tests are also needed as outlined in 4.1 through 4.7.

Table 4.1. Existing Test Methods for Coatings

Type of Test	Test Designation
Abrasion, resistance to	ASTM D658, D968, Fed. Std. 141a
Adhesion	ASTM B571, C633, D2197, D3359, ISO 2819
Atmospheric pollutants, resistance to	ASTM B117, B287, D1543, D1654, D3129, G1, G33, Fed. Std. 141a, Fed. Specs. TT-P-31D, TT-P-103B, TT-C-530A, TT-C-00498A, TT-E-516A, TT-E-522A, TT-P-102D
Cleanability	ASTM C756, D2486
Color change	ASTM D1535, D1543, D1729, D2244, D2616, G45
Corrosion resistance	ASTM B117, D1014, D1654, D2933, G1, ISO 1462
Flammability	ASTM D1360, E162, E286
Flexural strength	ASTM B571, D522, D1737, Fed. Std. 141a
Fungus resistance	ASTM D3129, D3272, D3273, G21, Mil. Std. 810C, Fed. Std. 141a, Fed. Specs. TT-P-31D, TT-P-51D, TT-P-61E, TT-P-71E, TT-P-81E, TT-P-19C, TT-P-55B
Gloss	ASTM D523, D1471
Impact resistance	ASTM D1474, D2794, D3170, SAE J400
Moisture, resistance to	ASTM D1010, D1187, D1735, D2246, D2247, D2366, D2932, Mil. Std. 810C, Fed. Specs. TT-P-641F, TT-C-1079A
Optical properties	ASTM E97, E424, E434
Permeability	ASTM C355, D1653, E96
Physical integrity	
checking	ASTM D660
cracking	ASTM D661
Scratch resistance	ASTM D2197
Surface uniformity	ASTM E136
Tensile strength	ASTM D522, D1737, D2370
Thermal aging, resistance to	ASTM D2246, Mil. Std. 810C
Thickness	ASTM B567, D1005, D1186, D1400, E376, ISO 2178, 2360, 2361
Weathering, resistance to	ASTM D822, D1006, D1014, D2620, G7, G23, G24, G25, G26, G27, Mil. Std. 810C, Fed. Std. 141a, Fed. Specs. TT-P-31D, TT-P-61E, TT-P-71E, TT-P-81E, TT-C-530A, TT-P-19C, TT-P-55B, TT-P-95B, TT-P-1181A, TT-C-00498A, TT-E-516A, TT-E-522A, TT-P-37C, TT-P-102D

Table 4.2. Existing Test Methods for Fluids

Type of Test	Test Designation
Analyzing stress	ASTM F218
Annealing point, strain point	ASTM C336, C598
Atmospheric pollutants, resistance to	ASTM C724, C777, ISO 1776
Coefficient of expansion	ASTM C824, E228, E289
Creep	Fed. Spec. DD-G-1403
Density	ASTM C693, C729
Fatigue	
Flatness	ASTM C314
Flexural strength	ASTM C158
Impact strength	ANSI Z97.1, Fed. Std. 406
Indentation hardness	ASTM C730
Optical properties	ASTM E424
Softening point	ASTM C338
Thermal aging, resistance to	ANSI Z97.1
Thermal conductivity	ASTM C177, C408
Thermal shock	ASTM C149
Young's modulus, shear modulus, Poisson's ratio	ASTM C623

Table 4.3. Existing Test Methods for Glasses

Type of Test	Test Designation
Ash content	ASTM D482, D1119
Autoignition temperature	ASTM D2155
Boiling point	ASTM D1120
Color	
Corrosivity	ASTM D807, D2688, D2776, D3263
Expansion coefficient	ASTM D1903
Fire point	ASTM D92
Flash point	ASTM D56
Foaming	ASTM D1881
Freezing point	ASTM D1015, D1177
pH	ASTM D1287
Reserve alkalinity	ASTM D1121
Specific gravity, density	ASTM D941, D1122
Specific heat	ASTM D2766
Thermal conductivity	ASTM D2717
Ultraviolet absorbance	ASTM D2008
Vapor pressure	ASTM D323
Viscosity	ASTM D445
Water content	ASTM D1123, D1744

Table 4.4. Existing Test Methods for Insulation

Type of Test	Test Designation
Atmospheric pollutants, resistance to	
Biodeterioration	ASTM D3273, G21, G22
Breaking strength	ASTM C446
Compressive strength	ASTM C165
Deflection	ASTM C209
Density	ASTM C167, C209, C302, C303, C519, C520
Dimensional stability	ASTM C548, D1042
Expansion	ASTM D1037
Flame spread	ASTM E84
Flexural strength	ASTM C203
Impact resistance (by dropping)	ASTM C487
Indentation hardness	ASTM C569
Mechanical stability	ASTM C421
Moisture absorption	ASTM C209
Moisture, resistance to	Mil. Std. 810C
Parting strength	ASTM C686
Properties at abnormal temperature	ASTM D759
Racking load	ASTM E72
Specific heat	ASTM C351
Tensile strength	ASTM C209
Thermal aging, resistance to	ASTM C356, C411, C447, D794, Mil. Std. 810C
Thermal conductivity	ASTM C177, C236, C335, C518, C745, D2326
Thermal resistance	ASTM C653, C687
Thermal transference	ASTM C691
Thickness	ASTM C167, C209
Transverse strength	ASTM C209
Vapor permeability	ASTM C355, E96
Weathering, resistance to	ASTM G7

Table 4.5. Existing Test Methods for Metals

Type of Test	Test Designation
Acetic acid, resistance to	ASTM B287, B368
Atmospheric pollutants, resistance to	ASTM B537, G33
Compression	ASTM E9, E209
Density and open porosity	ISO 2738
Corrosion, resistance to	ASTM C464, D130, D538, D849, D930, D1280, D1374, D1384, D1616, D1654, D2247, D2251, D2570, D2649, D2809, D2933, D2966, G3, G4, G31, G32, G46, G48, AWPA M-14-72, NACE TM-01-71, TM-02-70, TM-02-74, TM-01-69
Creep	ASTM E139
Creep at elevated temperature	ASTM E150
Ductility	ASTM B489
EMF	ASTM E189
Fatigue	ASTM E466
Fracture toughness	ASTM E399
Grain size	ASTM E112
Hardness	ASTM E10, E18, E103, E110, E384, E448
Impact, resistance to	ASTM E23
Oil content	ISO 2737
Salt spray, resistance to	ASTM B117, G44, Fed. Std. 151b
Stress corrosion	ASTM G30, G35, G37, G38
Tensile strength	ASTM E8
Thermal expansion	B95, E80

Table 4.6. Existing Test Methods for Plastics

Type of Test	Test Designation
Abrasion, mar, resistance to	ASTM D673, D1044, D1242
Atmospheric pollutants, resistance to	ASTM B117, B287, D543, D1149, D1712, G1, G33, Fed. Std. 406
Blister-delamination	ASTM C363
Burst strength	ASTM D774
Cleanability	AIMA-7
Coefficient of expansion	ASTM D696, D864, D1204
Color change	ASTM D1729, D1925, D2244, D2616, D3134, G45, Fed. Std. 141
Creep	ASTM D674, D2552, D2648, D2990, D2991, Fed. Std. 406
Deflection	ASTM D621, D648
Density	ASTM D792, D1505
Embrittlement	ASTM D1790
Fatigue	ASTM C394, D671, SAE J783
Flammability	ASTM D635, D658, D876, D1692, D1929, D3014, E84, E136
Flatness	ASTM D1604, Fed. Spec. DD-G-1403, Mil. Spec. 3787
Flexural strength	ASTM C393, D747, D790
Fungus resistance	ASTM G21, G22, G29, Fed. Std. 406, Fed. Spec. L-P-380C
Impact strength	ASTM D256, D1790, D1822, D3029, D3099, D3420, ANSI Z97.1, Fed. Std. 406
Indentation-hardness	ASTM D785, D2240, D2583, Fed. Std. 406
Modulus of elasticity	ASTM D638, D695, D882
Moisture, resistance to	ASTM D756, D2126, D2383, Mil. Std. 810C, Fed. Spec. L-P-380C
Optical properties	ASTM E424, E434, Fed. Spec. DD-G-451
Permeability	ASTM C355, D1434, E96, F372, Fed. Std. 406, TAPPI T-482
Refractive index	ASTM D542
Scratches, defects	Fed. Spec. DD-G-1403
Tensile strength	ASTM C297, D638, D882
Thermal aging, resistance to	ASTM D648, D793, D1299, D2115, D2126, D2288, D2445, D2951, D3045, Mil. Std. 810C
Thermal conductivity	ASTM C177, C518, D2326
Thickness	ASTM D374, D1777
Ultimate elongation	ASTM D638, D882
Warping, bowing	ASTM D709, D1181

Table 4.6. (continued)

Type of Test	Test Designation
Weathering, resistance to	ASTM D1435, D1499, D1501, D2565, G7, G23, G24, G25, G26, G27, Fed. Spec. L-P-508f, Fed. Std. 406, ANSI Z97.1
Wind, resistance to	ASTM E330

Table 4.7. Existing Test Methods for Rubber Materials

Type of Test	Test Designation
Adhesion/cohesion	ASTM C719, C766
Adhesion, peel	ASTM C794, D413, D429, D903, D1781, D1876 D2630
Atmospheric pollutants, resistance to	ASTM D518, D1149 (ozone)
Brittleness point	ASTM D2137
Compression-recovery	ASTM F36
Compression set	ASTM D395, D1229
Creep resistance	ASTM D1390, D1456, D1780, D2293, D2294, F38
Extrusion rate	ASTM C603
Flexural strength	ASTM D1184
Flow properties	ASTM C639
Fungus resistance	ASTM D1286, D1877
Impact strength	ASTM D950
Hardness	ASTM C661, D1415, D2240
Low temperature flexibility	ASTM C711, C734, C765, D797, D1053, D1329 D2137
Moisture or liquid immersion, resistance to	ASTM D471, D1101, D1151, D1460, D3137, F82
Sealability	ASTM D1081, F37, F112
Shear strength	ASTM D905, D1002, D2919, D3165
Staining	ASTM D925, D2203
Tear resistance	ASTM D624
Tensile strength	ASTM D412, D897, D906, D2095, D2295, F152
Thermal aging, resistance to	ASTM C771, C792, D573, D865, D1870
Ultimate elongation	ASTM D412
Weathering, resistance to	ASTM C718, C732, C793, D904, D1171, D1183, D1828, D2559, ANSI A116.1, AAMA 802.2, 804.1, 805.2, 806.1, 807.1, 808.1, Fed. Specs. TT-G-410E, TT-S-00227E, TT-S-00230C, TT-S-001543A, TT-S-001657
Young's modulus	ASTM D797

5. CONCLUSIONS AND RECOMMENDATIONS

The observations made during inspections of operational solar energy systems, described in Chapter 2, illustrate that numerous material related problems have occurred in operational systems and the results of the questionnaire, described in Chapter 3, illustrate that many types of materials have been used in components and subsystems. Field problems were identified in each of the major subsystems, collector, transport and storage, of one or more of the solar energy systems surveyed. Also materials problems were identified for most components within the subsystems. For example, problems were identified in one or more collector subsystems with materials used for cover plates, absorptive coatings, absorber plates, insulation, seals, enclosures and structural supports.

It is imperative that premature failure of materials be minimized and that systems and subsystems be made as maintenance free as possible to ensure widespread consumer acceptance of solar as a viable energy alternative. The primary concern, then, is to identify a path of action to ensure improved materials performance in solar systems and subsystems.

There are at least two factors which contribute to the premature failure of materials in the field and must be addressed by the planned path of action: 1) improper design considerations and 2) inadequate resistance of materials to the conditions experienced in solar energy systems. Many of the field problems result from improper selection of materials for the particular design. At present, the process of selecting materials for specific applications is hindered by the lack of an adequate data base of materials performance under the conditions experienced in solar systems and subsystems. In particular, data are not available to characterize the longterm performance of various materials under expected in-service conditions. It is often impossible to compare adequately the expected long-term performance of various candidate materials and identify the best candidate. Clearly, the development of a data base of materials performance which identifies the attributes and limitations of materials under specific use conditions would significantly aid the process of selecting materials and hence reduce the extent of field problems.

