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PRELIMINARY DESIGN REVIEW PACKAGE ON AIR FLAT PLATE COLLECTOR FOR SOLAR HEATING AND COOLING SYSTEM

Prepared by

Life Sciences Engineering
Route 1, Box 746
Morrison, Colorado 80465

Under Contract NAS8-32261 with

National Aeronautics and Space Administration
George C. Marshall Space Flight Center, Alabama 35812

For the U. S. Department of Energy

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This work was done under the technical management of Mr. John Caudle, George C. Marshall Space Flight Center, Alabama.

16. ABSTRACT

This Preliminary Design Review Package as received from Life Sciences Engineering covers development and fabrication of a prototype air flat plate collector subsystem containing 320 square feet (10-4' x 8' panels) of collector area.

The package contains:

- Verification Plan
- Thermal Analysis
- Safety Hazard Analysis
- Drawing List
- Special Handling, Installation and Maintenance Tools
- Structural Analysis
- Selected Drawings

The MSFC review and critique of this Design Review Package are not included.

Some reformatting and renumbering of this package have been done for clarity purposes.

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SECTION A

VERIFICATION PLAN
No. SHC-3071

Air Flat Plate Collector

December 30, 1976

Life Sciences Engineering
Rt. 1, Box 746
Morrison, Colorado 80465

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1. Introduction

This Verification Plan is a process of proving that the hardware meets applicable physical and functional design requirements. The process begins with the Development Phase and is completed at the end of the Verification Phase.

1.1. Purpose

The purpose of the Verification Plan is to verify that the subsystem and components comply with the Subsystems Performance Specification. Where applicable, special handling and maintenance equipment will be evaluated to ensure they meet design requirements.

1.2. Objectives

The tasks specified in the Statement of Work and in Appendix C shall be accomplished to meet the following objectives:

1.2.1 Meet Interim Performance Criteria

1.2.2 Meet Subsystem Performance Specifications

1.2.3 Meet Design Requirements for special handling, installation and maintenance equipment

2. Development Phase

During the Development Phase analyses and tests of various design approaches will ensure that the final selected approach will result in reliable hardware that will function with a high probability of success. The Test Matrix, Figure 2-1 shows the various design tests to be accomplished. The Air Flow/Plenum Depth testing is considered very important to the design concepts and to the Subsystem Performance Specification. This test is designed to determine the optimum plenum spacing and air flow rate for the collector to provide a maximum temperature of 130°F for heated air at the outlet at the register in the house.

3. Verification Phase

The final selected approach determined during the Development Phase will be analyzed and tested to design limits to ensure that it meets the physical and functional requirements. Qualification testing is planned to be completed prior to manufacturing the deliverable prototype units. If an item has not changed to the extent that it would invalidate the Development Test Results, then the development test results may be used as a basis for qualifying the item in lieu of running qualification tests.

4. Acceptance Phase

The Acceptance Phase consists of inspecting and testing the subsystem to verify that physical and operational characteristics are within specifications.

5. Verification Cross Reference Matrix

The following Verification Cross Reference Matrix briefly summarizes individual performance requirements and the verification method used in each verification phase to assure compliance. Section 6 provides the rationale for the verification method and explains comments in the Remarks column.

6. Verification Method Rationale

This section will provide an explanation for the verification method (1. similarity, 2. analysis, 3. inspection and 4. test) selected for the individual performance requirement in the Verification Cross Reference Matrix. In addition, comments briefly mentioned in the Remarks column will be elaborated upon. Items that were designated 'NA' on the October 1, 1976 Verification Crosss Reference Matrix will not be elaborated upon.

Paragraph	Explanation
1.2.4 Operational Impairment	This item is considered NA as paragraph 1.2 specifies HW System/Subsystem Performance. This is a heating system only.
1.3 Collector Performance	Collector performance shall be determined by evaluation of the drawings, analytical calculations and testing under operational conditions, as further described in the following paragraph.
1.3.1 Collector Efficiency	Test Data shall be presented at the Design Reviews. This data includes: input air temperature and flow rate output air temperature collector absorber back surface temperatures solar radiation outside ambient temperature and time
2.1 System Design Conditions	The collector shall be operated and tested at the design temperatures and flow rates and in accordance with the following paragraphs:

Capabilities — rates will be monitored with Thomas meters. Initial Thomas meter data indicated that it can detect poor blower loading. Thomas meter data recordings will be evaluated into flow rates.

2.1.2 Noise or Erosion Corrosion — The collector was designed for laminar flow rates and minimizing noise. Inspection of drawings and operational demonstration will show minimum noise conditions. Erosion-corrosion is minimized in the collector as all metal components are of aluminum.

2.1.3 Operating Conditions — Collector drawings, specifications, and historical performance, prior test data and design calcultaions will show capabilities of components to function at operational conditions without deterioration.

2.1.4 Fluid Flow in Collectors — The test facility manifolds to the collectors have Thomas meters to monitor flow rates. If the meter data indicates flow rates are unequal dampers will be adjusted to equalize flow rates.

2.1.7 Pressure Drops — Inspection of the collector drawings and test facility drawings will show that they were designed to minimize flow resistance.

2.2 Mechanical Stress — Mechanical stress on the Collectors have been minimized by design and will be reviewed in the following paragraphs:

2.2.1 Vibration Stress Levels — The collectors have no moving parts. Inspection of drawings and demonstration of the system in operation will show minimal vibration.

2.2.2 Vibration from Moving Parts — The blower is the only moving component in the system. Inspection of drawings and the blower will show it has been mounted properly to minimize vibrations. An operational demonstration of the blower will demonstrate minimal vibrations or sympathetic vibrations in the collector.

2.2.5 Thermal Changes — A review of the drawings, specifications and calculations will show that the collector design has allowed for thermal movement.

2.2.6 Flexible Joints — This item is considered NA as there are no flexible joints in the collectors or total system.

2.3 Leakage Prevention — The collector has been designed to minimize air leakage, and this design feature will be reviewed in item 3.3.2

2.3.1 Pressure Test: Nonpotable Fluids	This item is considerd NA as it is required for heat transfer fluids other than air.
2.3.2 Pressure Test: Potable Water	This item is considered NA as it is required of systems using potable water.
2.3.3 Air Transport Systems	Inspection of test facility ducting will show it meets NPS specifications. Insulation for the collector plenum or ducting is provided on the outer sides and behind the collector as shown in drawings.
2.4 Collector Adjustment	This item is considered NA as the design specifies a fixed orientation and tilt.
2.4.1 Orientation and Tilt	This item is considered NA for the same reason as item 2.4.
2.4.2 Mutual Shadowing	Mutual shadowing will be shown by photographs taken of the collectors at various times during the day and year.
2.6 Heat Transfer Quality	The heat transfer fluid quality shall be maintained in accordance with the following applicable paragraphs:
2.6.2 Air Quality	A review of the drawings, specifications and the collector will show provisions for minimizing deposits of dust and dirt. The test facility blower will be checked for dust and cleaned if needed.
2.8 Excessive Pressure and Temperature Protection	This item is considered NA as this item is considered a system function.
3.1 Structural Design Basis	The collector structural design basis has been developed in accordance with the following paragraphs:
3.1.1 Applicable Standards	The HUD Minimum Property Standards for One and Two Family Dwellings shall be used in the evaluation of connections and supporting elements based on loads anticipated during the service life of the collectors. The MPS will be used in the review of drawings, specifications and structural calculations.
3.1.2 Service Loads	The following loads shall be used in evaluating the structural design of the collectors: Dead Loads shall be calculated using the actual weight of the collector. Calculations shall be based on generally accepted engineering practices.

Live Loads shall be evaluated in accordance with MPS 601-3, to consider the weight of all moving or variable loads on the collectors. For the collectors designed for a tilt angle between 50° and 70°, the live load shall be 15 psf, on the horizontal projection of the collector area.

Snow Loads on the collectors shall be evaluated in accordance with ANSI A58.1.

Wind Loads effects on the collector structure shall be evaluated in accordance with MPS standards for roofs. The analysis for collectors designed for 50° to 70° tilt angle shall show capability to withstand pressures acting inward normal to the surface, equal to the design wind pressure.

Earthquake Loads analysis for the collectors shall be based on the latest available Uniform Building Code.

Constraint Loads caused by the environment shall be shown in the 1 year history of the prototype collector that has been in daily stagnation testing. Samples of Tedlar are available from indoor storage, the outer glazing and the inner glazing. The inner Tedlar glazing had the more severe constraint load, high stagnation temperatures.

Constraint Loads induced by differential foundation settlement effects on the collector are considered NA as IPC 3.8.1 considers conventional elements as meeting this criterion. All components are considered conventional elements.

Ice Loads shall be analyzed in accordance with IPC load combinations:

(1) 1.4D 1.7L

(4) 1.1D 1.3L 1.7W

The mean annual number of days with glaze varies from 4 to 8. The live load calculation for ice will be a 3/4 inch thickness.

Hail Loads analysis shall be developed in accordance with IPC which indicated 4 to 6 days of hail per year which estimates the hail size at 1.5". NASA test data on Tedlar is requested to support this analysis.

Vehicular Loads are considered NA as the collectors will be on structures away from roads.

3.2 Failure Loads and Load Capacity

The structural elements and connections of the collectors shall not fail under ultimate loads as described in the lollowing paragraphs:

3.2.1 Ultimate Load Combinations

This item is considered NA as all components are conventional elements.