The needed data base of materials performance can be obtained from experience based on actual installations and from laboratory studies(including tests performed in a laboratory and tests performed on materials and subsystems outdoors). The field experience with solar energy systems in recent years has provided a start toward obtaining an adequate data base. For example, changes incorporated in recently marketed systems and subsystems by collector manufacturers and system designers to help alleviate problems observed with earlier designs reflect a growing data base of materials performance. One problem, however, is that information on the experience gained is often not widely disseminated within the solar industry. Another problem is that, even if data obtained from field experience were widely disseminated, the time required to obtain an adequate data base would be prohibitively long if trial and error in the field were the only source of data.

Laboratory studies of materials is another source of materials performance data. Initial properties of materials can often be determined using existing standard test methods, as shown in Chapter 4. Such property measurements are available for many materials used in components and subsystems, e.g. strength properties of glass, plastics and metals, hardness of rubber materials, thermal properties of insulation etc. Aging tests, which provide for exposure of materials to environments that may change their properties, can be useful in obtaining long-term performance data. The effect of the environment on materials properties during an aging test can be determined by measuring one or a group of properties before and after aging. Accelerated aging tests, which have been designed in an attempt to induce changes in materials properties in a short period of time, have been developed for many materials as mentioned in Chapter 4. One problem with testing by accelerated aging procedures is that it is difficult to relate the results of accelerated tests quantitatively with in-service performance [5, 6]. A systematic approach to predicting service life has been developed [7] which may aid in obtaining improved correlations between accelerated test results and in-service performance. The systematic approach is also being prepared as an ASTM standard practice by Committee E6 on Performance of Building Constructions. Another problem with existing accelerated tests for materials, as shown in Chapter 4, is that the exposure environments are seldom adequate to simulate the exposure conditions of materials experienced in solar energy components and subsystems. Thus, in developing a data base of materials performance for solar energy applications, it will be necessary to first establish standard test procedures for obtaining the data. The test procedures needed are primarily accelerated aging tests in which the exposure environments simulate the service conditions experienced in solar. However, Chapter 4 points out that improved property measurement tests are also needed for some materials.

In order to expedite the development of the urgently needed data base of materials performance for solar applications, the following is proposed:

1. Compile materials performance data from solar energy systems that are installed in the field.

<u>Commentary</u>: It was mentioned earlier in this chapter that experience gained from field installations is often not widely disseminated within the solar industry. One reason for this is that the materials used in many systems are proprietary. During the course of this study, it has been difficult to obtain from the private sector, the type of data needed. It is unlikely that a comprehensive compilation of materials performance on operational systems can be obtained. It is suggested, therefore, that the data compilation be limited to Federally sponsored or owned installations. The data which could be obtained would serve two purposes: 1) it would provide an interim data base and 2) it would aid the interpretation of data from accelerated tests of materials and subsystems.

2. Perform laboratory studies of materials and subsystems to develop test method standards.

Commentary: Standard test methods are needed at the materials level, particularly for estimating the long-term performance of materials in solar applications. In order to develop test method standards, laboratory tests of available and currently used materials must be performed and the data obtained from the tests compared to actual field data from operational systems. Also accelerated tests of subsystems, particularly stagnation tests of collectors, must be performed to develop standard procedures and to obtain data for comparison with materials tests.

3. Develop a data base of materials performance for solar applications.

Commentary: The data base should be developed as rapidly as possible, utilizing input from the areas 1 and 2 above. The data base should be a compilation of materials test results, based on field and laboratory tests, which could be used by manufacturers and designers in selecting the best candidate material for each specific application. It is unlikely the data base could ever be complete. In particular, new materials will undoubtedly be utilized in solar applications in an attempt to lower the initial cost or improve the performance of systems. However, if there are standards by which the new materials can be evaluated quickly and reliably, and if data are available in the data base to minimize the selection of materials of poor or questionable performance, the benefits to the solar industry and to the consumer would be invaluable.

The remainder of this chapter will outline the recommended priorities for the development of test method standards for evaluating materials and the types of laboratory-based studies that are needed in regard to the proposal mentioned above to perform laboratory studies of materials.

5.1 Recommended Priorities for the Development of Material Test Method Standards

The National Bureau of Standards has prepared a plan for the development and implementation of standards for solar heating and cooling applications [8]. Based upon that plan, upon the types of material-related problems which have occurred in operational systems (Chapters 2 and 3 of this report) and upon the availability of existing standards (Chapter 4 of this report), the following components (listed in alphabetical order) are recommended for the development of material test method standards: absorptive coatings, coatings/liners for transport or storage subsystems, collector insulation, cover plates, dessicants, dielectric insulators, filters and getter columns, flexible couplings, heat transport liquids, metallic containment materials, nonmetallic containment materials, transport and storage subsystem insulation, reflective surfaces, seals and thermal storage media. In addition, standards are needed in two related areas: stagnation testing of collector subsystems and measurement of surface temperature of materials.

Table 5-1 lists the areas for standard development according to recommended priority for actions. Priority ratings of high, medium and low are used in the table. The priority ratings reflect the need for standards to determine the functional and durability/reliability attributes of materials for use in solar systems. Criteria used in establishing the priorities are:

1. The importance of the material to the total system performance.

2. The extent of field problems observed within the material.

3. The availability of existing standards to measure functional and durability/reliability attributes.

4. The potential for developing useful consensus standards.

5.2 Recommendations for Laboratory-Based Studies

In order to develop definitive test method standards for the material-related areas listed in table 5-1, laboratory-based studies of available and currently used materials must be performed to obtain data needed to prepare the standards. The purpose of this discussion is to outline the types of studies that are needed for each area identified in table 5-1 in terms of key needs, key properties to be measured and key aging tests needed and subsystems to which the standards could be applied. A general need for each of the materials areas in which aging tests are studied is to relate the results of the aging tests to results obtained from stagnation testing of collector subsystems (5.2.8) and to field results obtained from operational systems. Another general need for each of the materials areas is to obtain data for use in the data base discussed earlier.

ASTM Committee E21.10 on Solar Heating and Cooling Applications is currently performing research in a number of the areas to be discussed. Task groups on absorptive coatings, collector insulation, cover plates, heat transport liquids, metallic containment materials, seals and stagnation testing are currently working to develop standards. In conjunction with ASTM, the National Bureau of Standards (NBS) is performing research to develop draft standards for absorptive coatings, collector insulation, cover plates and seals. These drafts will be submitted for consideration by ASTM as consensus standards.

Table 5-1. Recommended Priorities for the Development of Material-Related Standards

Material Standards Area	Priority
Absorptive coatings	High
Collector insulation	High
Cover plates	High
Heat transport liquids	High
Metallic containment	High
Nonmetallic containment and absorber substrates	High
Seals	High
Stagnation testing of collector subsystem	High
Surface temperature measurement	High
Flexible couplings	Medium
Reflective surfaces	Medium
Thermal storage media	Medium
Transport and storage insulation	Medium
Coatings/liners for transport or storage subsystems	Low
Dessicants	Low
Dielectric insulators	Low
Filters/getters	Low

5.2.1 Absorptive Coatings

Key Needs

1. Develop aging tests which can be used to estimate long-term in-service performance.

2. Develop lower cost property measurement tests for measuring reflectance and emittance.

3. Develop standard coatings which can be used to compare results obtained in different laboratories and on different instruments.

Key Properties to be Studied

1. Reflectance (absorptance).

2. Emittance.

3. Adhesion.

Key Aging Tests Needed

1. Accelerated tests

    a. Effects of elevated temperature and temperature cycles (including test to measure the effect of outgassing products on other components).

    b. Effects of moisture.

    c. Effects of solar radiation.

    d. Compatibility with heat transport fluids (for trickle systems and systems in which the absorber is dispersed in the transport fluid).

    e. Compatibility with substrate.

2. Natural Exposure

    a. Exposure of coatings in several climates using an exposure apparatus to simulate service conditions in actual collectors.

Applicable Subsystems

1. Collector.

5.2.2 Collector Insulation

Key Needs

1. Develop aging tests which can be used to estimate long-term in-service performance.

Key Properties to be Studied

1. Thermal conductivity.

2. Chemical stability.

3. Water absorption.

4. Form retention.

5. Dimensional stability.

Key Aging Tests Needed

1. Accelerated tests

   a. Effects of elevated temperature and temperature cycles (including test to measure the effect of outgassing products on other components).

   b. Effects of moisture.

   c. Effects of solar radiation and atmospheric pollutants (for exterior applications).

Applicable Subsystems

1. Collector.

5.2.3 Cover Plates

Key Needs

1. Develop aging tests which can be used to estimate long-term in-service performance.

2. Assess existing property measurement tests and develop new tests where needed.

Key Properties to be Studied

1. Transmittance.

2. Abrasion resistance.

3. Impact strength.

4. Embrittlement.

Key Aging Tests Needed

1. Accelerated tests

   a. Effects of elevated and depressed temperature and temperature cycles (particularly for plastics).

   b. Effects of moisture (particularly for plastics).

   c. Effects of solar radiation (particularly for plastics).

   d. Compatibility with reflective/anti-reflective coatings.

   e. Effects of atmospheric pollutants.

2. Natural Exposure

   a. Exposure of coatings in several climates using an exposure apparatus to simulate service conditions in actual collectors.

Applicable Subsystems

1. Collector.

5.2.4 Heat Transport Liquids

Key Needs

1. Develop aging tests which can be used to estimate long-term in-service performance.

2. Assess property measurement tests and tests to characterize flammability of organic fluids and develop new tests as needed.

Key Properties to be Studied

1. Specific heat.

2. pH and reserve alkalinity.

3. Thermal conductivity.

4. Viscosity.

5. Safety related properties (autoignition temperature, fire point, flash point).

Key Aging Tests Needed

1. Accelerated tests

   a. Effects of elevated and depressed temperature and temperature cycles.

   b. Compatibility with materials with which fluids come in contact (particularly corrosion).

   c. Effects of additives.

   d. Effects of decomposition products.

Applicable Subsystems

1. Collector.

2. Transport.

3. Storage (if transport and storage contain the same liquids).

5.2.5 Metallic Containment Materials

Key Needs

1. Develop aging tests which can be used to estimate long-term in-service performance.

2. Develop nondestructive property measurement tests for characterizing properties, particularly during and after aging tests.

Key Properties to be Studied

1. EMF.

2. Nondestructive evaluation (including visual inspection).

3. Mechanical properties.

4. Weight.

5. pH of liquids.

Key Aging Tests Needed

1. Accelerated tests

   a. Compatibility with heat transfer fluids under various conditions of flow, oxygen content, temperature and additives.

Applicable Subsystems

1. Collector.

2. Transport.

3. Storage.

5.2.6 Nonmetallic Containment Materials and Absorber Substrates

Key Needs

1. Develop aging tests which can be used to estimate long-term in-service performance.

2. Assess existing property measurement tests, particularly for plastics, and develop new tests as needed.

Key Properties to be Studied

1. Transmittance (e.g. solar ponds).

2. Impact strength (e.g. solar ponds, piping, absorbers).

3. Burst strength (e.g. piping).

4. Embrittlement (e.g. solar ponds, piping, absorbers).

5. Flexural strength (e.g. absorbers).

6. Abrasion resistance (e.g. solar ponds, piping).

Key Aging Tests Needed

1. Accelerated tests

    a. Effects of elevated and depressed temperature and temperature cycles.

    b. Effects of solar radiation.

    c. Compatibility with heat transfer or storage liquids.

    d. Effects of atmospheric pollutants.

    e. Compatibility with absorber coatings (particularly for absorber substrates).

2. Natural Exposure

   a. Exposure of materials in several climates to simulate in-service conditions in field applications.

Applicable Subsystems

1. Collector.
2. Transport.
3. Storage.

5.2.7 Seals

Key Needs

1. Modify existing aging tests to include temperatures which more closely simulate those observed in solar systems.
2. Develop a test to determine the effect of outgassing products on other components.

Key Properties to be Studied

1. Adhesion.
2. Compression set.
3. Hardness.
4. Tensile strength.
5. Ultimate elongation.

Key Aging Tests Needed

1. Accelerated tests

   a. Effects of elevated and depressed temperature.

   b. Effects of atmospheric pollutants (particularly ozone).

c. Effects of moisture.

d. Effects of solar radiation.

e. Compatibility with heat transfer liquids (for hydraulic seals).

Applicable Subsystems

1. Collector.

2. Transport.

3. Storage.

5.2.8 Stagnation Testing of Collector Subsystems

Key Needs

1. Develop a standard stagnation aging test which can be used to estimate stability of materials to stagnation conditions.

2. Obtain materials data under stagnation conditions in order to relate the results of stagnation tests, materials tests and in-service performance.

Key Properties to be Studied

1. Thermal performance of collector before and after stagnation exposure.

2. Selected properties of materials.

3. Visual observation.

Key Aging Tests Needed

1. Natural Exposure

a. Exposure under stagnation conditions in several climates.

Applicable Subsystems

1. Collector.

5.2.9 Surface Temperature Measurement

Key Needs

1. Development of standard procedure for measuring the surface temperature of materials in subsystems.

2. Obtain measurements of materials temperatures under various operational and stagnation conditions and feed the data into projects aimed at developing aging tests for materials. Temperature data are needed to establish maximum and minimum test temperatures for aging tests of materials.

5.2.10 Flexible Couplings

Key Needs

1. For rubber based couplings, modify existing aging tests to include temperatures which more closely simulate those observed in serivce.

2. Identify other materials used for couplings and assess existing aging tests and develop new tests as needed.

3. Develop recommendations for joining flexible couplings to other components.

Key Properties to be Studied

1. Compression set (rubbers).

2. Hardness (rubbers).

3. Tensile strength (rubbers).

4. Ultimate elongation (rubbers).

5. Dimensional stability (rubbers).

6. Other properties dependent upon materials used.

Key Aging Tests Needed

1. Accelerated tests

   a. Effects of solar radiation.

   b. Effects of elevated and depressed temperatures.

   c. Effects of atmospheric pollutants (for rubbers).

   d. Compatibility with heat transfer liquids.

Applicable Subsystems

1. Collector.

2. Transport.

3. Storage.

5.2.11 Reflective Surfaces

Key Needs

1. Develop aging tests based upon laboratory studies which can be used to estimate long-term in-service performance.

2. Develop lower cost property measurement tests for measuring reflectance and emittance.

Key Properties to be Studied

1. Reflectance.

2. Emittance.

Key Aging Tests Needed

1. Accelerated tests

   a. Effect of solar radiation.

   b. Effect of moisture.

c. Compatibility with substrate.

d. Effect of atmospheric pollutants.

Applicable Subsystems

1. Collector.

5.2.12 Thermal Storage Media

Key Needs

1. Develop aging tests which can be used to estimate the long-term in-service performance of thermal storage media other than rock and water.

Key Properties to be Studied

1. Accelerated tests

a. Effects of elevated temperature and temperature cycles.

b. Effects of moisture.

c. Compatibility with adjoining materials.

Applicable Subsystems

1. Storage.

5.2.13 Transport and Storage Insulation

Key Needs

1. Develop aging tests which can be used to estimate long-term in-service performance.

Key Properties to be Studied

1. Thermal conductivity.

2. Thermal resistance.

Key Aging Tests Needed

1. Accelerated tests

   a. Effects of elevated temperature and temperature cycles.

   b. Effects of solar radiation and atmospheric pollutants (for exterior applications).

   c. Effects of moisture.

   d. Effects of soil constituents (for buried insulation).

   e. Dimensional stability.

   f. Compatibility with protective coatings.

Applicable Subsystems

1. Transport.

2. Storage.

5.2.14 Coatings/Liners for Transport or Storage Subsystems

Key Needs

1. Develop aging tests based upon laboratory studies which can be used to estimate long-term in-service performance.

Key Properties to be Studied

1. Adhesion (coatings).

2. Permeability (coatings, plastics).

3. Color (coatings, plastics).

4. Thickness (coatings, plastics).

5. Strength properties (plastics).

Key Aging Tests Needed

1. Accelerated tests

   a. Effects of elevated temperature and temperature cycles.

   b. Compatibility with transport or storage liquids.

   c. Compatibility with substrate.

Applicable Subsystems

1. Transport.

2. Storage.

5.2.15 Dessicants

Key Needs

1. Develop aging tests which can be used to estimate long-term in-service performance.

Key Properties to be Studied

1. Moisture absorption.

2. Dimensional stability.

Key Aging Tests Needed

1. Accelerated tests

   a. Effects of elevated temperature.

   b. Effects of heating/drying cycles.

   c. Compatibility with adjoining materials.

   d. Effects of moisture.

Applicable Subsystems

1. Collector.

5.2.16 Dielectric Insulators

Key Needs

1. Develop aging tests which can be used to estimate long-term in-service performance.

Key Properties to be Studied

1. Hardness

2. Electrical conductivity.

3. Compression set (rubber-based materials).

Key Aging Tests Needed

1. Accelerated tests

   a. Effects of elevated and depressed temperatures and temperature cycles.

   b. Compatibility with heat transfer or storage liquids and other adjoining materials.

Applicable Subsystems

1. Collector.

2. Transport.

3. Storage.

5.2.17 Filters/Getters

Key Needs

1. Develop aging tests which can be used to estimate useful lifetime under various conditions of use.

Key Properties to be Studied

1. Dependent upon the material used.

Key Aging Tests Needed

1. Accelerated tests

    a. Compatibility with transport or storage liquids.

Applicable Subsystems

1. Transport.

2. Storage.

6. GUIDELINES TO AID THE SELECTION OF MATERIALS FOR USE IN SOLAR ENERGY SYSTEMS

Factors which must be included in criteria for selecting materials to be used in solar energy systems include 1) ability of the material to perform the intended function, 2) durability/reliability, 3) safety, 4) maintainability, 5) cost and 6) compliance with local building codes. As pointed out in Chapter 5, the process of selecting materials for specific applications is hindered by the lack of an adequate data base of materials performance under the conditions experienced in solar systems and subsystems. Because of the lack of an adequate data base, it is not possible to provide definitive recommendations for the use of materials. The purpose of this chapter is to present guidelines to aid the selection of materials for specific applications. The guidelines outline a general procedure for obtaining the data needed to make the selection. The guidelines should be useful in identifying the types of data that should be considered in selecting materials for use in solar energy systems.

The process of selecting a material for a specific application can be outlined into ten steps:

1. Define in-service performance requirements.

2. Identify key functional attributes (or properties).

3. Identify environmental conditions to which the material will be exposed in service.

4. Identify key durability/reliability attributes.

5. Identify key safety attributes.

6. Identify the types of test or field data needed to demonstrate compliance with requirements for function, durability/reliability and safety attributes.

7. Obtain test data.

8. Rank candidate materials in order of predicted short-term and long-term performance.

9. Consider factors related to maintainability, cost, and code compliance.

10. Select the "best" material.

Tables 6-1 and 6-2 are is included to aid in identifying primary attributes of materials typically used in collector, transport and storage subsystems. Table 6-1 lists functional attributes while table 6-2 lists durability/reliability and safety attributes. Attributes of each material which are generally considered to be important are marked with an "X". However, the importance of attributes may vary depending on design and geographic location in service. These tables will be referenced in the following discussion regarding the ten steps outlined above.

Step 1. Define In-Service Performance Requirements

Performance requirements identified in Step 1 of the above outline should provide answers to two important questions: 1) what is the material expected to do in the system or subsystem and 2) how long should it perform its function before replacement?

Step 2. Identify Key Functional Attributes (or Properties)

The key functional attributes (or properties) should be identified. The attributes should be based upon the requirements identified in Step 1. Functional attributes of materials typically used in solar energy systems are identified in table 6-1 and are divided into two categories: optical and physical. Optical attributes include absorptance, reflectance, emittance and transmittance. Physical attributes include abrasion resistance, adhesion, boiling point, burst strength, compression set, density, dimensional stability, electrical conductivity, embrittlement, expansion coefficient, flexural strength, freezing point, hardness, impact strength, melting point, permeability, specific heat, stress cracking, swelling/shrinking, tensile strength, thermal conductivity, ultimate elongation, viscosity and water absorption.

Table 6-1. Primary Functional Attributes of Materials Performance for Consideration in Selecting Materials for Use in Solar Energy Systems

Materials	OPTICAL (Functional Attributes)				PHYSICAL (Functional Attributes)																						
	Absorptance	Reflectance	Emittance	Transmittance	Abrasion resistance	Adhesion	Boiling point	Burst strength	Compression set	Density	Dimensional stability	Electrical conductivity	Embrittlement	Expansion coefficient	Flexural strength	Freezing point	Hardness	Impact strength	Permeability	Specific heat	Stress cracking	Swelling/shrinking	Tensile strength	Thermal conductivity	Ultimate elongation	Viscosity	Water absorption
A. COLLECTOR SUBSYSTEM																											
1. Absorptive Coatings																											
Solid	x		x			x							x	x										x			
Liquid or dispersed in transport fluid	x		x				x									x				x				x		x	
2. Absorber Substrate																											
Metallic														x										x			
Nonmetallic											x		x	x										x			
3. Cover Plates																											
Glass				x	x									x	x			x						x			
Plastics				x	x						x		x	x	x			x			x	x	x	x			
4. Insulation										x	x			x								x		x			x
5. Transport Liquids							x							x		x				x				x		x	
6. Containment																											
Metallic								x						x										x			
Nonmetallic								x			x		x	x					x			x	x	x			
7. Seals[1/]						x			x				x				x		x			x		x	x		
8. Reflective Surfaces		x	x			x					x			x													
9. Dessicants											x																x
10. Dielectric Insulators[1/]												x	x				x							x			
11. Enclosure					x						x		x	x	x			x	x					x			
12. Structural Supports														x	x						x		x				
13. Connections (adhesives, solders, etc.)[1/]						x							x	x			x				x			x			
B. TRANSPORT SUBSYSTEM																											
1. Piping																											
Metallic								x						x				x			x			x			
Nonmetallic								x					x	x				x			x	x	x	x			
2. Pipe Lining[2/]																											
Organic						x					x		x	x					x		x	x		x			
Inorganic						x							x	x					x		x			x			
3. Flexible Couplings																											
Metallic								x						x										x			
Nonmetallic								x	x				x				x					x	x	x	x		
4. Insulation										x	x											x		x			x
5. Filters/Getters										x	x																
C. STORAGE SUBSYSTEM																											
1. Tank Material																											
Metallic								x						x				x			x			x			
Nonmetallic								x			x		x	x				x			x	x		x			
2. Storage Media							x			x	x			x		x				x		x		x		x	
3. Insulation										x	x											x		x			
4. Heat Exchanger								x			x		x	x					x					x			

1/ Also applicable to transport and storage subsystems.
2/ Also applicable to storage liners.

Table 6-2. Primary Durability/Reliability and Safety Attributes of Materials Performance for Consideration in Selecting Materials for Use in Solar Energy Systems

Materials	DURABILITY/RELIABILITY: RESISTANCE TO									DURABILITY/RELIABILITY: COMPATIBILITY WITH			SAFETY		
	Elevated temperature	Depressed temperature	Thermal cycling	Solar radiation	Moisture	Pollutants	Ozone	Imposed stresses	Outgassing	Adjoining materials	Heat transport liquids	Soil constituents	Flammability	Toxicity	Structural adequacy
A. COLLECTOR SUBSYSTEM															
1. Absorptive Coatings															
Solid	x	x	x	x	x				x	x	x				
Liquid or dispersed in transport fluid	x	x	x	x						x	x			x	
2. Absorber Substrate															
Metallic	x	x	x		x			x		x	x				
Nonmetallic	x	x	x		x			x	x	x	x		x		
3. Cover Plates															
Glass	x	x	x					x		x					
Plastics	x	x	x	x	x	x	x	x		x			x		
4. Insulation	x		x		x			x	x	x					
5. Transport Liquids	x	x	x							x			x	x	
6. Containment															
Metallic	x	x	x		x					x	x				
Nonmetallic	x	x	x						x	x	x		x		
7. Seals 1/	x	x	x	x	x	x	x		x	x					
8. Reflective Surfaces		x	x	x	x	x				x					
9. Dessicants					x	x				x					
10. Dielectric Insulators 1/	x		x							x					
11. Enclosure		x	x	x	x	x		x		x			x		x
12. Structural Supports		x	x	x	x	x		x		x			x		x
13. Connections (adhesives, solders, etc.) 1/	x	x	x		x			x		x	x				x
B. TRANSPORT SUBSYSTEM															
1. Piping															
Metallic	x	x	x		x					x	x	x			
Nonmetallic	x	x	x		x	x				x	x	x	x		
2. Pipe Lining 2/															
Organic	x	x	x							x	x				
Inorganic	x	x	x							x	x				
3. Flexible Couplings															
Metallic	x	x	x		x			x		x	x				
Nonmetallic	x	x	x		x		x			x	x				
4. Insulation	x	x	x	x	x					x		x			
5. Filters/Getters	x		x							x	x				
C. STORAGE SUBSYSTEM															
1. Tank Material															
Metallic	x		x		x			x		x		x			
Nonmetallic	x	x	x		x			x		x		x	x		
2. Storage Media	x		x							x			x	x	
3. Insulation	x		x		x					x		x			
4. Heat Exchanger	x		x							x	x				

1/ Also applicable to transport and storage subsystems.
2/ Also applicable to storage liners.