3.2.2 Ice Loads	This item is considered NA as the IPC intent of this criterion is to account for the effect of ice loads primarily on wires, pipes and similar components which are exposed to the natural environment. . . The collectors have no exposed wires or pipes etc.
3.2.3 Vehicular Loads	This item is considered NA as the collectors are installed above grade in all cases.
3.2.4 Load Capacity	This item is considered NA as all components are conventional items.
3.3 Damage Control	The structural elements and connections of the collectors shall withstand service loads without damage as described in the following paragraphs:
3.3.1 Resistance to Damage	This item is considered NA as all components are conventional items.
3.3.2 Glazing Design	The collector outer glazing shall be tested for air leakage and water infiltration in accordance with ASTM E283 and ASTM E331 respectively. Physical Load tests shall be conducted in accordance with ASTM E330. Glazing shall comply with the manufacturers directions for installing Tedlar, and the experience of the NASA test program on Tedlar. The inner glazing of glass shall have a minimum clearance on all 4 sides equal to the thickness of the glass. Sealer space between the face of the glass and fixed or applied stops shall be sufficient to prevent glass-to-stop contact.
3.4 Cyclic Loads	This item and sub-item 3.4.1 are considered NA as all components are conventional elements.
3.7 Hail Resistance	The collectors shall be capable of resisting impact of hail without unacceptable damage as described in the following paragraphs:
3.7.1 Hail Size and Loading	Evaluation of the Tedlar glazing to withstand hail impact will be based on results of the NASA Tedlar test program.
3.8 Constraint Loads	This criterion is considered NA as all components are conventional elements. NA also applies to 3.8.1 for the same reason.
3.9 Ponding Conditions	Collector horizontal surfaces have been designed to assure stability in service under ponding conditions as follows:

3.9.1 Design Provisions	The only surface of the collector in a horizontal plane is the 1/8" grove in the aluminum H-bar. However, this grove contains Tedlar and a 1/8" plastic spline. Hence inspections will show there is little room for ponding. There is expected to be minimal collection of water on the taut Tedlar at angles between 50° and 70°.
4.1 Plumbing and Electrical Installation	This criterion and 4.1.1 and 4.1.2 are considered NA as there is no plumbing or electrical installation on the collector.
4.2 Fail-Safe Controls	This criterion, 4.2.1 and 4.2.2 are considered NA as fail-safe controls are considered a system function.
4.3 Fire Safety	The design and installation of the collectors shall provide a minimum level of fire safety as follows:
4.3.1 Applicable Fire Standards	The collector drawings and specifications reviews will show conformance with applicable fire standards. Test data will be available for such parameters as potential heat, rate of heat release and ease of ignition. The last item will be obtained from handbooks.
4.4 Toxic	This criterion is considered NA as toxic and flammable fluids are not used.
4.5.2 Identification and Location of Controls	This criterion is considered NA as the collectors do not contain controls.
4.6 Protection of Potable Water and Circulating Air	The collector design and development carefully checked that no material, form of construction, appurtenance or item of equipment shall be employed that will support the growth of micro-organisms or introduce substances, impurities, bacteria or chemicals into circulating air systems, in quantities sufficient to cause disease or harmful physiological effects. Furthermore, the following applicable items will continue to be monitored.
4.6.1. Contamination by Materials	This criterion is considered NA as it concerns potable water.
4.6.2 Separation of Circulation Loops	This criterion is considered NA as the collector heat transfer fluid is air.
4.6.3 Backflow Prevention	This criterion is considered NA as it concerns nonpotable heat transfer fluids.

4.6.4	Growth of Fungi	Growth of fungi will be checked by inspection and by the certification company. If fungi growth is found tests will be made and corrective actions taken.
4.7	Excessive Surface Temperatures	Temperatures of exterior surfaces of the collectors shall not create a hazard and shall be checked as follows:
4.7.1	Protection from Heated Components	Only the lower horizontal edge of the collector may be accessible to public traffic. It is not normally expected to reach temperatures of 140°F or more. However an electric power failure or blower motor failure may cause the temperature to reach between 140°F and 160°F. The temperature of this component will be monitored during stagnation tests. If temperatures reach these limits, insulation will be provided where the collectors will be installed near public traffic.
5.1	Effects of External Environment	The collectors shall not be affected by external environment factors to an extent that will significantly impair their function during their design life as described in the following paragraphs:
5.1.1	Solar Degradation	Collector components and materials have been exposed to UV radiation for 1 year under Colorado weather conditions. The Tedlar inner glazing of our experimental SC4X10 model has undergone extreme stagnation heat testing with temperatures reaching a minimum of 180°F every sunny day. Samples of this inner glazing will be analyzed.
5.1.2	Soil Corrosion	This criterion is considered NA as collectors will not be buried in the ground.
5.1.3	Airborne Pollutants	Airborne Pollutants will be checked by inspection and by the certification company. No data is currently available as the test facility environment is relatively airborne polutant free. If airborne pollution contamination is found, analysis of samples will determine the corrective action to be taken.
5.1.4	Dirt Retention on Cover Plate Surface	Dirt retention shall be monitored by photographing a small target behind the outer glazing and recording weather conditions. During long periods without precipitation, dirt may be washed off by hosing after phitographic data has been taken.

5.1.5 Abrasive Wear	Engineering analysis and data on the Tedlar glazing that has been in enviornmental testing for the past year and surface hardness specifications will be reviewed.
5.1.6 Flutter by Wind	Outer glazing flutter by wind will be minimized by controlled shrinkage during fabrication. Wind flutter will be checked using small fibres temporarily attached to the Tedlar and photographed. Wind and temperature data will be taken by our instrumentation.
5.2 Temperature and Pressure Resistance	Collector components have been designed to perform their intended function of their design life when exposed to maximum temperatures that could be developed in the system, as follows:
5.2.1 Thermal Degradation	Data will be supplied on Tedlar and absorber paint degradation. Effects of thermal degradation will be monitored after stagnation tests and recorded in the test report.
5.2.2 Deterioration of Heat Transfer Fluids	This criterion is considered NA as air is the heat transfer fluid.
5.2.3 Thermal Cycling Stresses	Thermal cycling is considered an important test as it may stress the inner glazing if the blower starts while the collector is at subzero temperatures. Test data will be recorded and the inner glazings inspected after the test.
5.2.4 Leakage	This criterion is considered NA as it refers to heat transfer fluids other than air.
5.2.5 Deterioration of Gaskets and Sealants	Gaskets and sealants in direct contact with heat transfer fluid and the exterior environment will be monitored by inspection to assure these materials will continue to function over their design life. Manufacturers data will be supplied.
5.2.6 Transmission Losses Due to Outgassing	Outgassing is expected to be minimized by oven heating of the absorber coating after painting. Subsequent outgassing during operation would be noticed during inspections as a fine coating on the interior surface of the inner glazing. Photographing resolution targets will assist in this evaluation.
5.3 Chemical Compatibility of Components	In the design of the collectors careful consideration was given to the selection of materials to prevent corrosion and deterioration. This will be further checked as follows:

5.3.1	Materials/Transfer Fluid Compatibility	This category is considered NA as the heat transfer fluid is air.
5.3.2	Corrosion of Dissimilar Metals	Inspection of the drawings and prototype collectors will show all metals are either of aluminum or in the same electro-conductive category. Two prototype collectors have been in environment test for one year without protection, and have shown no corrosion or deterioration problems.
5.3.3	Leaching of Dissimilar Materials	This criterion is considered NA as it is an air system and insulation is separated from the air plenum by the back plate.
5.3.4	Effects of Decomposition Products	This will be monitored by inspections. Two prototypes have not shown any decomposition. Absorber paint may decompose after 10 years but is retained within an enclosure and cannot affect other materials.
5.4	Components Involving Moving Parts	This criterion and 5.4.1 are considered NA as the collector has no moving parts.
6.1	Accessibility for Maintenance	Accessibility for maintenance will be demonstrated by review of drawings, and specifications and prototype collectors.
6.1.1	Access for System Maintenance	Access may be required to remove and replace the inner glazing, or repaint the absorber coating after 10 years. Inspection of drawings will show that the outer glazing may be removed for access to the inner glazing or absorber coating without removing adjacent units.
6.1.2	Access for System Monitoring	Access for system monitoring has been included in the test facility design and construction. Thomas flow meters and supporting instrumentation are used to measure flow rates. Temperatures will be monitored on the absorber plate back, with resistance thermometers, input and output air temperatures. Backup thermometer probes will be used at special ports to check regular instrumentation.
6.2	Installation, Operation and Maintenance Manual	This manual shall be prepared in accordance with similar manuals. Drawings, diagrams and photographs will support written instructions prepared at the appropriate reading level.
6.2.1	Installation Instructions	Installation instructions shall include physical, functional and procedural instructions. Particular attention will be given to safety functions, especially the output temperature from

the collectors into the house will not be more than 140°F. Directions will be supplied for required test instruments.

6.2.2	Maintenance and Operation Instructions	Maintenance instructions will describe the relationship of the major components to the collector operation. Collector maintenance is expected to consist of repairing the inner and outer glazings due to wilful damage, primarily (or accidents.) Routine maintenance will include occasional washing with a hose and inspection of the outer glazing/caulking and leakage.
6.2.3	Maintenance Plan	The maintenance plan will provide a schedule and procedures for outer glazing washing and inspections, and minor repair work.
6.2.4	Replacement Parts	Lists of parts, components, special tools and test equipment for service, repair or replacement will be provided along with sources for supplies.
6.3	Repair and Service Personnel	A review of the Installation, Operation and Maintenance Manual will demonstrate that the instructions, diagrams and procedures and the collectors design can easily be used by qualified service personnel.
6.3.1	Maintenance of Heating Systems	Review of drawings, specifications, maintenance manual and test equipment will show maintenance can be accomplished with a minimum amount of special equipment.
6.3.2	Maintenance of DHW Systems	This criterion is considered NA as it concerns hot water heating.
11.2.1	Chemical Corrosion	Chemical corrosion as mentioned in 5.3.2 and 5.3.4 has not been found in two prototype collectors or the adjacent site elements for 1 year. Chemical corrosion will continue to be monitored for during inspections.
11.2.2	Heat and Moisture	Review of installation plans, specifications, drawings and calculations will demonstrate that the roofing structure is protected by insulation from excessive build-up and from moisture by design and caulking.
11.3.1	Material Compatibility	As described in 5.3.2, and 11.2.1, materials requirements have been included in the design of the collectors. Connections between the collectors and the dwelling will be reviewed by drawings, specifications and by inspection.

7. Test Plan

The Collector Subsystem Test Program consists of 3 phases, Development Testing, Qualification Testing, and Acceptance Testing. The Test Program Plan defines the milestones for testing this subsystem (Figure 7.1.)

7.1 Development Testing

Development testing is designed to verify that the preliminary design specifications are feasible and performance requirements are realistic. Three major inter-related tests are planned for this phase: Air Flow, Plenum Spacing and Air Temperature Output. Changes to air flow and/or plenum spacing will result in changes in air temperature output. The objective of this phase is to optimize air flow and plenum spacing for the optimum temperature output and obtain data on basic collector efficiency.

This test data for combined air flow and plenum spacing for optimum temperature output will be presented at the Preliminary Design Review. It will also be used for planning additional testing during the next phase.

7.2 Qualification Testing

Qualification testing is designed to optimize subsystem components and also to analyze and test the subsystem to design limits. This will ensure that the subsystem meets physical and functional requirements. Component testing includes absorber coatings tests and glazings tests, followed by a combined absorber-glazings test. Systems qualification tests include stagnation, and other environmental tests and structural analysis or testing.

7.3 Acceptance Testing

Acceptance testing is designed to inspect and test each prototype collector to verify that each prototype collector's physical and operational characteristics are within specifications. These tests will be performed for 3 units prior to First Article Configuration Inspection FACI and for the remaining 7 units Acceptance Testing will be performed prior to delivery.

ITEM (NAME & PART NO.)

SOLAR COLLECTOR, SC4X8

VERIFICATION CROSS

REFERENCE MATRIX

VERIFICATION METHOD: 1. SIMILARITY 3. INSPECTION 5. N/A NOT APPLICABLE
2. ANALYSIS 4. TEST

PERFORMANCE REQUIREMENT	VERIFICATION PHASE Development	Qualification	Acceptance	REMARKS
1.2.4 Operational Impairment	NA	NA	NA	IPC requires for DHW only
1.3 Collector Performance	4	4	4	
1.3.1 Collector Efficiency	4	4	4	
2.1 System Design Conditions	3/4	3/4	3/4	
2.1.1 Equipment Capabilities	4	4	4	
2.1.2 Noise of Erosion-Corrosion	3	3	3	
2.1.3 Operating Conditions	3/4	3/4	3/4	
2.1.4 Fluid Flow in Collectors	4	4	4	
2.1.7 Pressure Drops	3	3	3	
2.2 Mechanical Stresses	3	3	3	
2.2.1 Vibration Stress Levels	3	3	3	
2.2.2 Vibration from Moving Parts	3	3	3	
2.2.5 Thermal Changes	2/3	2/3	3	
2.2.6 Flexible Joints	NA	NA	NA	No flexible joints
2.3 Leakage Prevention	3	3	3	
2.3.1 Pressure Test: Non- Potable Water	NA	NA	NA	Not a water collector
2.3.2 Pressure Test Potable Water	NA	NA	NA	Not a water collector
2.3.3 Air Transport Systems	2/3	2/3	3	
2.4 Collector Adjustment	NA	NA	NA	Fixed Collector
2.4.1 Orientation and Tilt	NA	NA	NA	Fixed Collector
2.4.2 Mutual Shadowing	3	3	3	
2.6 Heat Transfer Fluid Quality	3	3	3	
2.6.2 Air Quality	3	3	3	
2.8 Excessive Pressure and Temperature Protection	NA	NA	NA	This is considered a system function

ITEM (NAME & PART NO.)

SOLAR COLLECTOR SC4X8

VERIFICATION CROSS REFERENCE MATRIX

VERIFICATION METHOD: 1. SIMILARITY 2. ANALYSIS 3. INSPECTION 4. TEST 5. N/A NOT APPLICABLE

PERFORMANCE REQUIREMENT	VERIFICATION PHASE			REMARKS
	Development	Qualification	Acceptance	
3.1 Structural Design Basis	3	3	3	
3.1.1 Applicable Standards	3	3	3	
3.1.2 Service Loads				
Dead Loads	2	2	3	
Live Loads	2	2	3	
Snow Loads	2	2	3	
Wind Loads	2	2	3	
Earth Quake Loads	2	2	3	
Env. Constraint Loads	3	3	3	
Foundation Constraint "	NA	NA	NA	Per IPC
Ice Loads	2	2	3	
Vehicular Loads	NA	NA	NA	
3.2 Failure Loads and Load Capacity	2/3	3/4	3	
3.2.1 Ultimate Load Combinations	NA	NA	NA	Per IPC
3.2.2 Ice Loads	NA	NA	NA	Per IPC see also 3.1.2
3.2.3 Vehicular Loads	NA	NA	NA	
3.2.4 Load Capacity	NA	NA	NA	All elements conventional
3.3 Damage Control	3	3	3	
3.3.1 Resistance to Damage	NA	NA	NA	All elements conventional
3.3.2 Glazing Design	3/4	3/4	3	
3.4 Cyclic Loads	NA	NA	NA	All elements conventional
3.7 Hail Resistance	1/2	1/2	1	
3.71 Hail Size and Loading	1/2	1/2	1	
3.8 Constraint Loads	NA	NA	NA	All elements conventional
3.8.1 Foundation Settlement	NA	NA	NA	All elements conventional
3.9 Ponding Condition	3	3	3	
3.9.1 Design Provisions	3	3	3	
4.1 Plumbing and Electrical Installation	NA	NA	NA	Not required
4.1.1 Plumbing Codes	NA	NA	NA	Not required
4.1.2 Electrical Codes	NA	NA	NA	Not required
4.2 Fail Safe Controls	NA	NA	NA	A system function

ITEM (NAME & PART NO.)

SOLAR COLLECTOR SC4X8

VERIFICATION CROSS REFERENCE MATRIX

VERIFICATION METHOD: 1. SIMILARITY 2. ANALYSIS 3. INSPECTION 4. TEST 5. N/A NOT APPLICABLE

PERFORMANCE REQUIREMENT	VERIFICATION PHASE Development	Qualification	Acceptance	REMARKS
4.2.1 System Failure Prevention	NA	NA	NA	A system function
4.2.2 Automatic Pressure Relief Valves	NA	NA	NA	A system function
4.3 Fire Safety	3/4	3/4	3	
4.3.1 Applicable Fire Standards	3	3	3	
4.4 Toxic	NA	NA	NA	No toxic/flammable fluids used
4.4.1 Provisions for Catch Basins	NA	NA	NA	
4.4.2 Detection of Toxic & Flammable Fluids	NA	NA	NA	
4.5.2 Identification & Location of Controls	NA	NA	NA	No controls on collectors
4.6 Protection of Potable Water and Circulating Air	3	3	3	
4.6.1 Contamination by Materials	NA	NA	NA	For potable water only.
4.6.2 Separation of Circulation Loops	NA	NA	NA	Not a water collector
4.6.3 Backflow Prevention	NA	NA	NA	
4.6.4 Growth of Fungi	3	3	3	
4.7 Excessive Surface Temperatures	3	3	3	
4.7.1 Protection from Heated Components	3	3	3	
5.1 Effects of External Environment	3	3	3	
5.1.1 Solar Degradation	3	3	3	
5.1.2 Soil Corrosion	NA	NA	NA	
5.1.3 Airborne Pollutants	3	3	3	
5.1.4 Dirt Retention on Cover Plate Surace	3	3	3	
5.1.5 Abrasive Wear	3	3	3	
5.1.6 Flutter by Wind	3	3	3	

ITEM (NAME & PART NO.)

SOLAR COLLECTOR SC4X8

VERIFICATION CROSS

REFERENCE MATRIX

VERIFICATION METHOD: 1. SIMILARITY 3. INSPECTION 5. N/A NOT APPLICABLE

2. ANALYSIS 4. TEST

PERFORMANCE REQUIREMENT	VERIFICATION PHASE Development	Qualification	Acceptance	REMARKS
5.2 Temperature and Pressure Resistance	3	3	3	
5.2.1 Thermal Degradation	3	3	3	
5.2.2 Deterioration of Heat Transfer Fluids	NA	NA	NA	
5.2.3 Thermal Cycling Stresses	3	3	3	
5.2.4 Leakage	NA	NA	NA	
5.2.5 Deterioration of Gaskets & Sealants	3	3	3	
5.2.6 Transmission Losses Due to Outgassing	3	3	3	
5.3 Chemical Compatibility of Components	3	3	3	
5.3.1 Materials/Transfer Fluid Compatibility	NA	NA	NA	
5.3.2 Corrosion of Dissimilar Materials	3	3	3	
5.3.3 Corrosion by Leachable Substance	NA	NA	NA	
5.3.4 Effects of Decomposition Products	3	3	3	
5.4 Components Involving Parts	NA	NA	NA	
5.4.1 Wear & Fatigue	NA	NA	NA	
6.1 Accessibility for System Maintenance	3	3	3	
6.1.1 Access for System Maintenance	3	3	3	
6.1.2 Access for System Monitoring	3	3	3	
6.2 Installation, Operation & Maintenance Manual	1	1	1	
6.2.1 Installation Instructions	1	1	1	
6.2.2 Maintenance and Operation Instructions	1	1	1	

ITEM (NAME & PART NO.)