Step 3. Identify Environmental Conditions to Which the Material Will be Exposed In-Service

The environmental conditions to which the material will be exposed in service should be identified. In particular, the temperature ranges, level of solar radiation and level and type of pollutants should be identified. The maximum temperature reached in service will probably be under stagnation conditions for collector materials and the solar radiation and pollutant levels will depend upon geographic location.

Step 4. Identify Key Durability/Reliability Attributes

The key durability/reliability attributes should be identified. The attributes should be based upon the performance requirements identified in Step 1 and the environmental conditions identified in Step 3. Table 6-2 contains a list of durability/reliability attributes. The list includes resistance to elevated temperature, depressed temperature, thermal cycling, solar radiation, moisture, pollutants, ozone, imposed stress and outgassing as well as compatibility with adjoining materials, heat transport liquids and soil constituents. Compatibility with adjoining materials includes chemical and physical compatibility and is important for each material. An example of the lack of chemical compatibility is corrosion caused by contact between two dissimilar materials while an example of the lack of physical compatibility is unacceptable levels of stress caused by the different thermal expansion coefficients of rigidly connected dissimilar materials. In Chapter 2, it was mentioned that one instance of extensive glass cover plate breakage in an operational system was observed. This breakage may have been the result of a lack of physical compatibility between the cover plates and the aluminum frame.

Step 5. Identify Key Safety Attributes

The key safety attributes should be identified. Safety attributes listed in table 6-2 include flammability, toxicity and structural adequacy.

Step 6. Identify the Types of Test or Field Data Needed

Based on the key attributes identified in steps 2, 4 and 5, the types of test of field data needed to demonstrate compliance with the level of required performance should be identified. This is a difficult task because of the lack of an adequate data base of materials performance and the lack of adequate standards for evaluating many materials. However, if the key attributes have been adequately defined in previous steps, the types of tests that should be performed can be identified and new tests can be designed or existing tests altered to give comparative data for the various materials being considered. The available standards identified in Chapter 4 should be helpful in this regard.

Step 7. Obtain Test Data

Once the types of materials performance data needed and tests to obtain the data are identified, the data should be obtained. Data are often available from manufacturers or in the technical literature for materials which have been used in the building industry. However, the adequacy of existing data must be assessed in view of the conditions of use in solar systems.

Step 8. Rank Candidate Materials

The materials should be ranked in order of predicted short-term and long-term performance based on the data obtained in Step 7. In particular, the adequacy of the material to perform its intended function both initially and for its design life should be addressed.

Step 9. Consider Factors Related to Maintainability, Cost and Code Compliance

Other factors affecting the selection of a material, such as maintainability, cost and code compliance, should be addressed.

Step 10. Select the Best Method

Based on materials performance data and other factors considered in Step 9, the "best" material should be selected.

7. REFERENCES

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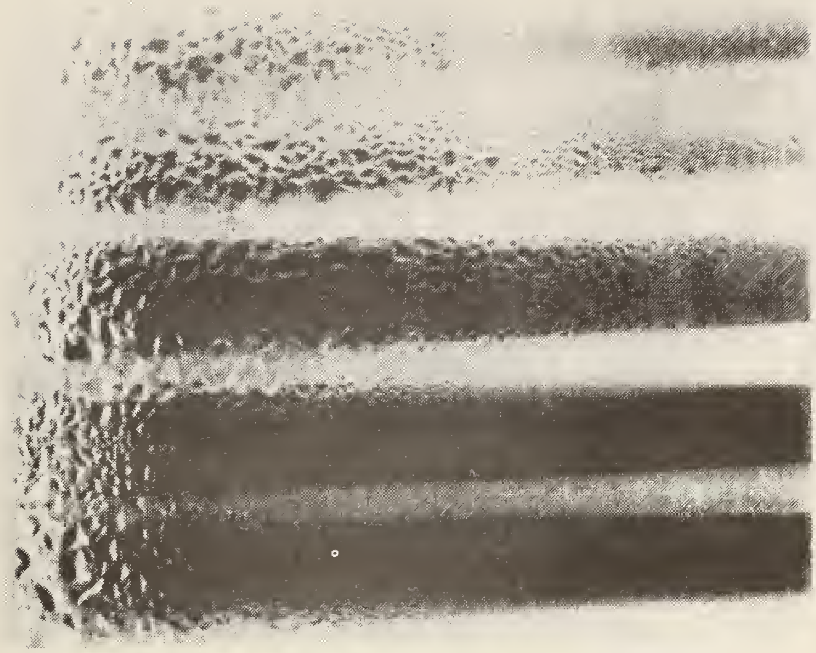

Figure 2-1. Condensation on Cover Plate Interior Surface

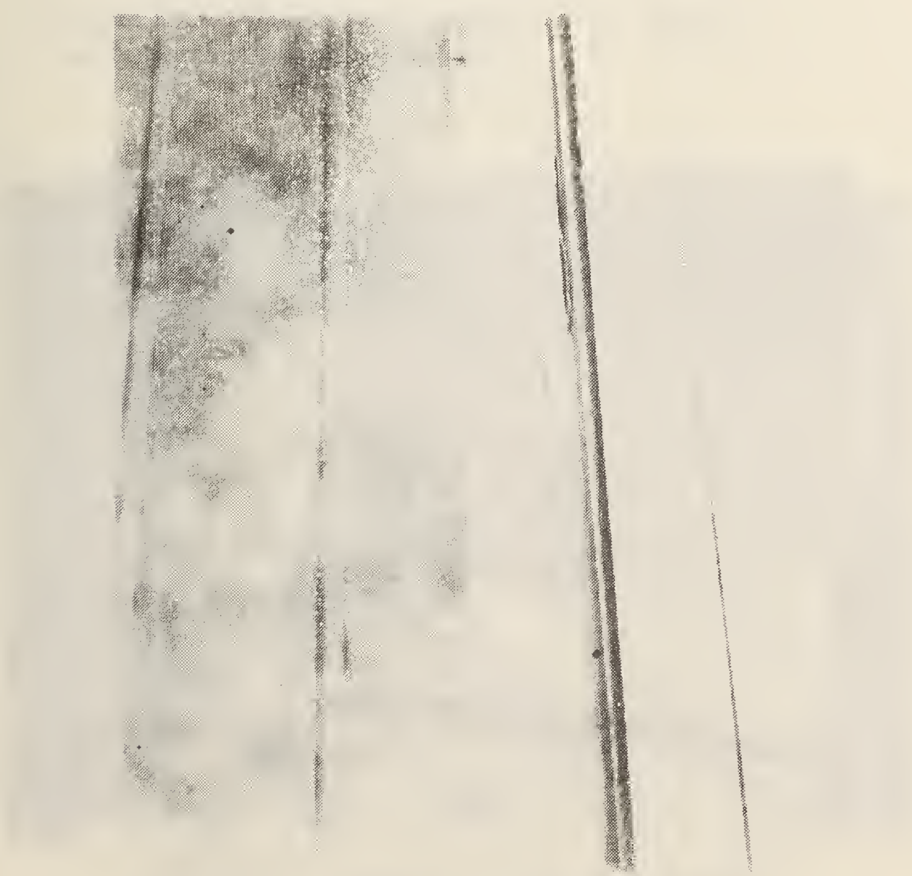

Figure 2-2. Deposits on Cover Plate Interior Surface

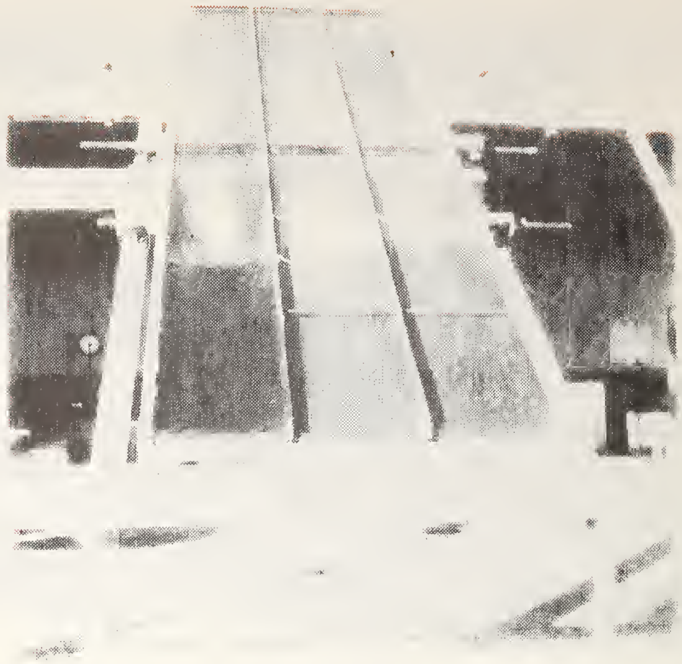

Figure 2-3. Fogging of Cover Plate Interior Surfaces Caused by Outgassing

Figure 2-4. Dirt on Cover Plate Exterior Surface

Figure 2-5. Dirt on Cover Plate Interior Surface

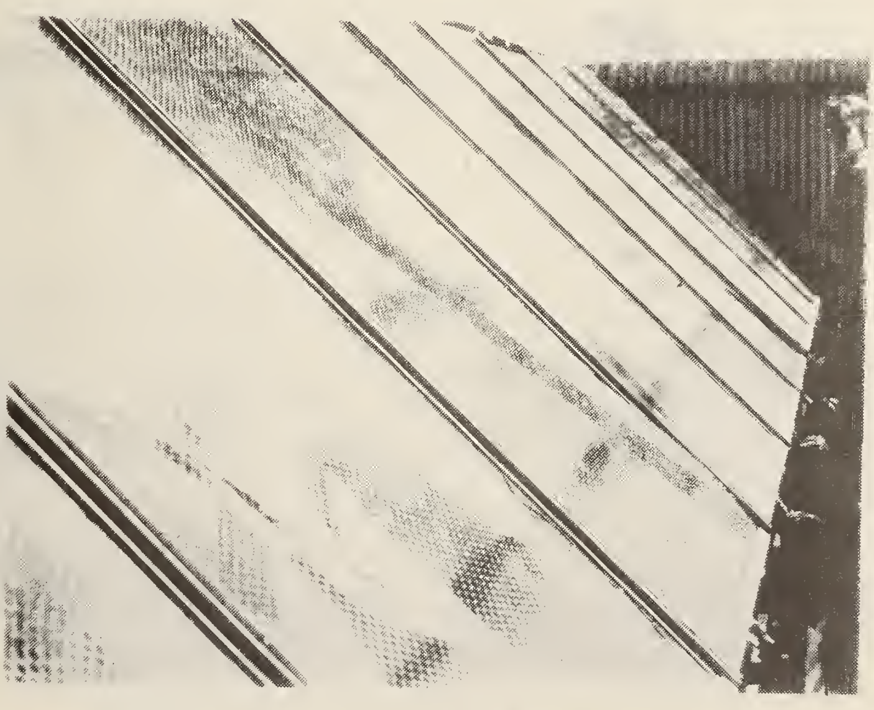

Figure 2-6. Extensive Breakage of Plate Glass Cover Plates

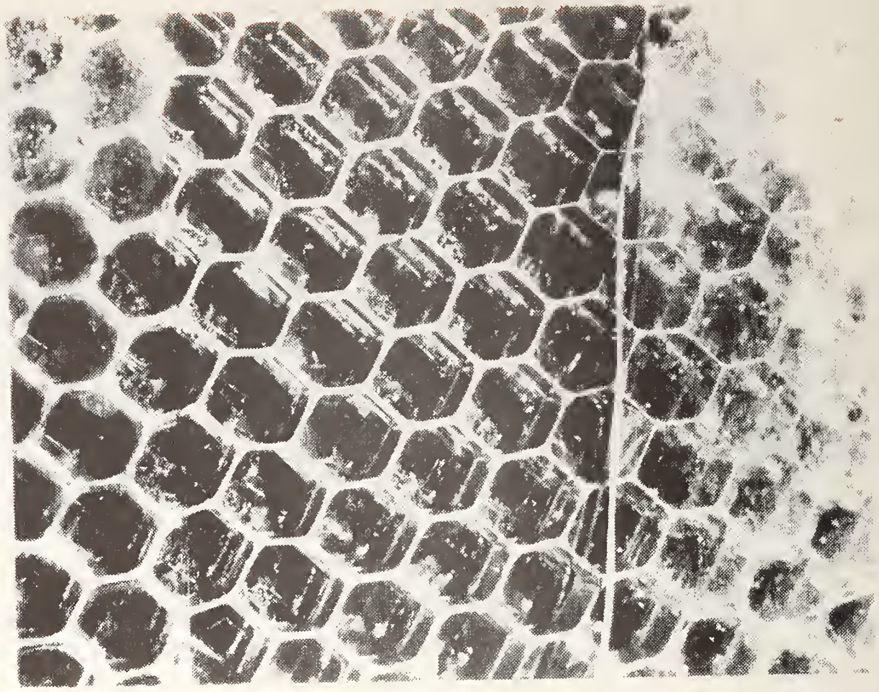

Figure 2-7. Adhesive Deterioration Which Resulted in Bond Failure Between Plate Glass Cover Plates and Aluminum Honeycomb Heat Trap