SOLAR COLLECTOR SC4X8

VERIFICATION CROSS REFERENCE MATRIX

VERIFICATION METHOD: 1. SIMILARITY 2. ANALYSIS 3. INSPECTION 4. TEST 5. N/A NOT APPLICABLE

PERFORMANCE REQUIREMENT	VERIFICATION PHASE Development	Qualification	Acceptance	REMARKS
6.2.3 Maintenance Plan	1	1	1	
6.2.4 Peplacement Parts	3	3	3	
6.3 Repair and Service Personnel	1	1	1	
6.3.1 Maintenanc of H Systems	1	1	1	
6.3.2 Maintenance of DHW System	NA	NA	NA	
11.2.1 Chemical Corrosion	3	3	3	
11.2.2 Heat & Moisture	3	3	3	

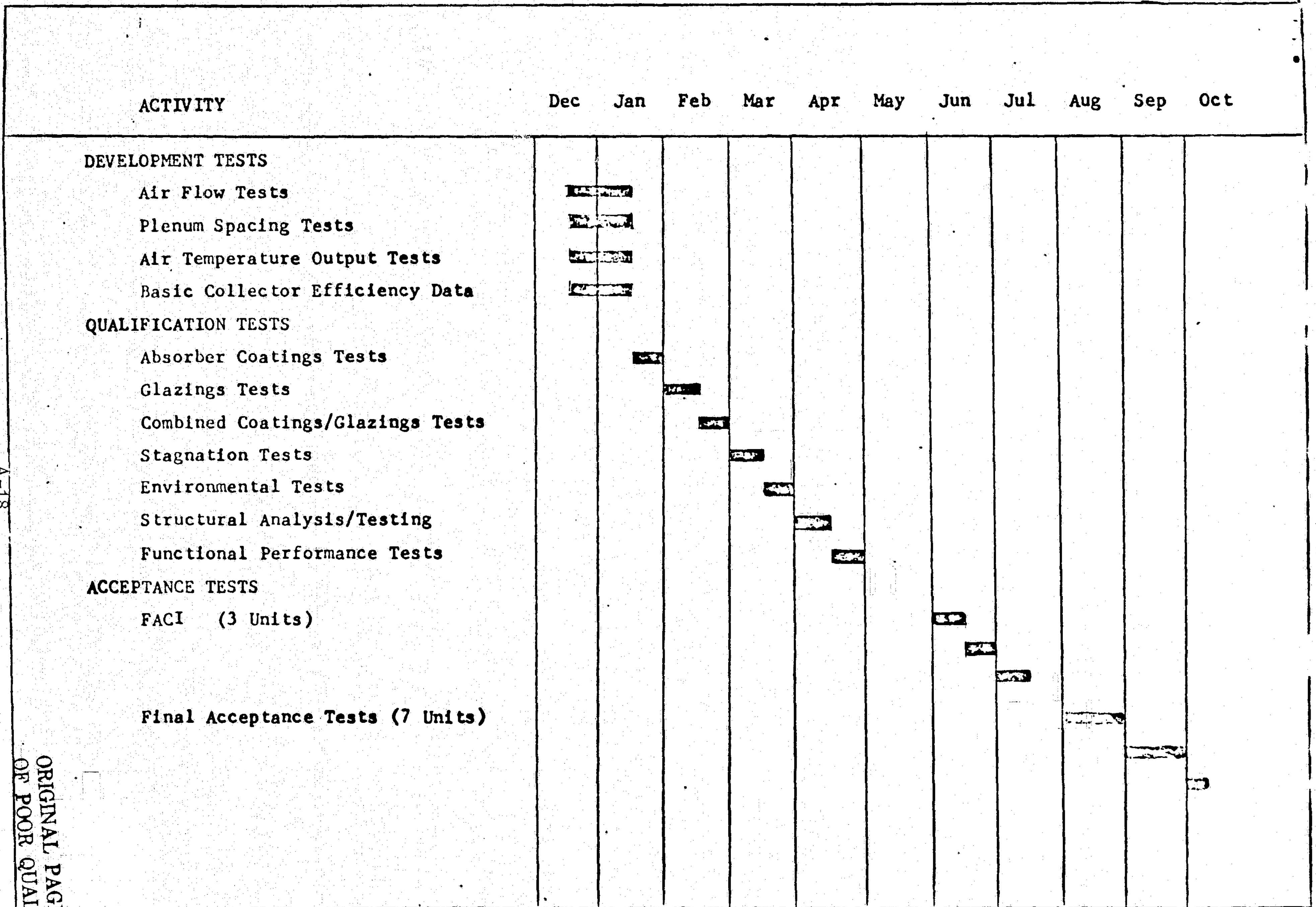

FIGURE 7.1 TEST PROGRAM PLAN

SECTION B

THERMAL ANALYSIS

Air Flat Plate Collector

December 30, 1976

Life Sciences Engineering
Rt. 1, Box 746
Morrison, Colorado 80465

TABLE OF CONTENTS

1. Introduction

Several designs are being investigated during the course of this contract. For the purposes of this analysis a baseline design is examined. For this design the covers will be assumed to be constructed using ASG Industries, "Sunadex" glass, 5/32 inch in thickness, having a transmittance of 0.91. This glass is manufactured with a non-specular textured surface which reduces reflection losses. It has been used widely in large solar projects. Combinations of glass and plastic films have also been examined. These will be reported upon later.

The absorber plate as well as the duct interior will be assumed to be coated with black paint which has a spectral reflectance of 5 percent throughout the visible and infrared wavelength region.

The heat transfer coefficient, U_L, for heat loss out of the top of the collector is shown in Figure L1 as a function of average plate temperature. This data is adapted from Reference 1. The coefficient is relatively linear with ambient temperature over the range shown.

2. Methods of Analysis

Several investigators (2-8) found that the performance of flat-plate collectors operating under steady-state conditions can be adequately described by the following relationship:

$$\frac{q_u}{A} = I\,(\tau\alpha)_e - U_L\,(\bar{t}_p - t_a) \qquad (1)$$

where

q_u =rate of useful energy extraction from the solar collector, in Btuh

A =cross-sectional area, ft^2

I =total solar enery incident upon the plane of the solar collector per unit time per unit area, $Btuh/ft^2$

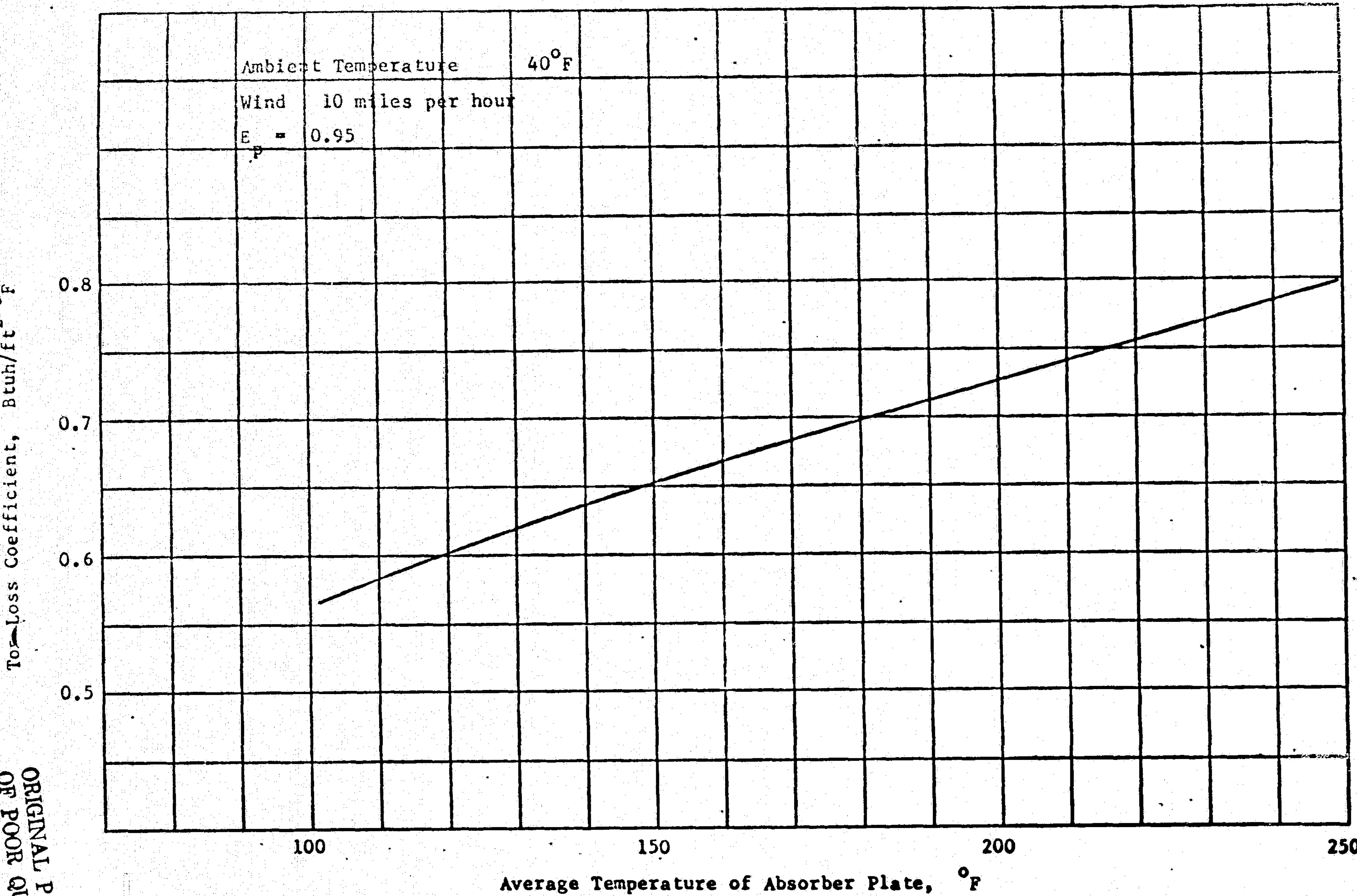

Figure 1.1, Top Loss Coefficient for Slope of 60°

B-5

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$(\tau\alpha)_e$ = effective transmission-absorptance product for the solar collector

U_L = heat transfer loss coefficient for the solar collector, Btuh/ft^2 ^oF

$\bar{t}_p$ = average temperature of the absorber surface of the solar collector, ^oF

t_a = ambient air temperature, ^oF

Two parameters F' and F_R have been developed to assist in obtaining detailed information about the performance of various kinds of solar collectors:

$$F' = \frac{\text{(actual useful energy collected)}}{\text{(useful energy collected if the entire collector surface were at the average fluid temperature)}}$$

Termed: Collector Efficiency Factor

and

$$F_R = \frac{\text{(actual useful energy collected)}}{\text{(useful energy collected if the entire collector surface were at the temperature of the fluid entering the collector)}}$$

Termed: Collector Heat Removal Factor

Introducing these factors into equation (1) results in new performance equations, respectively:

$$\frac{q_u}{A} = F' \left[I\,(\tau\alpha)_e - U_L \left(\frac{t_{f,i} + t_{f,e}}{2} - t_a \right) \right] \tag{2}$$

and

$$\frac{q_u}{A} = F_R \left[I\,(\tau\alpha)_e - U_L\,(t_{f,i} - t_a) \right] \tag{3}$$

where

t_o = temperature of the fluid leaving the collector, ^oF

t_i = temperature of the fluid entering the collector, ^oF

If the solar collector efficiency can be defined as:

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$$\eta = \frac{\text{(actual useful energy collected)}}{\text{(solar energy incident upon or intercepted by the collector)}}$$

or in equation form

$$\eta = \frac{q_u/A}{I} \quad , \tag{4}$$

then the efficiency of the flat plate collector is given by:

$$\eta = (\tau\alpha)_e - U_L \frac{(\bar{t}_p - t_a)}{I} \tag{5}$$

or

$$\eta = F' (\tau\alpha)_e - F' U_L \left(\frac{\frac{t_i + t_o}{2} - t_a}{I} \right) \tag{6}$$

or

$$\eta = F_R (\tau\alpha)_e - F_R U_L \frac{(t_i - t_a)}{I} \tag{7}$$

Equations 5, 6, and 7 indicate that if the efficiency is plotted against some appropriate $\frac{\Delta t}{I}$, a straight line will result where the slope is some function of U_L and the y intercept is some function of $(\tau\alpha)_e$. In reality U_L is not a constant but rather a function of the operating temperature of the collector and of the ambient weather conditions. In addition, the product $(\tau\alpha)_e$ varies with incident angle to the collector.

The line drawn in Specification Sheet SHC-3058 is representative of the plot that results from equation (7). The y-axis is the thermal efficiency (η) and the x-axis, the temperature difference between the collector fluid inlet and the ambient air divided by the incident solar radiation $((t_i - t_a)/I)$. The slope of a linear curve fit for the efficiency curve represents the product $F_R U_L$. The y-axis intercept is equal to $F_R (\tau\alpha)_e$.

The value of this approach is that later data taken from performance tests can be plotted from which slopes and y intercepts can be used together to determine the values of F_R, F', U_L and $(\tau\alpha)_e$. The efficiency expression shown in Specification Sheet SHC-3058 is used with test data on flow and temperature difference between inlet and outlet air to compute efficiency. As discussed in Reference 1, solar collector performance for specific operation conditions can be predicted with reasonable accuracy once the values of F_R, U_L and $(\tau\alpha)_e$ have been determined.

3. <u>Collector Efficiency</u>

The collector efficiency factor is essentially a constant for any collector design and fluid flow rate. For the collector video study

$$F' = \left[1 + \frac{U_L}{h + \left(\frac{1}{h} + \frac{1}{h_r}\right)^{-1}}\right]^{-1}$$

where h_r = radiation coefficient between the two air duct surfaces.

h = heat transfer coefficient between air and duct walls

For analysis purposes it is convenient to define a quantity that relates the actual useful enery gain of a collector to the useful gain if the whole collector surface were at the fluid inlet temperature. This quantity, termed the Collector Heat Removal Factor, F_R, can be expressed by :

$$F_R \hat{=} \frac{GC_p}{U_L}\left(1 - e^{\frac{-U_L F'}{GC_p}}\right)$$

where G = flow rate per unit of collector area, lb/hr-ft^2

C_p = specific heat of fluid, 0.24 for air

4. <u>Effective Transmissivity-Absorptivity Product</u>

All of the solar radiation that is absorbed by a cover system is not lost, since this absorbed energy tends to increase the cover temperature and consequently reduce the losses from the plate. This partial usefulness of the radiation absorbed in the cover plates is most conveniently thought of as an artificial increase in transmittance and gives rise to the concept of "effective transmissivity-absorptivity product", $(\tau\alpha)_e$.

It is necessary to evaluate the transmittance-absorptance product $(\tau\alpha)$. Of the radiation passing through the cover system and striking the plate, some is reflected back to the cover system. All of the radiation is not lost however, since some is reflected back to the plate. The energy ultimately absorbed is:

$$(\tau\alpha) = \frac{\tau\alpha}{1 - (1-\alpha)\rho_d}$$

where

τ = transmittance

α = absorptance

ρ_d = diffuse reflectance = 0.24 (for two glass cover system, Ref. 1)

$$(\tau\alpha) = \frac{(0.91)^2 \times 0.95}{1 - (1 - 0.95)\ 0.24}$$

$(\tau\alpha)$ = 0.797

The effective transmissivity absorptivity product can be expressed by

$$(\tau\alpha)_e = (\tau\alpha) + (1 - \tau_{a,1})\ a_1 + (1 - \tau_{a,2})\ a_2\tau_1$$

where

τ_a = transmittance considering only absorption

$\tau_a = e^{-KL}$

where

K = extinction coefficitnt

L = length of path through the glass

For K = 0:2 / inch

L = 5/32 inch

$\tau_a = e^{-0.2 \times 0.16}$

$= 1.032$

$(\tau\alpha)_e = 0.797 + (1 - 1.032)\ 0.15 + (1 - 1.032)\ 0.62 \times 0.91$

$= 0.82$

Constants a_1 = 0.15 and

a_2 = 0.62 ave from Ref. 1

Examinations were made for the effect of variations in the parameters of air flow and duct spacings. Air flow was varied from 60 to 360 CFM ($0.06\ lb/ft^3$ Denver altitude). Duct spacings were varied from 3/8 to 1 inch. Efficiency was computed using equation (3). This requires making an estimate of the collector plate temperature, t_p, for the purpose of determining the heat loss coefficient, U_L. T_p is a function of specific air flow through the collector. Estimates of plate temperatures at various air flows are shown in Figure 5.1 , together with resulting values for U_t and h_r. These are used in computing the useful heat, q_u, collected per unit area, the resulting efficiency, and the air temperature, t_o, as it leaves the collector. The calculations are based on the conditions that the collector is tilted at an angle of 60^o above the horizontal and that at noon the insolation per unit area of exposed glass is 300 $Btuh/ft^2$. In the computations the values of U_t are increased by 15 percent to allow for back and edge losses. This estimate is in accordance with information from Reference (7). With urethane insulation the percentage may be less. The resultant is U_L, the overall loss coefficient.

5.a Heat Transfer Coefficients

The radiation coefficient between the two air duct surfaces is calculated by using mean plate temperatures taken from and using the experssion

$$h_r = \frac{4\sigma \bar{T}^3}{\frac{1}{E_1} + \frac{1}{E_2} - 1}$$

where the Stefan - Boltzmann constant $\sigma = 0.1714 \times 10^{-8}$ Btu/hr $ft^2\ {}^oR^4$

$T = {}^oR$

and E = surface emittance

The heat transfer coefficients between the air and the duct wall will be assumed to be equal. The characteristic leagth is the hydraulic diameter, which for flat plates is twice the plate spacing.

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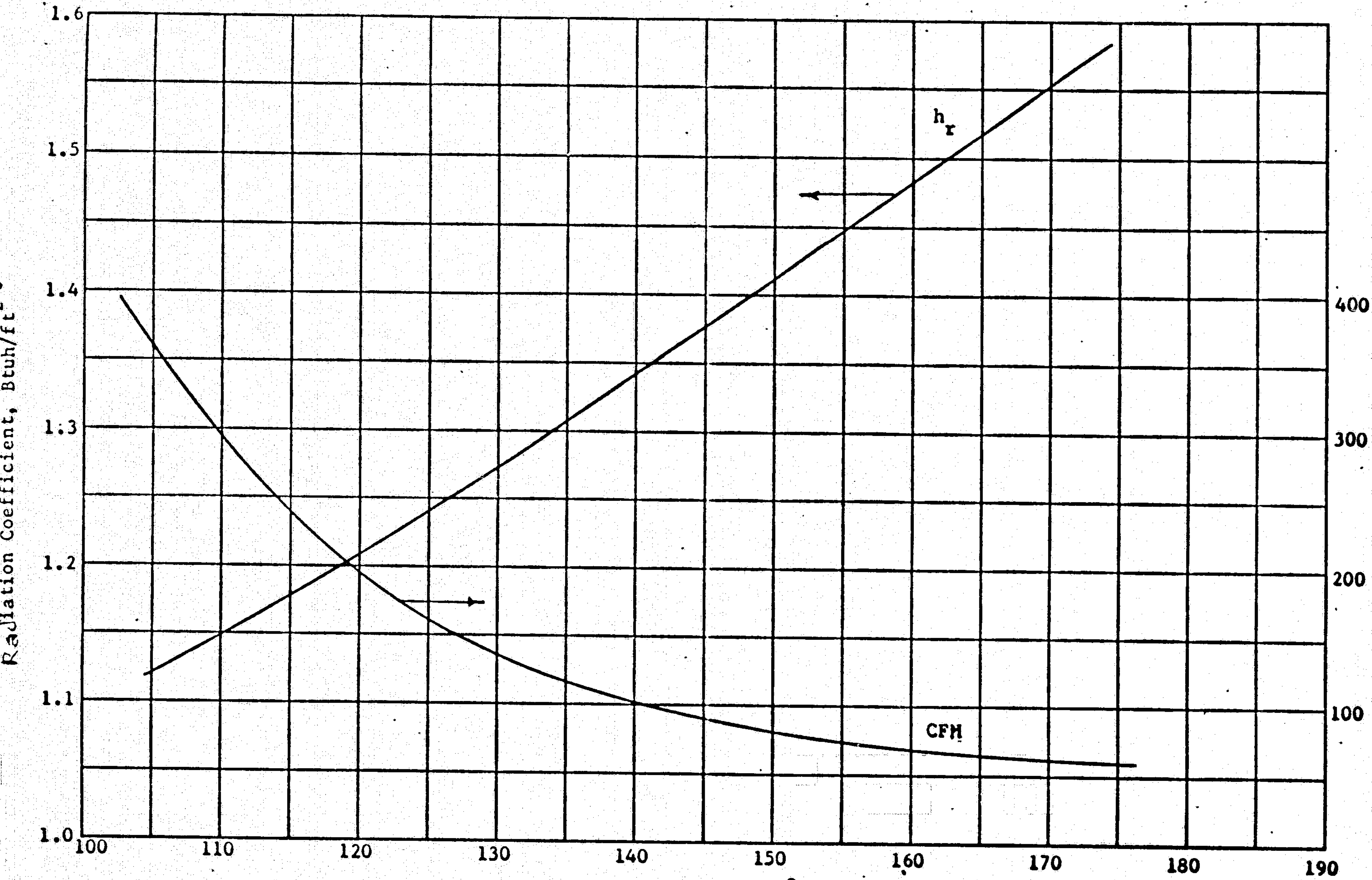