Figure 2-8. Plastic Heat Trap Distortion and Decomposition as a Result of Stagnation Exposure

Figure 2-9. Undersized and Improperly Bedded Tempered Glass Cover Plates

Figure 2-10. Warpage of Polycarbonate Cover Plates

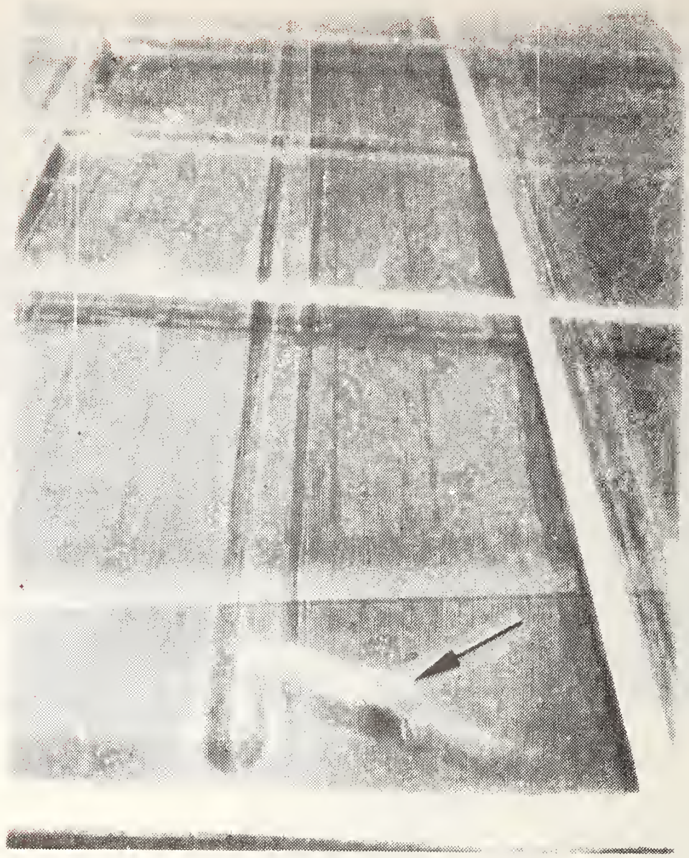

Figure 2-11. Incompatibility Between Polycarbonate Cover Plates and EPDM Standoffs

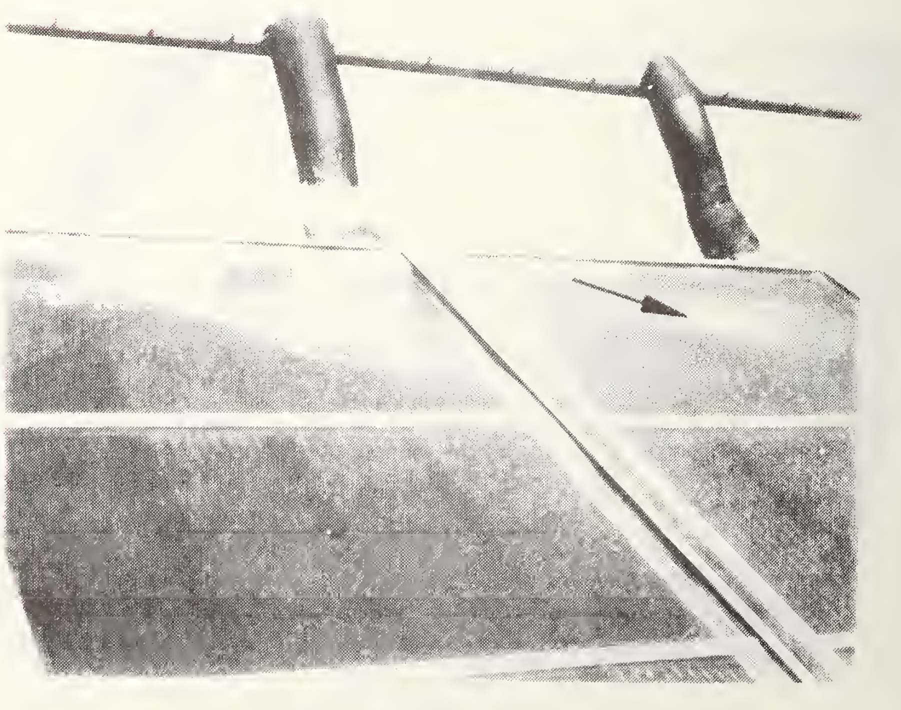

Figure 2-12. Absorber Plate and Cover Plate Warpage Resulting in Contact Between Absorber and Cover

Figure 2-13. Cracking of Polycarbonate Cover Plates at Edge of Indented Stiffening Ribs

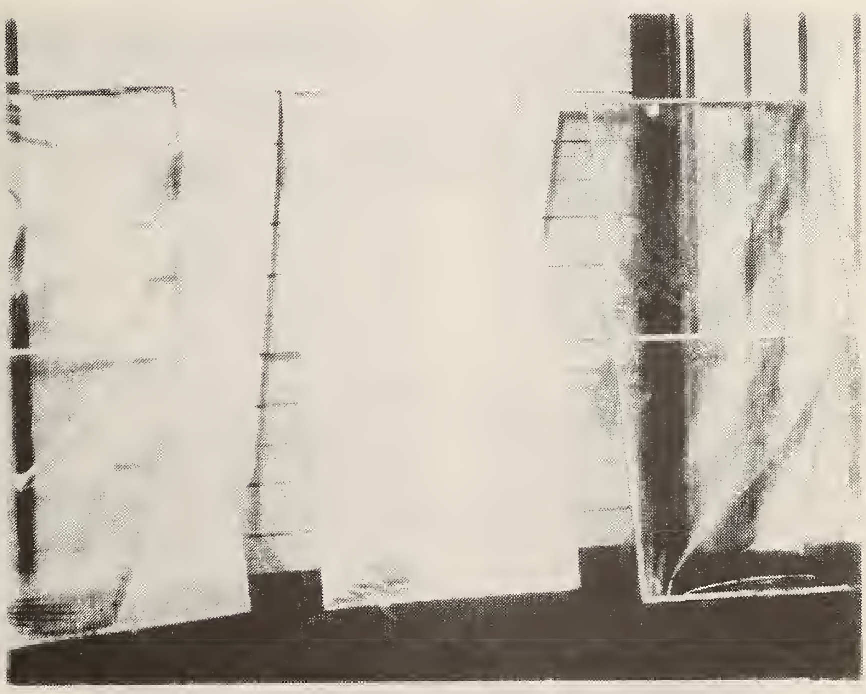

Figure 2-14. Embrittlement of Polyvinyl Fluoride Cover Plates after Exposure to Stagnation Conditions

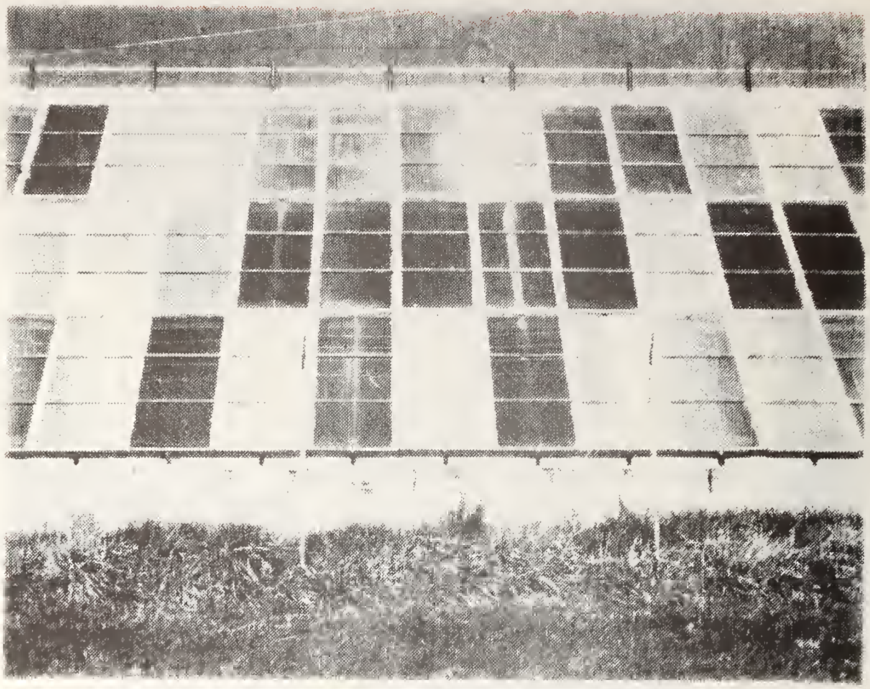

Figure 2-15. Color Variations of Anodized Aluminum Absorber

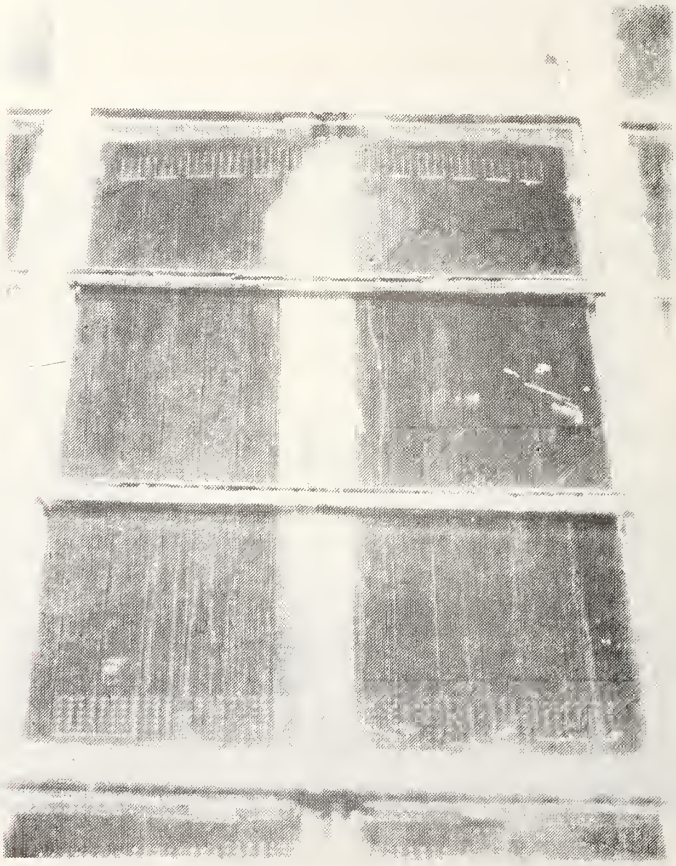

Figure 2-16. Effect of Transfer Fluid Flows, Due to Hose Failure, on the Color of Anodized Aluminum Absorber