Figure 5.1, Relationship of Plate Temperatures, Air Flow and Radiation Coefficient

For air, the following correlation for turbulent flow between flat plates with one side heated has been derived. (Ref. 1)

$$Nu = 0.0158\ Re^{0.8}$$

where

Nu = Nusselt number $(h\ D/K)$

Re = Reynolds number $(\frac{M}{A_c}\ D/\mu)$

and

h = Convective film coefficient

D = Hydraulic diameter

K = Fluid thermal conductivity

M = Mass flow rate, lbs / hr

A_c = Free flow area, ft^2

μ = Viscosity, lb / hr ft

The advantages of the dimensional analysis that utilizes the Nusselt number are well known in correlating large amounts of data.* An arithmetic operation is used to obtain h from the Nusselt number once the Reynolds number has been obtained.

Calculations for the convective film coefficient h are tabulated below:

Table 1. Convective Film Coefficients.

Plate Spacing	M	M/A_c	Re	Nu	h
0.375 in.	216	1800	2483	8.216	2.054
"	432	3600	4967	14.306	3.577
"	864	7200	9934	24.909	6.227
"	1296	10800	14900	34.451	8.613
0.500 in.	216	1350	2483	8.216	1.538
"	432	2700	4967	14.306	2.678
"	864	5400	9934	24.909	4.663
"	1296	8100	14900	34.451	6.449
1.000 in.	216	675	2483	8.216	0.769
"	432	1350	4967	14.306	1.339
"	864	2700	9934	24.909	2.331
"	1296	4050	14900	34.451	3.225

*Summaries of experiment and analysis for gas flow in rectangular tubes are reported in Reference 9, Kays and Loudon Compact Heat Exchangers, as a function of the Stanton number. Comparisons of results of the above calculations and their data show good agreement for h.

Calculations for the collector efficiencies for different air flows and plate spacings defining the air duct behind the absorber plate are tabulated in Table 2. Also shown are the outlet air temperatures, t_o, for the collector. These may be used in selecting the air flow to achieve a given temperature rise across the collector.

Table 2. Collector Efficiency Calculations

CFM	W	G	hr	h	U_L	F'	$\frac{GC_p}{U_L}$	F_R	$\frac{q_u}{A}$		$t_{f,e}$
0.375 Inch Plate Spacing											
60	216	7.06	1.59	2.05	0.79	0.79	2.14	0.66	147	0.49	157
120	432	14.11	1.31	3.58	0.72	0.84	4.70	0.77	174	0.58	121
240	864	28.16	1.18	6.23	0.69	0.91	9.79	0.87	196	0.65	99
360	1296	42.34	1.12	8.61	0.67	0.93	15.17	0.90	204	0.68	90
0.5 Inch Plate Spacing											
60	216	7.06	1.59	1.54	0.79	0.75	2.14	0.63	140	0.47	153
120	432	14.11	1.31	2.68	0.72	0.83	4.70	0.76	170	0.57	120
240	864	28.16	1.18	4.66	0.69	0.89	9.79	0.85	191	0.64	98
360	1296	42.34	1.12	6.45	0.67	0.92	15.17	0.89	202	0.67	90
1.0 Inch Plate Spacing											
60	216	7.06	1.59	0.77	0.79	0.62	2.14	0.54	120	0.40	144
120	432	14.11	1.31	1.34	0.72	0.74	4.70	0.68	153	0.51	115
240	864	28.16	1.18	2.33	0.69	0.82	9.79	0.79	177	0.59	96
360	1296	42.34	1.12	3.22	0.67	0.86	15.17	0.84	189	0.63	89

REFERENCES

1. Duffie, J.A., and W.A. Beckman, Solar Energy Thermal Processes, John Wiley and Sons, 1974.

2. Hottel, H.C., and B.B. Woertz, "The Performance of Flat-Plate Solar Heat Collectors", ASME Transactions, Vol. 64, p. 91, 1942.

3. Whillier, A., Solar Energy Collection and its Utilization for House Heating, ScD. Thesis, MIT, 1953.

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6. Liu, B.Y.H., and R.C. Jordan, "A Rational Procedure for Predicting the Long-Term Average Performance of Flat-Plate Solar Energy Collectors", Solar Energy, Vol. 7, No. 2, 1963.

7. Whillier, A., "Design Factors Influencing Collector Performance", Low Temperature Engineering Application of Solar Energy, American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc., 345 East 47th Street, New York, N.Y. 10017, 1967.

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SECTION C

SAFETY HAZARD ANALYSIS
FOR
AIR FLAT PLATE COLLECTOR

January 3, 1977

Life Sciences Engineering
Rt. 1, Box 746
Morrison, Colorado 80465

SAFETY HAZARD ANALYSIS

1. Scope

1.1 Purpose

The purpose of this report is to identify and evaluate significant hazards to the installation crew, resident occupants and visitors.

1.2 Scope

This report presents an assessment of hazards peculiar to this equipment. The hazards have been identified and categorized. The possible causes and effects have been listed, together with the methods or safeguards required to control or limit the hazard. This analysis does not consider facility or manufacturing features that are required to be made safe under the local codes and regulations.

1.3 Summary

The Hazards Analysis identified no potentially catastrophic hazards and one critical hazard. A catastrophic hazard (Category 1) is one in which death or severe injury to personnel or system loss can occur. A critical hazard (Category 2) is one which could result in personnel injury or cause major damage.

ITEM NO.	NOMENCLATURE OF HARDWARE/ACTIVITY		POTENTIAL/INHERENT HAZARD CAUSES AND EFFECTS	HAZARD CATEGORY	PROPOSED METHOD OF HAZARD CONTROL OR ELIMINATION	REMARKS
1	Solar Panel Assembly	1.	Large areas of dielectric (Tedlar) surface exposed to sky could build up sufficient static charge to act as flat plate capacitance attractor for lightning. Large amounts of metal in frames could also attract lightning.	2 marginal	Installation will require electrical busing of panel assemblies together and to ground per standards and codes for locality	Lightning rods may be required by code in areas of high strike potential (ie. Colorado Springs)
		2.	Aluminum frame of panels will conduct stagnation temperatures to surrounding structure if forced convection air flow is inhibited. High stagnation temp. (500°F) could cause local charing or combustion.	marginal 2	Installation will provide for adequate insulation between panel assembly frame and surrounding structure.	
		3.	Toxic outgassing of materials could have debilitating effect on residents	3 marginal	Materials used in solar panel assembly shall not produce toxic or noxious products when exposed to expected temperature.	

ITEM NO.	NOMENCLATURE OF HARDWARE/ACTIVITY	POTENTIAL/INHERENT HAZARD CAUSES AND EFFECTS	HAZARD CATEGORY	PROPOSED METHOD OF HAZARD CONTROL OR ELIMINATION	REMARKS
2	Installation of Solar Panel Assembly to Supporting Structure	1. Installation personnel could be burned by hot frame or panel when handling.	3 negligible	Personnel should wear gloves whenever working around exposed panel frames. Panel storage prior to installation should be in a shady area. Panels should be transported with collector face away from direct sunlight.	
		2. Large panel assemblies (4 x 8 ft.) will be heavy (100 lbs.) and act as sails in wind. Above ground installations present potential for severe injury to personnel by being blown off or by dropping panel on self or another.	2 critical	Installation should be designed to maximize use of lifting apparatus	
		3. Improper sealing of panel/supporting structure could result in water leaks.	3 negligible	Installation manual will recommend proper installation techniques/requirements.	Local codes may take precedent.

SECTION D

DRAWINGS LIST, STANDARDS AND SYMBOLS
FOR
AIR FLAT PLATE COLLECTOR

January 1, 1977

Life Sciences Engineering
Rt. 1, Box 746
Morrison, Colorado 80465

DRAWINGS LIST

SC4X8100-9 Top Drawing SC4X8 Solar Collector

SC4X8200-9 Assembly

Consisting of:

SC4X8200-19 Absorber Panel and Frame Installation

Drilling Holes Detail

Installation Thermal Resistors Detail

RTV 560 Detail

SC4X8200-29 Back Panel Installation

SC4X8200-29-1 Back Panel Detail and Hole Drilling

SC4X8200-29-3 Back Panel Support

SC4X8300-9 Main Frame Assembly

Consisting of:

SC4X8300-9-1 Side Detail

SC4X8300-9-3 End Detail

SC4X8300-9-5 Corner Detail

SC4X8400-9 Absorber Panel and Frame

Consisting of:

SC4X8400-9-1 'U' Channel Side Detail

SC4X8400-9-3 Angle Aluminum Detail

Drilling Holes Detail

Paint Detail

SC4X8500-9 Glazing

Consisting of:

SC4X8500-19 Inner Glazing Installation

SC4X8500-19-1 Inner Glazing Detail

SC4X8500-19-3 Pressure Tape Detail

SC4X8500-29 Outer Glazing Installation

SC4X8500-29-1 H-Bar Side Detail

SC4X8500-29-3 H-Bar End Detail

Outer Glazing Bonding Detail

Outer Glazing Spline Detail

STANDARDS

ASTM E283 for Air Leakage Testing, American Society for Testing and Materials

ASTM E330 for Water Infiltration Testing, American Society for Testing and Materials

ASTM E331 for Load Test Conductance, American Society for Testing and Materials

Building Code Requirements for Minimum Design Loads in Buildings and Other Structures, 1972, ANSI A58.1 - 1974

Heat Producing Appliance Clearances, 1971, National Fire Protection Association, NFPA No. 89M

HUD Minimum Property Standards, One and Two Family Dwellings (No. 4900.1) U.S. Dept. of Housing and Urban Development, Washington, D.C. (1973 revised 1974)

Installation of Air Conditioning and Ventillating Systems, 1976. National Fire Protection Association, NFPA No. 90 A

Marking for Shipment, Life Sciences Engineering 1977

MS 33586 Metals, Definition of Dissimilar

National Electric Code , 1975

Warm Air Heating and Air Conditioning Systems, 1973. National Fire Protection Association, No. 90 B

A = Cross-sectional area of a plenum in ft^2

A_c = Free flow area of collector in ft^2

α = Absorptance

CFM = Cubic feet per minute

C_p = Specific heat of transport fluid in BTU/lb.^{o}F (for air 0.24)

D = Hydraulic diameter

E = Surface emittance

F' = Collector efficiency factor:

$$F' = \frac{\text{(actual useful energy collected)}}{\text{(useful energy collected if the entire collector surface were at the average fluid temperature.)}}$$

F_R = Collector heat removal factor:

$$F_R = \frac{\text{(actual useful energy collected)}}{\text{(useful energy collected if the entire collector surface were at the temperature of the fluid entering the collector.)}}$$

G = Flow rate per unit of collector area in lb/hr/ft^2, or Flow stream mass velocity: $G = \frac{W}{AC}$

h = Heat transfer coefficient between air and duct walls, or Convective film coefficient

h_r = Radiation coefficient between 2 air duct surfaces

I = Total solar insolation on the plane of the solar collector per unit time per unit area in BTU/hr ft^2

K = Fluid thermal conductivity

k = Extinction coefficient

L = Length of path through glass

η = Efficiency of the flat plate collector:

$$\eta = (\tau\alpha)_e - U_L \frac{(\bar{t}_p - t_a)}{I} \quad \text{or} \quad \eta = M\,C_p \frac{(t_o - t_i)}{AC\ I}$$

Nu = Nusselt number

$$Nu = \frac{h, D}{K}$$

P_d = Diffuse reflectance

Q_u = Heat transfer loss coefficient in BTU/hr/ft^2 ^oF

Re = Reynolds number

$$Re = \frac{G\ D}{\mu}$$

σ = Stefan - Boltzmann constant

τ = Transmittance

$\bar{\tau}$ = ^oR

$(\tau\alpha)_e$ = Effective transmission-absorptance product for the solar collector

t_a = Ambient air temperature

$t_{f,e}$ = Temperature of the fluid leaving the collector in ^oF

$t_{f,i}$ = Temperature of the fluid entering the collector in ^oF

$\bar{t}_p$ = Average temperature of the absorber surface of the solar collector in ^oF

t_p = Collector plate temperature

μ = Viscosity

U_L = Heat transfer loss coefficient in BTU/hr/ft^2/^oF

U_t = Glass thermal losses (top losses)

W = Mass flow rate in lbs/hr

SECTION E

LIST OF DATA RECOMMENDED FOR PROTOTYPE DESIGN REVIEW

AND

DESCRIPTION AND RATIONALE FOR PROPOSED

SPECIAL HANDLING, INSTALLATION AND MAINTENANCE TOOLS

LIFE SCIENCES ENGINEERING
Rt. 1, Box 746
Morrison, Colorado 80465

LIST OF DATA RECOMMENDED FOR PROTOTYPE DESIGN REVIEW

Recommended data for the Prototype Design Review will be additional performance evaluation data resulting from the test program which will reflect differences in performance due to:

Plenum Spacing (flow passage) Tests

Coatings Tests

Glazings Tests

Stagnation Tests

DESCRIPTION AND RATIONALE FOR PROPOSED SPECIAL HANDLING, INSTALLATION AND MAINTENANCE TOOLS

The only special test equipment projected at this time to be used follows installation of the collectors during total system checkout. This special test equipment is:

Micro Tector Electronic Hook Gage Model 1430

The purpose of this Hook Gage is to accurately measure the velocity pressure associated with the very low flow rates in the collectors and provide for balancing flow rates through parallel collectors.

SECTION F

STRUCTURAL ANALYSIS

AND

SELECTED DRAWINGS

AIR FLAT PLATE COLLECTOR

TO

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

January 3, 1977

Life Sciences Engineering
Route 1, Box 746
Morrison, Colorado 80465

STRUCTURAL ANALYSIS

This preliminary Collector Subsystem structural design analysis is based on the following references:

Verification Plan No. SHC-3071, Sections 3.1 to 3.9.1

Interim Performance Criteria, Sections 3.1 to 3.9.1

HUD Minimum Property Standards, 4900.1, Section 601 and applicable standards

<u>Aluminum</u> - The preliminary analysis showed a maximum projected stress assuming yield on secondary load carrying members (i.e. Tedlar) is ≈ 6900psi. Since 6063 T-6 allows at least 25ksi in tension, the Safety Factor for the frame is at least 3. Thermal stresses will be analyzed later this month. The absorber panel sag may be excessive and if so, it will require stiffening support. Testing and further analysis will be performed to determine if stiffening is required. The deflections in the glass supporting structure are well within the allowable limits specified in the Minimum Property Standards.

<u>Glass</u> - The maximum projected stress for 5/32" glass is 4300psi, assuming Tedlar carries 25% of the wind load. If the Tedlar should rupture, thereby dumping all the load on the glass, the result will be approximately 5800psi stress in the glass. Tests shown in ASTM 251 on testing window assemblies showed that large plate sheets break at ≈ 3000psi stress. Tempering of glass increases the breaking stress by a factor of 2 1/2 to 3 1/2 (ref. Glass Engineering Handbook - Shand) resulting in a design limit of 7500psi which is a Safety Factor of 1.3. Also the Minimum Property Standards in Fig. 5-8.1 permits a 3/16" glass sheet for use up to 50 square feet in size for the design of 15psf

windloads. Short duration loads on glass such as in a wind gust were shown in ASTM 251 to have a stress increase to breakage of a factor of about 2.

Summary - The deflections of the Tedlar, glass, and absorber panel are expected to act as air trapping membranes such that the Tedlar will not contact the glass and the glass will not contact the absorber panel when rapid loading occurs. The deflection of the glass at 4300psi is approximately 1.2" at the center. Test results from ASTM 251 indicated that actual stress and deflections could be as low as 2/3 the calculated values.

The shear stresses in the rivet connections appear minimal from preliminary calculations and the maximum allowable spacing will be allowed. When thermal stresses are analyzed, the rivet loads will be reevaluated.

Tedlar stress with maximum wind loading is $\approx$ 1000psi for a deflection of 1.5". Yield is approximately 6000psi for a safety factor of 6.

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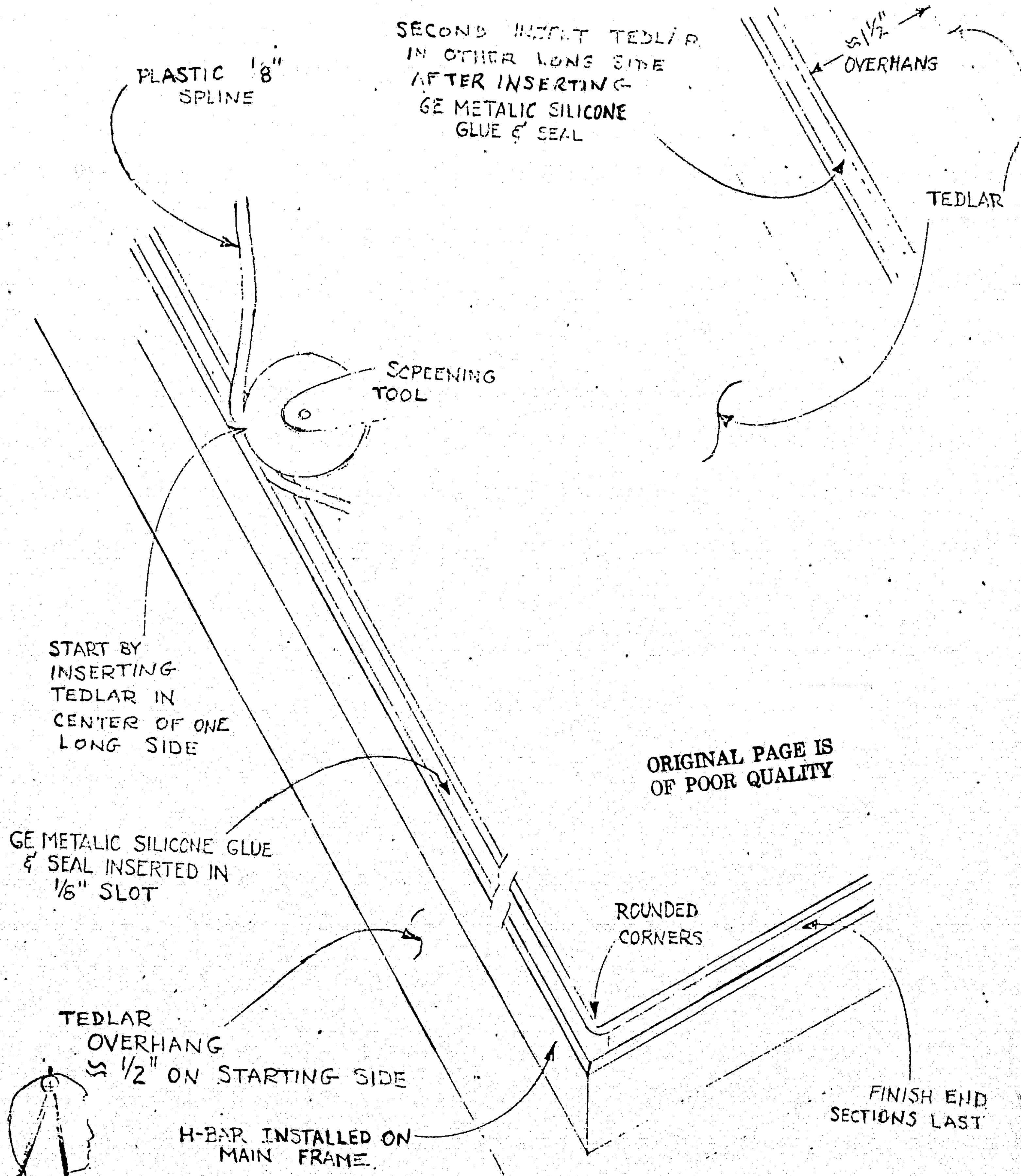
OF POOR QUALITY