Figure 2-18. Adhesion Failure of Absorber Coating to Steel

Figure 2-17. Formation of Deposits on Absorber Coating

Figure 2-19. Leaking Aluminum Absorber Plate

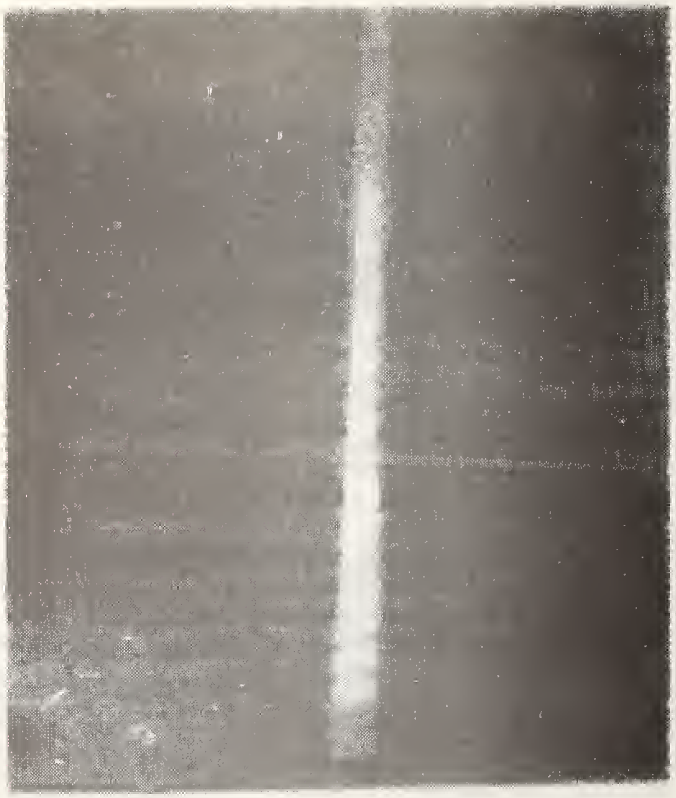

Figure 2-20. Gaps in Absorber Plate Resulting in Exposure of Insulation

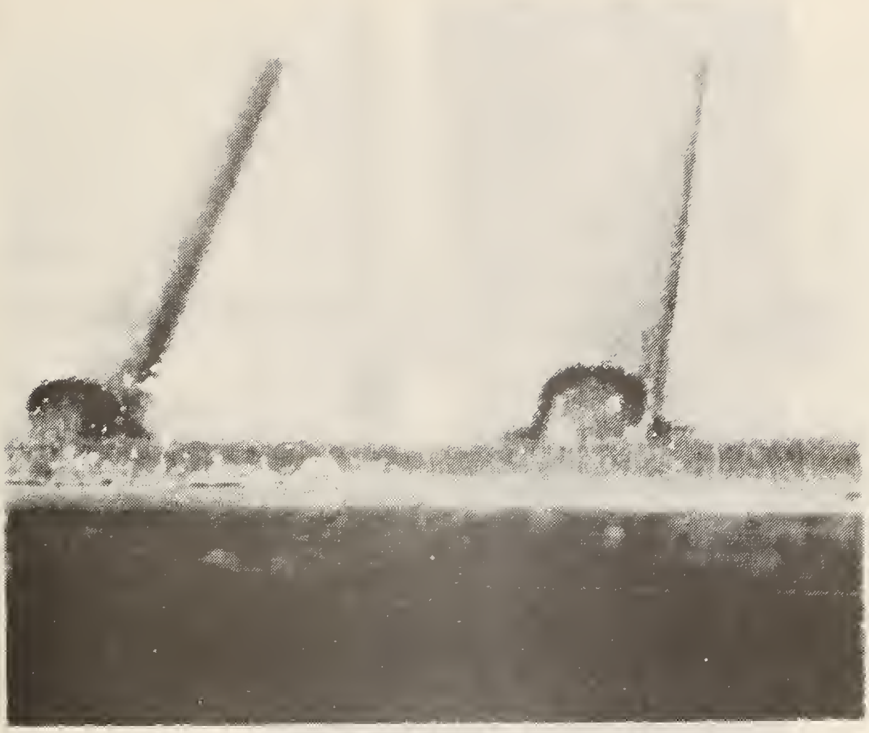

Figure 2-21. Failure of Joint Between Fluid Conduits and Absorber Plate

Figure 2-22. Aluminum Weld Failures

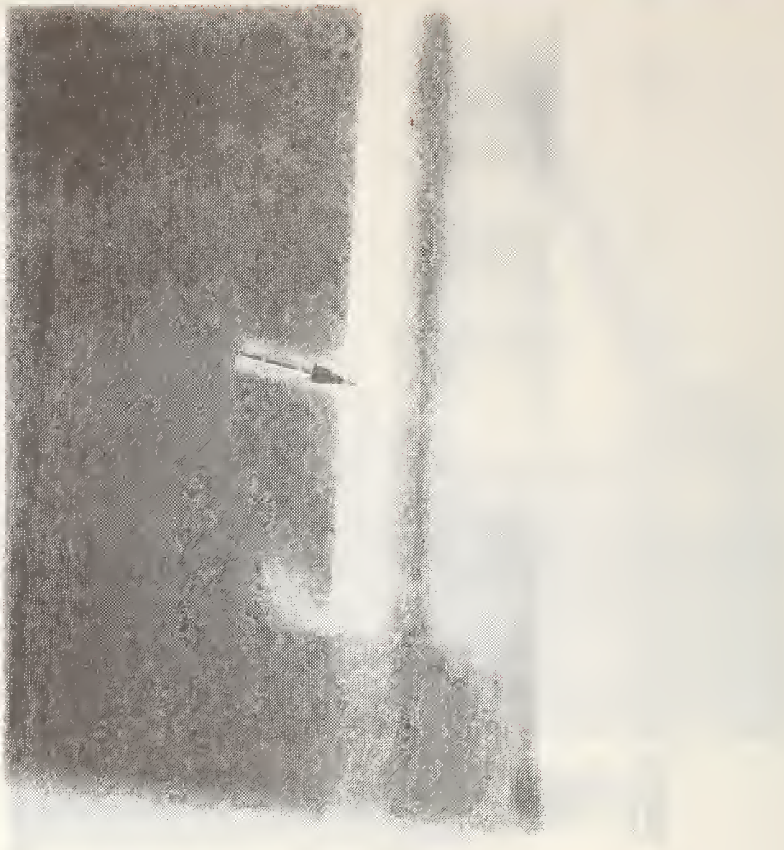

Figure 2-23. Exposed Urethane Collector Insulation

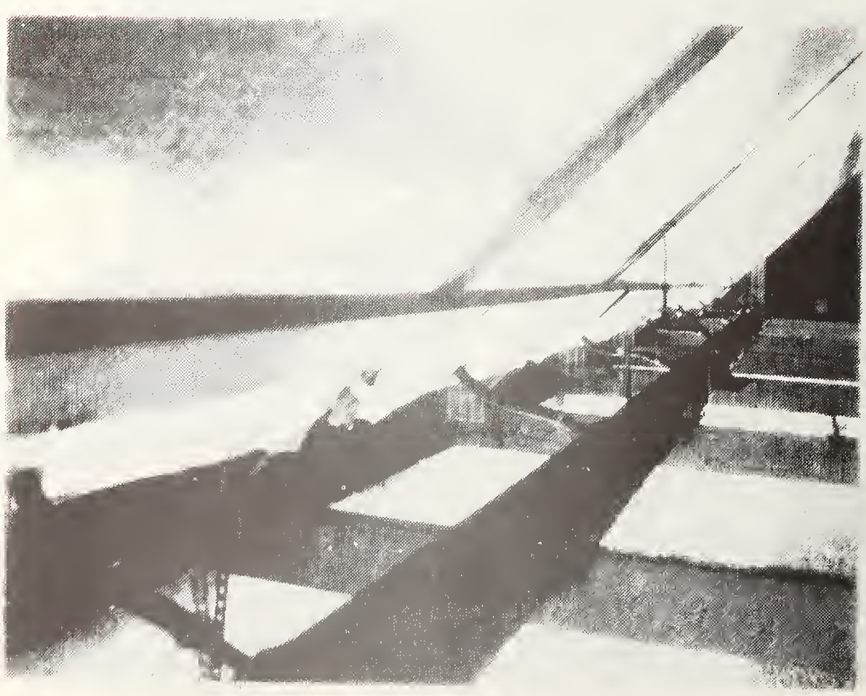

Figure 2-24. Fiberglass Insulation Sagging Away from Back of Absorber Plate

Figure 2-25. Failure of Sealant Between Tempered Glass Covers and Aluminum Extrusion