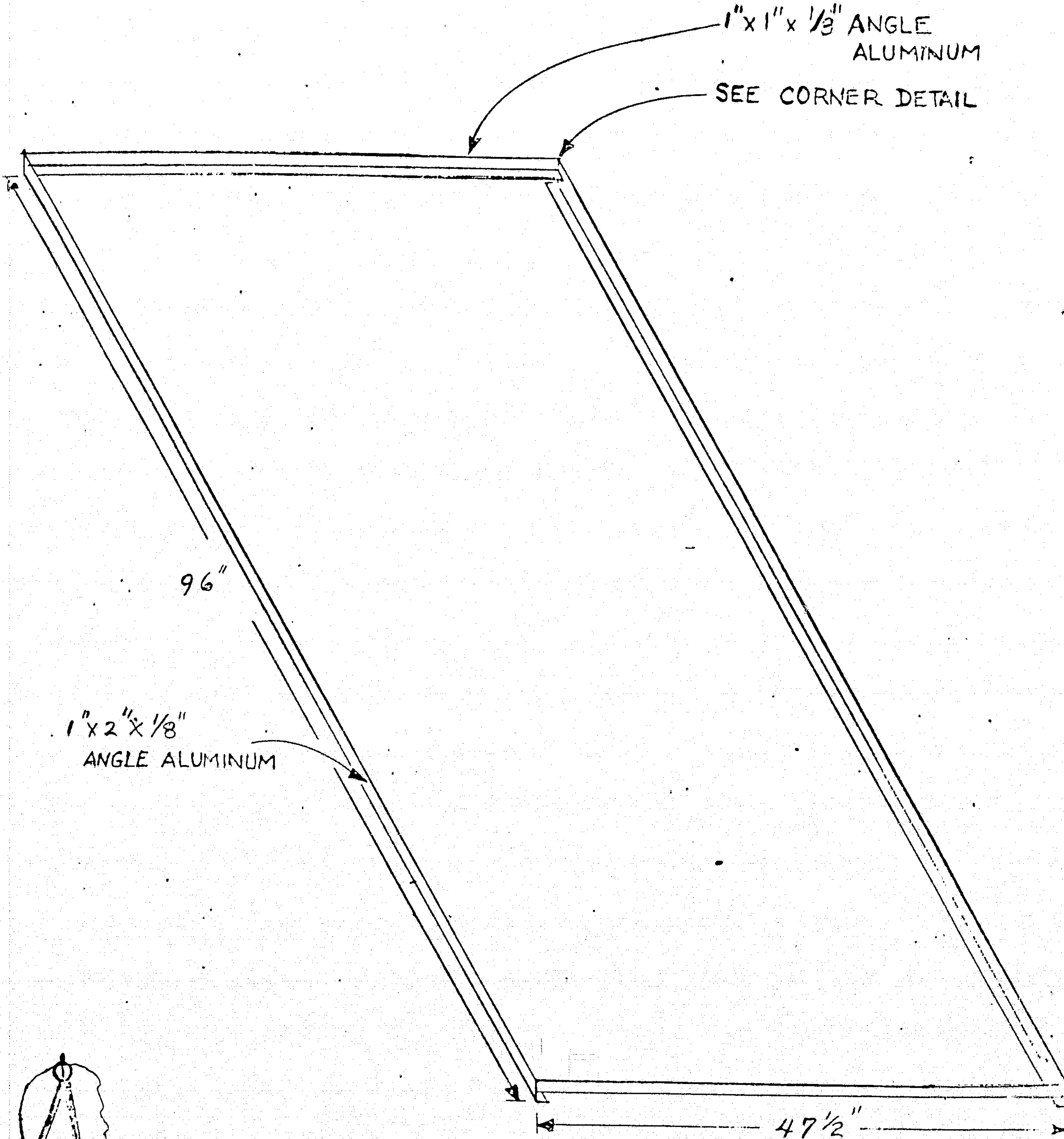


SOLAR OUTER GLAZING INSTALLATION SKSC4X8500-29

1/3/77

DRAWN BY R.S. CHECKED BY

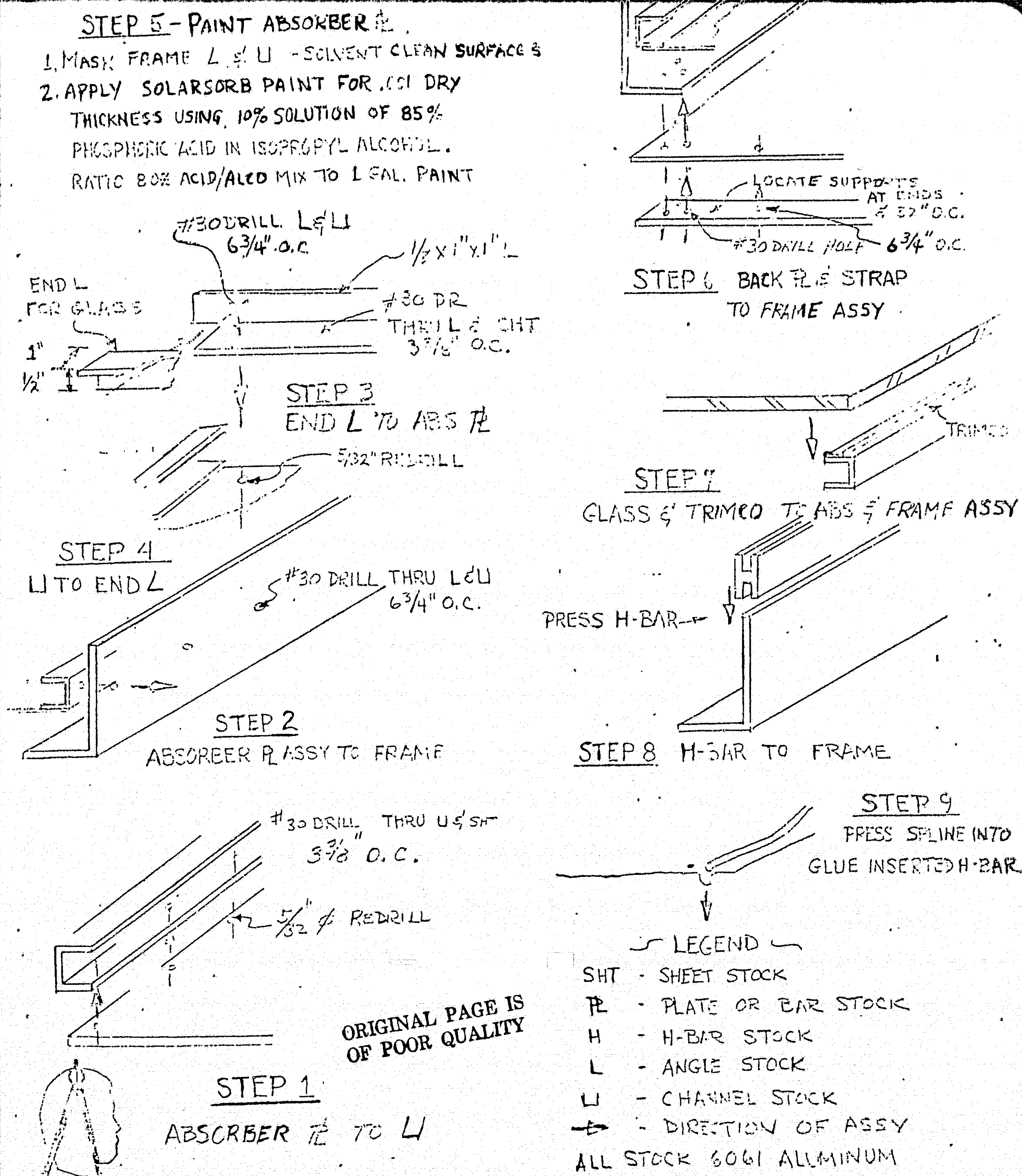
SCALE 1" = 1"



SOLAR II COLLECTOR MAIN FRAME SKSC4X8300-9

1/x/77.
DRAWN BY Rod CHECKED BY

SCALE 1"=1'



SOLAR II COLLECTOR FINAL ASSEMBLY STEPS SKSC4X81C0

NOT TO SCALE

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