Figure 2-26. Discoloration of Silicone Seals

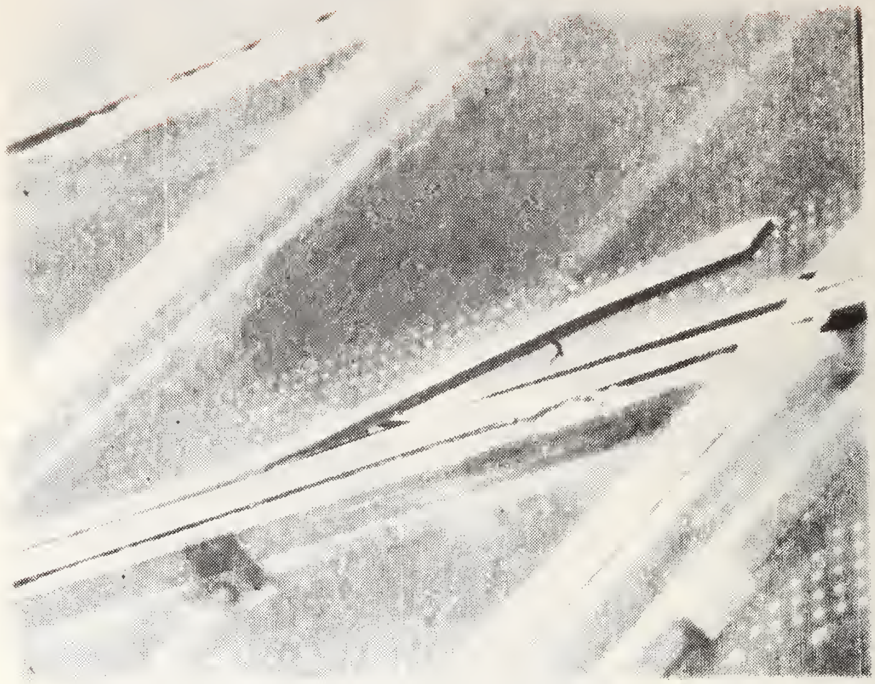

Figure 2-27. Deterioration of Wooden Restraining Frames

Figure 2-28. Reflective Surfaces

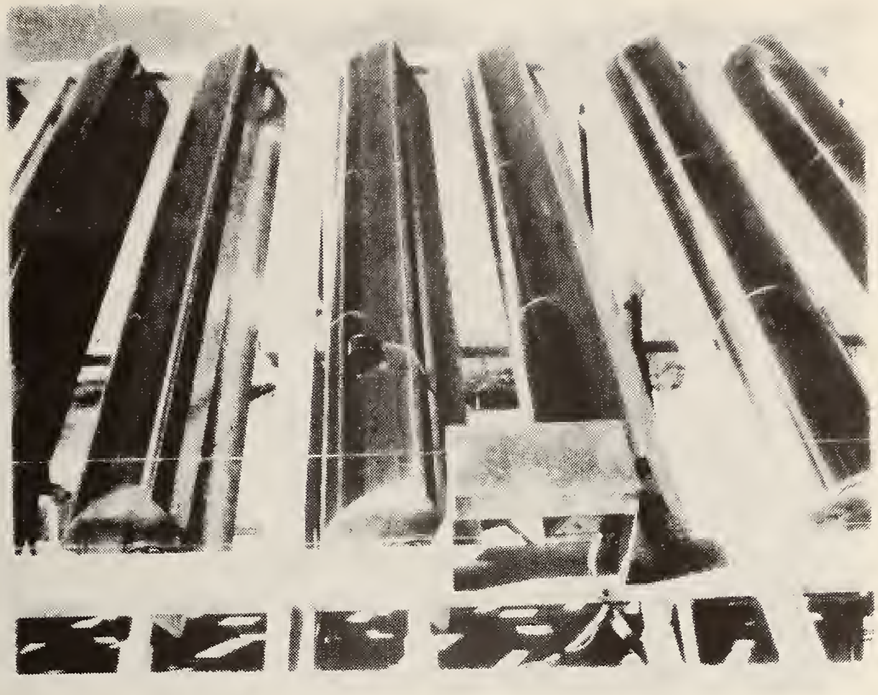

Figure 2-29. Tracking Collectors

Figure 2-30. Concentrating Collector with Roof Mounted Reflective Surfaces

Figure 2-31. Evacuated Tube Breakage

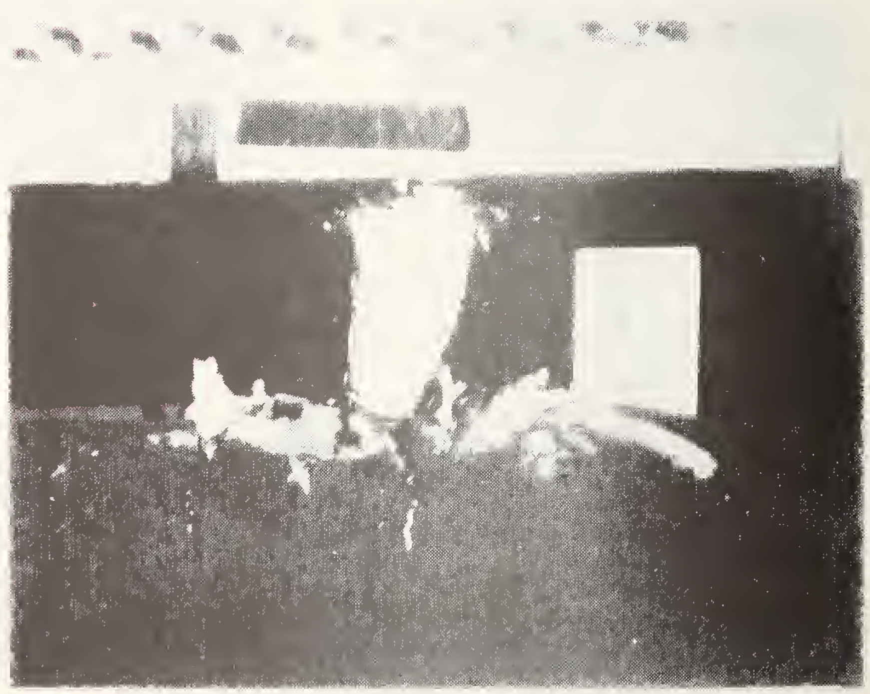

Figure 2-32. Field Expedient Repair of Flexible Coupling Hose

Figure 2-33. Copper Coil Replacement of Flexible Hoses

Figure 2-34. Inaccessible Hose Connection

Figure 2-35. Uninsulated Flexible Coupling

Figure 2-36. Surface Cracking on Cellular Insulation

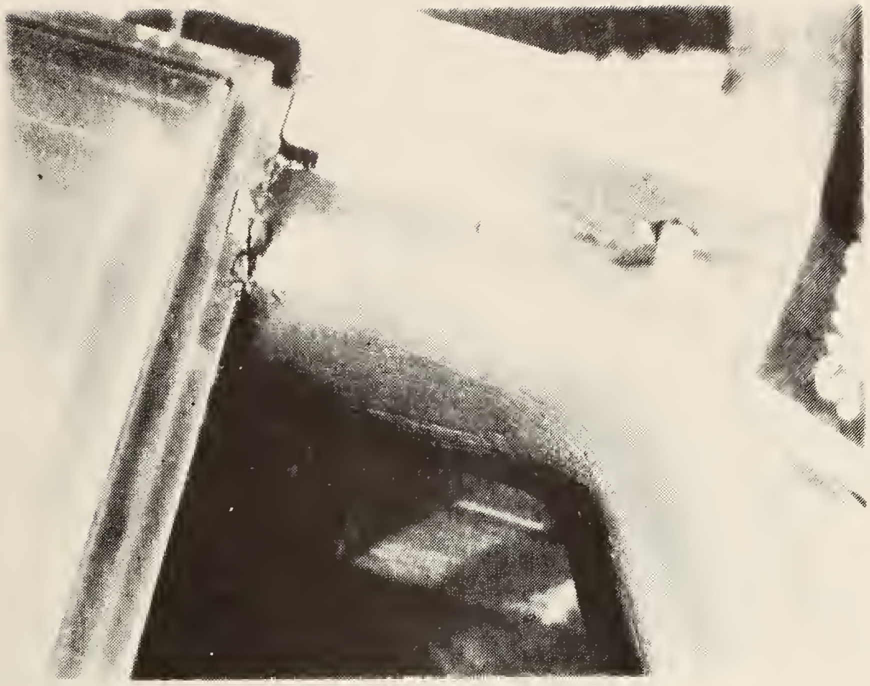

Figure 2-37. Effective Coating Protection on Cellular Insulation

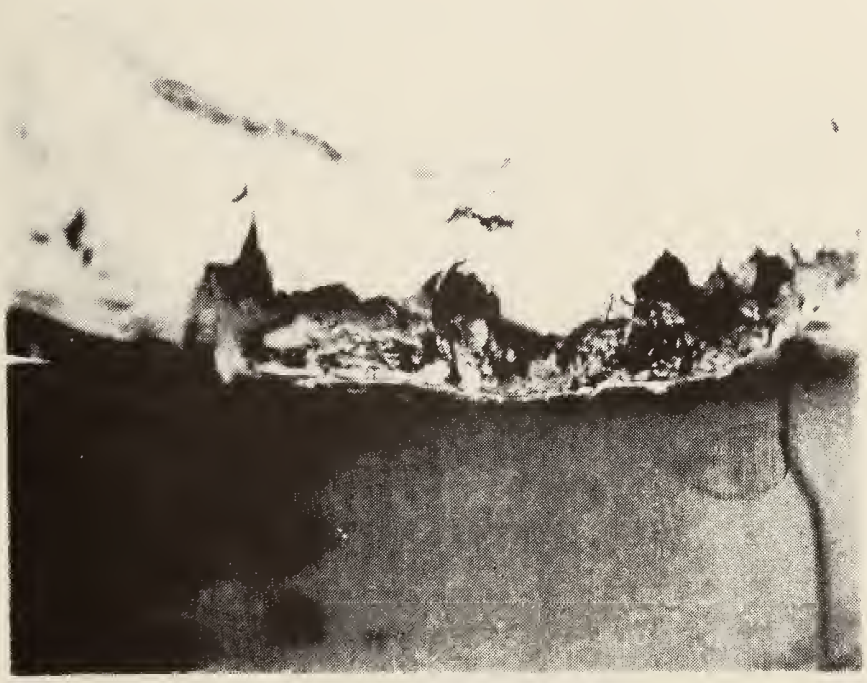

Figure 2-38. Deterioration of Vermiculite Plaster Storage Tank Insulation

APPENDIX A

Mr. John Doe
600 Main Street
Anywhere, U. S. A.

Dear Mr. Doe:

The National Bureau of Standards (NBS) has initiated a project, sponsored by the Energy Research and Development Administration (ERDA), to identify the needs for performance standards for materials used in solar energy systems. The results of the project will include recommended priorities for the development of materials standards and recommended laboratory studies needed to develop the standards. The recommended priorities and recommended laboratory studies for the development of materials standards will aid ERDA in its effort to support the development of consensus standards through standards setting organizations such as ASTM and ANSI.

The purposes of this letter are to briefly describe the project and to ask your cooperation and assistance in obtaining data regarding the types of materials used and the performance of materials in currently operative solar energy systems.

One part of the project will include tasks to (1) identify solar energy systems that are currently being used in the field and their locations, (2) identify the types of materials used and obtain information regarding materials performance in those systems by communicating with manufacturers, installation contractors, and other knowledgeable sources.

Your company has been identified by the Solar Energy Industries Association as an installation contractor of solar energy systems. In order to complete the project, your assistance in providing the following information is needed: (1) the types of materials used, and (2) the performance of the materials in operational systems that have been installed by your company. A form is enclosed for presenting the information along with a brief instruction sheet. Your cooperation in completing the form will be greatly appreciated. The reports prepared during the project will not refer to specific systems by manufacturer's name or to sources of data. The data will be compiled and presented solely for the purpose of illustrating the types of materials that have performed well and those that have experienced problems in the field.

The project is being performed in a compressed time frame so that the results can be used in standards development activities. Your response within thirty days will help keep the project on schedule.

Thank you for any assistance you can provide in this activity. If you have any questions, please contact me or Larry Masters at any time. The phone number is 301-921-3371.

Sincerely,

Leo F. Skoda
National Bureau of Standards
Materials and Composites Section
Building 226, Room B-348
Washington, DC 20234

Enclosures

OMB No. 38-S76003, Approval Expires 9/30/77

NBS-1061
(12-76)

U.S. DEPARTMENT OF COMMERCE
NATIONAL BUREAU OF STANDARDS

This Report is authorized by law (42 U.S.C. 5813). While you are not required to respond, your cooperation is needed to make the results of this survey comprehensive, accurate and timely.

DATA SHEET FOR OPERATIONAL SOLAR ENERGY SYSTEMS

Part I - Manufacturer or Installer of System

(Check one) ☐ Manufacturer or ☐ Installation Contractor

Name and Address of Above

Person to Contact

Telephone No.
(   )

Part II - Building and System Information

How many buildings are equipped with operational solar systems manufactured or installed by your Company?

PLEASE PROVIDE, TO THE EXTENT POSSIBLE, THE FOLLOWING INFORMATION:

Name of System Manufacturer	BUILDING			Installation Date	FUNCTION OF SYSTEM		
	Designation Number	Owner	Address		Domestic Hot Water	Heating	Cooling
	1						
	2						
	3						
	4						

Part III - Collector Information

	BUILDING DESIGNATION NUMBER			
	1	2	3	4
A. General 1. Collector manufacturer (if different from parent company)				
2. Model number				
3. Type of collector (✓ as applicable) a. Flat plate				
b. Concentrating				
c. Air				
d. Liquid (designate open or closed)				
4. Number of collectors in system				
5. Liquid transfer medium (if applicable) a. Type				
b. Additives				
c. Flow rate				
B. Cover Plates 1. Material and thickness a. Primary				
b. Secondary				
c. Other				
2. Type of reflective coating, if applicable (material and thickness)				
C. Absorber 1. Absorptive coating (material and thickness)				
2. Substrate (material and thickness)				
D. Collector Fluid Passages 1. Material and thickness				
2. Material used to bond passages to substrate				
E. Gaskets and Sealants 1. Material and manufacturer				
2. Locations of use within collector				

Part III - Collector Information (continued)

	BUILDING DESIGNATION NUMBER			
	1	2	3	4
F. Insulation 1. Material (s) and thickness				
2. Locations of Use (✓ as applicable) a. Back				
b. Edge				
G. Collector Enclosure (other than cover plates) 1. Material and thickness				
2. Type of protective finish				
H. Reflectors 1. Material				
2. Coating or finish (if applicable)				
I. Dessicants 1. Material				
2. Location				
J. Have changes been observed in any of the collector materials that have affected the performance of the collector?	☐ Yes ☐ No	☐ Yes ☐ No	☐ Yes ☐ No	☐ Yes ☐ No
K. Has it been necessary to repair or replace due to inadequate performance?	☐ Yes ☐ No	☐ Yes ☐ No	☐ Yes ☐ No	☐ Yes ☐ No
L. Have signs of corrosion been observed in the collector?	☐ Yes ☐ No	☐ Yes ☐ No	☐ Yes ☐ No	☐ Yes ☐ No
Part IV - Thermal Storage Information				
A. Tank or Container 1. Storage manufacturer (if different than parent company)				
2. Material and wall thickness				
3. Location (✓ as applicable) a. Buried				
b. Above ground (sheltered)				
c. Above ground (unsheltered)				
d. In basement				

Part IV - Thermal Storage Information *(continued)*

	BUILDING DESIGNATION NUMBER			
	1	2	3	4
A. Tank or Container *(continued)*				
4. Interior finish or coating				
5. Exterior finish or coating				
B. Storage Medium 1. Liquid (type)				
2. Aggregates (type)				
3. Other (type)				
C. Tank or Container Insulation 1. Material and thickness				
2. Protective coating (if applicable)				
D. Gaskets and Sealants (if applicable) 1. Materials and manufacturer				
2. Locations of use				
E. Are heat exchangers used inside the tank or container?	☐ Yes ☐ No	☐ Yes ☐ No	☐ Yes ☐ No	☐ Yes ☐ No
F. Have changes been observed in any of the storage materials that affect the performance of the system?	☐ Yes ☐ No	☐ Yes ☐ No	☐ Yes ☐ No	☐ Yes ☐ No
G. Has it been necessary to repair or replace materials due to inadequate performance?	☐ Yes ☐ No	☐ Yes ☐ No	☐ Yes ☐ No	☐ Yes ☐ No
H. Have signs of corrosion been observed in the storage subsystem?	☐ Yes ☐ No	☐ Yes ☐ No	☐ Yes ☐ No	☐ Yes ☐ No
Part V - Energy Transport Information				
A. Inlet piping or ducting (from storage to collector) 1. Material and wall thickness				
B. Outlet piping or ducting (from collector to storage) 1. Material and wall thickness				
C. Manifolding (if used) 1. Material and thickness				
D. Connections 1. Rigid (check as applicable)				
a. Soldered				
b. Bonded				
c. Threaded				
d. Bolted				

Part V - Energy Transport Information *(continued)*

D. Connections (continued)	BUILDING DESIGNATION NUMBER 1	2	3	4
2. Flexible a. Material and manufacturer				
b. Attachment method (e.g., clamped, threaded)				
c. Location (1) Indoors				
(2) Outdoors				
E. Insulation 1. Material and thickness				
2. Protective coating (if applicable)				
F. Gaskets and Sealants 1. Material and manufacturer				
2. Locations of use				
G. Filters and/or Getters 1. Type				
2. Location				
H. Have changes been observed in any of the transport materials that affected the performance of the system?	☐ Yes ☐ No	☐ Yes ☐ No	☐ Yes ☐ No	☐ Yes ☐ No
I. Has it been necessary to repair or replace materials due to inadequate performance?	☐ Yes ☐ No	☐ Yes ☐ No	☐ Yes ☐ No	☐ Yes ☐ No
J. Have signs of corrosion been observed in the transport subsystem?	☐ Yes ☐ No	☐ Yes ☐ No	☐ Yes ☐ No	☐ Yes ☐ No

PLEASE RETURN TO:

Larry W. Masters
Building Research, Room B348
National Bureau of Standards
Washington, D. C. 20234

USCOMM-NBS-DC

Instructions for Completion of "Data Sheet for Operational Solar Energy Systems"

Part I. MANUFACTURER OR INSTALLER OF SYSTEM

Name of person to contact: The individual sited here should be one that is familar with the operation of the solar systems reported as to materials durability and required maintenance. A follow-up phone call to this individual will be made after return of the data sheet to NBS to discuss materials performance.

Part II. BUILDING AND SYSTEM INFORMATION

Building Designation Number: Please assign a number (Building Designation Number) to each building that contains an operational solar energy system manufactured or installed by your company. Use these same numbers in completing Parts III, IV and V of the questionnaire. Space is provided on the forms for up to four buildings. If more than four buildings are available, please include the building that has been equipped with a solar system for the longest time, the building most recently equipped with a solar system and two other buildings which, in your opinion, illustrate typical materials performance data observed by you in regard to solar energy systems.

Part III. COLLECTOR INFORMATION

A.3. "Open" collector refers to a trickle system. "Closed" refers to a collector in which the transfer fluid cannot absorb oxygen in addition to that which is in the fluid initially.

B.1. "Primary" cover plate is the outermost plate, i.e. the one that forms the exterior envelope of the collector.

B.2. The "reflective coating" is the material (if any) applied to the underside of each cover plate.

D.2. Refers to mechanism for attaching tubing to absorber plate, i.e. solder, adhesive, mechanical clamp, etc.

F.1. Include all insulating materials and thicknesses used if more than one.

F.2.a. "Back" refers to insulation used behind absorber plate.

F.2.b. "Edge" refers to peripheral insulation.

I.1.2. Report generic name or trade name if generic name is not used. "Location" would refer to loose dessicant within collector body or dessicant filled vent plugs, etc.

J-K-L. If the answer to any of these questions is "yes" it is not necessary to explain in detail as the details will be discussed in follow-up telephone conversations.

Part IV. THERMAL STORAGE INFORMATION

A.5. Exterior finish refers to material applied directly to container surface not including insulation. Insulation and coatings for insulation to be reported in IV-C.

B.1. Water, potable water, or other transfer liquid.

D.1 & D.2. Materials used (gaskets or sealants) at inlets or outlets of storage tank or container.

F-G-H. If the answer to any of these questions is "yes" it is not necessary to explain in detail as the details will be discussed in the follow-up telephone conversations.

Part V. ENERGY TRANSPORT INFORMATION

A-B. If more than one size or type of material is used, please report all sizes and types.

C. "Manifolding" refers to any special method of interconnecting collectors other than those listed in D-1 and D-2.

D.1. If more than one connection system is used indicate type and where used, i.e. soldered at collector, threaded at tank, bonded to pumps, etc.

D.2. Refers to any flexible connectors used, for example, connecting collectors with rubber hose, etc.

D.2.b. If clamps are used on flexible rubber or plastic connectors, indicate whether spring type, worm drive open web, worm drive solid band, etc.

D.2.c. If flexible hose connectors are used outdoors indicate if any protective coating or covering is used.

E.1 & E.2. Pipe or duct insulation only.

F.1 & F.2. Include gaskets or sealants used at inlet and outlet of pumps or blowers and at connections to collectors (if any).

G. Filters or getter columns refer to liquid systems only.

H-I-J. If the answer to any of these questions is "yes" it is not necessary to explain in detail as the details will be discussed in the follow-up telephone conversations.

APPENDIX B

AAI Corporation
Box 6767
Baltimore, MD 21204
Irwin R. Barr

A-1 Hydro Mechanics Corporation
94-150 Leokane Street
Waipahu, Oahu, Hawaii 96797

The A. Bentley & Sons Company
P. O. Box 956
Toledo, OH 43695
John D. Hilton

Acorn Glas - Tint International
1123 W. Century Blvd.
Los Angeles, CA 90044
Chris T. Dunkle

A. Goodman & Company, Inc.
7621 Greenwood Avenue, S.
Chicago, IL 60619
Robert L. Goodman, V.P.

Aaron Plumbing & Mechanical Systems, Inc.
15 Poland Place
Staten Island, NY 10314
Paul Gardner, Pres.

Albuquerque Western Industry, Inc.
Albuquerque, NM 87107

Alcan Aluminum Corp.
1108 Hereford Rd.
Cleveland Heights, OH 44112

Allied Fabricators, Inc.
1254 Thomas Avenue
San Francisco, CA 94124

Alpha Designs
Suite 2230 Kroeger Bldg.
Cincinnati, OH 45202
M. Uroshevich

Alternative Systems
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Conway, NH 03818
Russ Lanoie

Aluminum Company of America
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Pittsburgh, PA 15219
William M. Foster

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Hasbruck Heights, NJ 07604

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Boulder, CA 80302
J. P. Sayler

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Denver, CO 80237
Bill L. Phillips, Pres.

American Pool Service Corporation
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Wayne, PA 19087
Samuel C. Miller, Pres.

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Edward Smith, President

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Albert H. Ziegler

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James Bartell, Pres.

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Brian Pardo, Pres.

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Hatfield, PA 19440
John Bowen

Arizona Solar Enterprises
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Scottsdale, AZ 85257

Arkla Industries Inc.
Special Products Division
400 East Capitol
Little Rock, AR 72203
Thomas M. Helms

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Falls Church, VA 22042
Mr. Robert A. Hermann

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Atlantic Solar Products, Inc.
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11800 Sunrise Valley Drive
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D. L. Ringwalt, Jr., Pres.

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Rehoboth, MA 02769
John M. McNamara

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San Antonio, TX 78102
Earl Brown

Barber-Nicols Engineering Co.
6325 West 55th Ave.
Arvada, CO 80002
Kenneth E. Nichols

Barwood
Boca Raton, FL 33432
George H. Sparling

B. Gilbert Contracting Company
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Bristol, CT 06010
Bruno J. Gilbert

Barrett Heating & Air
Conditioning Company, Inc.
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Bayshore, NY 11706
Gary Shoemaker

Basic Designs, Inc.
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Sausalito, CA 94965

Bateman & Son, Inc.
2004 Rhode Island Avenue, N.E.
Washington, D.C. 20018
Joseph L. Bateman, Pres.

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Edison, NJ 08817
Calvin C. Beatty

Boeing Aerospace Company
Field Operations and Support Division
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Mail stop 85-57
Seattle, WA 98124
John H. McGowan

R. H. Bohman
Amana Refrigeration Inc.
Amana, IA 52203

Mr. Stanley R. Borgman
709 N. Federal Hy.
Stuart, FL 33494

Bonhag Company, Inc.
116 Washington Avenue
Hawthorne, NJ 07506
Wayne T. Bonhag, V.P.

Brewer Sheet Metal Company
125 Garfield Avenue
West Chester, PA 19380
Vernon S. Brewer

Bright Horizons
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Carollton, TX 75006
Mike Goetz

Brown Manufacturing Co.
P. O. Box 14546
Oklahoma City, OK 73114
Russell Brown

D.W. Browning Contracting Co.
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Holly Hill, FL 32017
Don Willis

Burke Rubber Co.
2250 S. Tenth St.
San Jose, CA 95112

Business & Technology, Inc.
2800 Upton Street, N.W.
Washington, D.C. 20008
S. Molivadas, Pres.

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Gulph Mills
King of Prussia, PA 19406
Robert Buswick

Butler Ventamatic Corporation
P.O. Box 728
Mineral Wells, TX 76067
Terry Siegel, V.P.

John C. Byram, Jr.
615 W. 50th Street
Kansas City, MO 64112

Calmac Manufacturing Corporation
150 S. Van Brunt Street, Box 710
Englewood, NJ 07631
Calvin D. McCracken

Cambridge Development Group
Rt. 2, Yacht Cove Road
Columbia, SC 29210
Keith B. Belser

Carlisle Tire & Rubber Co.
P. O. Box 99
Carlisle, PA 17013

Carrier Air Condition Co.
Carrier Parkway
Syracuse, NY 13201

Caster Development Co.
634 Crest Drive
El Cajon, CA 92021

Central Virginia Sunglow
4905 Radford Avenue
Richmond, VA 23230
Donald K. Hudson, Pres.

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Valley Forge, PA 19482

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Elmhurst IL 60126
Charles H. Franke

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Lanham, MD 20801
Paul M. Emmons

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5573 North Street
Dryden, MI 48428
Henry H. Leck

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7949 Towers - P. O. Drawer 10
Santee, CA 92071
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George W. Myler

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Walter H. Barrett

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Sacramento, CA 95814
Edward R. Atkins

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Dr. E.S. Rittner

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Seymour Polansky, Pres.

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Howard Kraye

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Philadelphia, PA 19104

Copper Development Association
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New York, NY 10017
George M. Hartley

Crayton Enterprises, Inc.
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Tampa, FL 33614
Gary F. Crayton, Pres.

Daylin, Inc.
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Beverly Hills, CA 90210

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Clearwater, FL 33520
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Rodney E. Boyd

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Frank J. Ginther

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15. SUPPLEMENTARY NOTES

16. ABSTRACT *(A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here.)*

A study was performed to obtain data regarding the performance of materials in operational solar energy systems, to identify and assess available standards for evaluating materials, to provide recommendations for the development of test method standards for materials and to provide guidelines to aid the selection of materials for use in solar energy systems. During the study, field inspections of approximately twenty-five operational solar energy systems were performed and a questionnaire was sent to 459 manufacturers and installation contractors to obtain materials performance data. This report contains the findings of the study. A primary conclusion is that the process of selecting materials for specific applications within solar energy systems is hindered by the lack of an adequate data base of materials performance under the conditions experienced in solar systems and subsystems. Recommendations are made that would help in establishing an improved data base.

17. KEY WORDS *(six to twelve entries; alphabetical order; capitalize only the first letter of the first key word unless a proper name; separated by semicolons)*

Absorber coatings; absorber plates; cover plates; enclosure; insulation; materials performance; reflective surfaces; seals; selection of materials; solar energy systems; standards

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